

Proceedings of the International Conference on Innovation - driven Knowledge Economies and Transformation in the Global South

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Innovation - driven Knowledge Economies and
Transformation in the Global South

Volume IX
Economic and Social Upgrading for sustainable
Catch-up: Trade policies, FDI. Value Chain and
innovation Networks in a Knowledge Driven
Economy

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Preface / A word of welcome and thanks

It is a matter of great pride that the 20th-anniversary Globelics International Conference is being held in Thiruvananthapuram. This conference deliberates on an issue of much contemporary relevance – Innovation-driven Knowledge Economies and Transformation in the Global South, which is at the centre stage of development strategy both at the national and that of the government of Kerala. In 2006, when inclusive development was a major issue of global concern, Globelics conference was held in Trivandrum and deliberated on Innovation Systems for International Competitiveness and Shared Prosperity.

This Conference intends to bring together scholars across disciplines from over 50 countries to pool together experiences and expertise to reflect on varied issues involved in the process of transforming developing economies into sustainable, resilient, and inclusive innovation-driven knowledge economies.

In the conference, to be inaugurated by Shri Pinarayi Vijayan, the Hon'ble Chief Minister of Kerala, scholars of eminence will join as keynote speakers and panelists in plenary sessions and special sessions. The conference, organized in nine parallel tracks, will also have book presentations, excursions, and cultural events. As part of the conference, about 20 leading scholars from Globelics will visit different universities and colleges in Kerala to deliver lectures and interact with faculty and students, which is facilitated by Kerala Higher Education Council and Kerala Economic Association.

We welcome with great appreciation the Honourable Chief Minister Shri Pinarayi Vijayan and all the dignitaries who joined us for the inaugural address and eminent scholars delivering keynotes and addressing in different plenary sessions, special sessions, and parallel sessions. While the invisible hand of our honourable Chief Minister is there in all the important initiatives of GIFT, this program has been ably guided and steered by our Chairperson Shri K N Balagopal, Hon'ble Finance Minister of Kerala.

This important event is the outcome of the collective effort of all those involved, especially the Co-organising institutions: RIS, New Delhi, who inter alia managed the political clearance from the Ministry of External Affairs, IIM Bangalore, K DISC and the Digital University of Kerala. Our partnering institutions, ICSSR, Kerala State Higher Education Council, Centre for Development Studies, Kerala Economic Association, and the Centre for Latin American Studies also have been helpful in organising this conference.

With much appreciation for all of you for being with us, we welcome you

K J Joseph

For the local organising Committee

About the 20th Anniversary Conference

The central theme of the 20th Anniversary Globelics International conference is Innovation-driven Knowledge Economies and Transformation in the Global South.

This conference intends to bring together scholars across disciplines from over 50 countries to pool together experiences and expertise to reflect on varied issues involved in the process of transforming developing economies into sustainable, resilient, and inclusive innovation-driven knowledge economies. Episodes of development in economic history highlight the successful experience of countries that have managed to harness Learning, Innovation and Competence-building Systems at the global, national, subnational and sectoral levels in order to transform their social and economic structures for achieving prosperity. In the current times, the constellation of innovations driven by rapid advances in digital technologies has given rise to a new technological revolution, commonly referred to as the fourth industrial revolution, or Industry 4.0, with profound impacts on all sectors of the economies and sections of societies. New and persisting developmental challenges have driven a renewed interest in different types of innovations that highlight their impact on society and the natural environment, such as inclusive innovation, responsible innovation, transformative innovation, grassroots innovation and Jugaad. At the core of all these approaches is how knowledge, both science-based and experience-based, is harnessed for addressing development challenges, the basic premise being “the knowledge divide is at the root of the development divide”

At the current juncture, wherein globalization is at the crossroads, the economies across the world, ravaged by the once-in-a-century pandemic and external shocks, consider strengthening the innovation system as a strategic approach towards building resilience. Evidently, there is an across-the-board drive among developing countries to transform their economies into innovation-driven knowledge economies. Such a transformation is often viewed as capable of building resilience by addressing many of the downsides

of globalization-induced high growth, like excessive exploitation of exhaustible resources and accentuated divides within and between countries. Such initiatives in India are manifested, among others, in Atal Innovation Mission (AIM), Digital India, Skill India, and Make in India and other concerted efforts to transform India into an innovation-driven knowledge economy. It is also in sync with the national agenda of harnessing Science, Technology, and Innovation (STI) to achieve sustainable development. The choice of the location of the conference is inspired by Kerala's strategy towards transforming the state into a knowledge economy, as explicitly stated in the budgets starting with 2020-2021 and the subsequent concerted efforts that followed. It is in this background that Globelics revisits India for the 20th Globelics International conference with the chosen central theme: 'Innovation-Driven Knowledge-Economies and Transformation in the Global South'.

The 20th Anniversary Globelics is also an occasion to celebrate the journey of Globelics from Brazil 2003 to India 2023 and its varied achievements. At the same time, it is also a forum for critically reflecting on our perspective and the approaches *inter alia* in terms of its achievements and limits. This is especially important at the current juncture wherein there is growing disenchantment with the development experience under globalisation on the one hand and the need on the other hand, for reimagining innovation systems in the COVID and Post COVID world towards building the much needed resilience in the South.

Globelics-India 2023 coincides with India's Presidency of G-20 that *inter alia* aims at influencing the development dynamics of Global South and it is an appropriate time for translating the insights of the conference with respect to strengthening Learning, Innovation and Competence-building Systems (LICS) into policy action. For the past two decades, we have observed an increasing influence of Global South in shaping the paradigms and trajectories of the global development agenda—sustainability, climate change, pandemic, and energy security issues—with India playing a key role; all being closely linked to the research domains of the Globelics.

World-leading scholars are set to give this year's keynote address on innovation and development. It is planned that the conference will be inaugurated by the Chief Minister of Kerala and there will be a special keynote on the conference theme along with a Globelics Lecture and Freeman Lecture. The conference will combine plenary sessions, presentations of research papers in parallel tracks, thematic panel sessions or special sessions, poster presentations, book presentation sessions, excursions, and cultural events.

Conference Tracks

While submissions on the central theme of the conference have been especially encouraged, submissions on all the issues conventionally deliberated in the Globelics international conferences are also included. Submissions have been organized around the following themes:

1. Science, technology, innovation: Theory and policy for a knowledge economy
2. Transformative innovation, responsible innovation and mission-oriented innovation
3. Knowledge-driven development of national, regional, local and sectoral innovation systems, including Agricultural innovation systems and rural development
4. Measurement of the knowledge economy: Indicators, data requirements, different approaches and methodologies
5. Skilling for the knowledge economy: Industry-academy interaction, Intellectual property rights, open innovation and development
6. Industry 4.0 and development: Digitalization and automatization, productivity and employment implications, gig economy and quality of employment
7. Economic and social upgrading for sustainable Catch-up: trade policies, FDI, value chains and innovation networks in a knowledge-driven economy
8. Innovation for inclusive development: Indigenous knowledge, Grassroot innovations, Jugaad, informal economy, micro and small enterprises
9. Entrepreneurship, employability and gender dimension in innovation and development
10. The green economy and financing innovation: Low carbon innovations, environmental technologies and renewable energy

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Technological Efforts, Trade Margins, and Patent Protection: An Empirical Investigation

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Abstract

In a gravity model setting, this study examines the impact of technological efforts on bilateral exports along with margins of trade. This study has implemented the Poisson Pseudo-Maximum Likelihood (PPML) estimation technique to estimate the impact of technological efforts (TEs) on bilateral exports along with the extensive and intensive margin of trade across 56 countries during 1996-2014. Extensive margin captures the increase in variety of exports and shows the changes in tastes of the importer while intensive margin is the change in volume of trade. To analyze the TEs, this study constructs a technology effort index by using principal component analysis including both input and output indicators of innovation, made by a country that contributes toward its bilateral export across countries. By utilising 6-digit disaggregated product level export data, we find a sharp increase in exports along with extensive and intensive margins through countries' technological efforts. For middle-income countries, we find strong evidence that countries' technological efforts augment high-technology products export along with product varieties. This study suggest that middle-income countries should support exporters in marketing of the products, brand creation through various schemes including participation in international trade fairs to increase the intensive margins. Policymakers of the middle-income countries should devise schemes to reduce the cost of exporters for patenting in different countries and ensure that market power enjoyed by the high-income countries' exporters is not abused.

Keywords: Technological efforts; trade margins; patent rights; PPML; Product level data

1. Introduction

Developing countries to become internationally competitive make extensive technological efforts¹ (TEs) that are expected to contribute to their export performance. Interestingly, high-technology exports as a percentage of total manufacturing exports are stagnant for high-income countries (20 % in 2008 and 20.2% in 2018) whereas for middle-income countries, there is a rising trend (17.8% in 2008 and 22.3% in 2018)². However, the empirical literature on the role of technology in developing country's export is inconclusive (Willmore, 1992; Siddharthan, 1994; Chadha, 2009; Shin et al., 2016). The technological activity of countries determines the resources devoted to creating new products and/or new processes to reduce the costs. Many a times such efforts lead to patents that provide firms with a strong competitive edge in the international market. We argue in this study that existing studies do not capture the variation in the technological activity of developing countries.³ And we extend the literature by considering the impact of technological efforts (TEs) on exports while employing gravity model. To support how TEs influence exports, we utilise a disaggregated product-level exports data to decompose the exports effect of TEs along with extensive and intensive margins. The very idea for considering such two margins is based on heterogeneous firm trade models as Chaney (2008) shows that trade policy changes affect number of trading partners or number of products traded (i.e. extensive margin) and change in volume of trade among two countries (i.e. intensive margin) as well. From a policy perspective, the changes in the extensive and intensive export margins have different growth and welfare implications. Extensive margin and intensive margin capture the breadth and the depth of countries' export profile. If countries will have higher extensive margin and lower intensive margin then they spread their exports lightly over products and partners and vice-versa. Therefore, to provide a comparative perspective, it is pertinent to examine the developing countries' export performance along with different margins.

Extensive margin captures the increase in variety of exports and shows the changes in tastes of the importer, as consumers abroad seek to try new goods. Further, increase in variety of exports has also been assumed to be growth and welfare enhancing owing to the increase in market share of the exporter, diversification of exports and protection against the trade shocks lead to stable export earnings (Hummels & Klenow, 2005; Chen, 2013; Aditya & Acharya, 2013; Gozgor & Can, 2016). This motivates the current research that utilizes disaggregated products-level export data to explore the impact of TEs on bilateral exports that are

further decomposed into extensive and intensive margins. The performance of trade margins in developing countries are also different among product groups (see Veeramani et al., 2018). Previous studies in international trade examine the impact of several policies, namely, trade liberalisation, membership in multilateral organisation, hosting mega-events (namely, the Olympics and the World Cup), and Patent Rights (PRs) on bilateral trade flows (Rose, 2004; Rose and Spiegel, 2011; Dutt et al., 2013; Ndubuisi and Foster, 2018). Ndubuisi and Foster (2018) examine the impact of source countries' PRs on bilateral exports along the extensive and intensive margins. They suggest that strong PRs of source countries stimulate exports along with extensive margins. However, these studies do not consider the impact of source countries' TEs on trade margins.

Studies use different measures to operationalise technological progress; for instance, technological capabilities (Bhaduri and Ray, 2004); technological efforts (Bhat and Narayanan, 2009); and level of technology (Shin et al., 2016). We note that these measures are limited as they capture either input or output in the knowledge production function,⁴ and these measures do not capture the extent of technology efforts made by developing countries. Earlier, Lall (2003) constructs an index of technology effort, based on national technological activity, an offshoot of the widely discussed and researched concept of technological capability⁵. In consonance with Lall (2003), we also construct a technology efforts index as patents do not represent the complete innovation value chain. According to Lall (1998), "a great deal of technological effort in the early years was based on copying foreign technologies, and the countries adopted a fairly relaxed attitude to intellectual property protection. As the industrial sectors matured and approached nearer to technological frontiers, local R&D needed greater protection; in addition, pressures for stronger intellectual property regimes grew internationally" (p. 235). Considering that within the developing countries, different variants of 'effort' exist, we extend Lall (2003) index by including different input and output indicators of innovation. Evidently, we find those countries' TEs ranges from 0 to 5.5 where higher values indicate intensive innovation activity. High- and middle-income countries' average values of the TEs are 1.9 and 0.41 and maximum value of TEs index are 5.5 and 2.14, respectively.

Scholars have widely employed the log-linear gravity model of trade to analyse trade flows. But recent empirical trade literature points out that the traditional log-linear gravity model leads to produce inconsistent estimates in the presence of heteroskedastic residuals. Liu (2009), Silva and Tenreyro (2006) and Felbermayr and Kohler (2006 and 2010) have observed that under heteroskedasticity, the parameters of log-linearised models estimated by ordinary least squares (OLS) lead to biased estimates of the true elasticities. Flowerdew and Aitkin (1982), and Silva and Tenreyro (2006) have proposed the Poisson regression as an alternative

solution. Therefore, in this study, we have implemented the Poisson Pseudo-Maximum Likelihood (PPML) estimation proposed by Silva and Tenreyro (2006) as an appropriate methodology to estimate the impact of technological efforts on bilateral exports along with the extensive and intensive margins of trade.⁶ By using 6-digit product level export data, we find a sharp increase in exports along with extensive and intensive margins through countries technological efforts.

Our paper contributes to the existing literature by examining the role of TEs on the bilateral exports along with margins of trade— extensive and intensive margins. Accordingly, we use exports data of knowledge-intensive goods at 6-digit product level. This study constructs a technology efforts (TE) index by employing principal component analysis (PCA), including both input and output indicators of innovation. In a gravity model setting, this study utilises the time-varying importer and exporter fixed effect to minimise the problem of omitted variable bias. We have used the PPML estimation model for the zero trade flows to account for heteroskedasticity, sample selection bias, and we implemented the country dyadic fixed-effects, the Poisson fixed-effects model to account for endogeneity issue. We have observed that countries' TEs boost exports along extensive and intensive margins. To the extent, the findings of our study support both the trade margins hold.

The rest of the paper is organised as follows: next section sets the background by reviewing the existing evidence on TEs, PRs, exports, and trade margins by describing their inter-relationship. Section 3 presents methodology, and estimation challenges. Section 4 provides details on the variables and data sources. The empirical results are presented in Section 5. Section 6 presents the synthesis of the empirical results. Section 7 provides robustness checks of the results. Section 8 summarises and concludes the paper.

2. Previous Literature

Post globalization, there has been a significant change in the world trade as the share of emerging economies increased in the manufacturing exports (Tewari and Veeramani, 2016). It is very important for every economy to boost their industrial output for which innovative technologies and products are required. By exporting, firms exploit idle operating capacity, develop production efficiency, and improve technological quality and service standard that raises their profits and returns to investment. Furthermore, such activities generate funds for future investment and growth (Guan and Ma, 2003). Studies argue that export performance is enhanced when countries, specifically, developing economies, are able to move beyond trade in primary and low technology goods to high-technology products (Lall, 2000; Srholec, 2007).

With the aim to understand different trade patterns, existing literature analyses the importance of firms' extensive and intensive margins of international trade. Owing to the extensive margin, there is a variation in trade across trading partners, while a change in the value of trade across one-year interval is due to the intensive margins (Bernard et al., 2009). Notably, Melitz (2003), Helpman et al. (2008) and Chaney (2008) explicitly develop trade models that reflect the decision to export, particularly the extensive margin of trade. Various studies have pointed out the importance of the intensive margin of trade for long-run export growth. Krugman (1980) envisages that all export variations happen only on intensive margin of trade because all firms are interested to exports to destination countries. Increases in the extensive margin or export diversification reduce the risk of crises in the balance of payments as well as large fluctuations in domestic output (Agosin, 2007; Lederman and Maloney, 2003). As the new exporting basket can improve the use and allocative efficiency of the economy, Feenstra and Kee (2008) suggest that, increase in sectoral export variety boost country productivity. Interestingly, Fernandes et al. (2016) suggest that larger economies and more developed economies have immense number of exporters. As countries develop and their exports grow, the expansion happens through both the extensive and the intensive margins, and more resources flow to the largest firms. They have found out a relatively larger role for the extensive margin in explaining why larger countries export larger volumes consistent with the standard model of trade with heterogeneous firms. Exports can differ across trading partners along with extensive and intensive margins of trade. Besedes and Prusa (2010) argue that for long-run export growth, the survival of trading relationships is important. It implies that a critical part of improved export growth for developing countries may be focusing on existing relationships. Veeramani et al. (2018) perform a comparative analysis of trade margins in emerging countries, namely, India and China. They suggest that India's exports penetration is the highest for technology-intensive and human capital-intensive products. Within all product sectors, they find that India and China's export performance is more noticeable along the intensive margin than extensive margin. A question arises that how these trade margins are important across developing countries along with their technological capacity.

Trade literature emphasize the fixed cost of exporting; that firms incur in order to become exporters (permits, compliance with regulations, building a base for shipping and other transportation, networks, security clearance, contracts, insurance, labeling, branding, and so forth). Let's call these costs C , some of which are fixed or sunk costs, while others could be variable costs. Now, firms export only if the exportable goods are sufficiently profitable (in terms of revenue or profits). Let's refer to the benefits of exporting as B . There are 3 possible cases determining the entry and sustenance of countries into new product category. The

first situation when $B < C$ for time $< T$, a country does not export. As soon as $B > C$ for time $= T$, entry occurs (extensive margin) and when $B > C$ for time $> T$, exports continue (intensive margin). C includes the sunk cost of investments made in R&D to produce new products, adopt existing products, and for process innovation. Considering the lag effect in such investments, let us say at T firms can reap benefits greater than costs incurred and hence enter the market. However, to sustain its international market, firms need to continue its efforts. However, it is only after certain level that a firm will be able to gain market share and expand its intensive margins.

Empirical studies examine the impact of several trade policies on the margins of trade. With a large panel data set of 175 countries, Rose (2004) suggests that joining GATT/WTO encourages trade. Moreover, Rose and Spiegel (2011) argue that hosting mega-events also enhances exports. By using 6-digit bilateral trade data, Dutt et al. (2013) investigate the effect of WTO/GATT membership on the extensive and intensive of trade. This study finds mixed results, such as WTO membership has a positive impact on the extensive product margin of trade, however, it is negatively related to the intensive margin. Foster (2014) suggests that destination countries' PRs affect export positively (negative) along with extensive (intensive) margin. A study by Ndubuisi and Foster (2018), examines the impact of source countries' PRs on bilateral exports along with extensive and intensive margins. They find that strong PRs of the source country matters more to the exporters than the level of destination country's PRs. They suggest that strong PRs of source countries stimulate exports along with extensive margins. However, these studies do not take into consideration the TEs of the country. We argue in this paper that how TEs determine the bilateral exports along with margins of trade.

Technology efforts consist of a broad spectrum of production engineering, design, and research work by firms. Such efforts translate into cheaper processes and/or new products (new to world and/or new to firm) enhancing productivity and profitability. In the context of developing countries, the product need not be new to world but a new to firm product may also increase its profitability by reaching out to untapped domestic market or by reducing price of the similar product in the international markets. Considering the adaptive nature of R&D efforts, firms in the developing countries may not have many patented technologies. The nature of R&D and the outcomes of such investments vary not only between developed and developing but also within the countries with the similar levels of economic development. Studies underscore the larger impact of R&D spending by firms on its productivity in the export market than in the domestic market. Thus, technological efforts are manifested in the firm's production efficiency and export activity. Such developments also depend on the dynamism in technology development, particularly in terms of national policies to improve factor markets

that influence the incentive environment (Lall, 1992). While operationalising the technological efforts, particularly if the focus of analysis is the developing countries, there is a need to consider all aspects of innovation value chain starting from investments to the patents. Accordingly, this study computes a technology effort index, five variables are included to construct the index where three of them represent input indicators: R&D expenditure as % of GDP, researchers in R&D per billion population, number of patent application by non-residents. Non-resident filings represent inward technology transfer, hence, are categorized as an input indicator. The remaining two variables represent output indicators: the number of the patent application by residents and the number of published scientific and technical journal articles. Scientific and technical journal articles and patents capture output produced due to investments made in R&D.

From the above discussions, we present our hypothesis regarding the effect of TEs on exporting across countries:

H1a: *Source countries' TEs influence bilateral export positively.*

H1b: *Source countries' TEs influence trade margins positively.*

The impact of destination countries' stronger PRs protection varies with existing TEs and the ability to innovate of source countries. TEs are positively correlated with export performances, through the proper enforcement of PRs. PRs influence countries' investment in innovative technologies that strengthen the competitiveness of industries (Cooper, 1991; Gold, 1982). A set of literature suggests that strong PRs in developing countries increase the value of developed countries' exports in patent-sensitive industries or high technology industries and enhance the product variety (Ivus, 2010 and 2015). Yang and Maskus (2009) suggest that strong patent protection enhances export platforms. Briggs and Park (2014) find that PRs play an important role in strengthening a local firm's position in technology trade. Kabir and Salim (2016) find that destination countries' strong PRs protection has a positive impact on China's export flows.

Shin et al. (2016) argue that if a source country has a high level of technology, then stronger foreign PRs protection spurs exporters to enhance the volume of exports. Studies conclude that there is an ambiguous relationship between strong PRs and trade flows, because of their two opposing effects, such as market-expansion effects and market-power effects. Strong PRs, through "market-expansion effect," allows firms to increase the market in the host country by reducing imitation. On the other hand, strong PRs may also result in a "market-power effect" that induces the firm to restrain their production. The market-power effect reduces the elasticity of demand for a firm that ordinarily induces firms to export less of its patentable

product (Taylor, 1993; Muskas and Penubarti, 1995; Smith, 2001). Following Shin et al. (2016), we capture the combined effects of the TEs of a source country and PRs of destination countries on the source countries' bilateral exports. They have studied the interaction impact of a destination country's PRs' protection and a source country's level of technology on exports. They have found that foreign PRs influence the marginal contribution of technology to export performance, and the innovative capacity of the source country influences the relationship between PRs and trade. An introduction of variation in the innovation activity of developing countries will further help us in analysing the impact of destination countries' PRs on exports from such countries that Shin et al. (2016) could not capture. Thus, it is pertinent to study the interaction impact between TEs of a source country and the PRs of destination countries on bilateral exports along with trade margins. From the above discussions, we present following hypotheses:

H2a: *Destination countries' PRs influence bilateral export along with margins of trade positively.*

H2b: *Possibly negative interaction effect between source countries' TEs and destination countries' PRs on bilateral exports along with margins of trade.*

3. Methodology

In a gravity model (GM) setting, this study examines the impact of technological efforts on exports along with margins of trade, to understand the bilateral export flows of 56 countries during 1996-2014. By analysing the relationship between economic size and distance (proxy for trade cost) among two countries (importer and exporter), such model is an important tool in the analysis of trade flows over many years. In this study, we estimate the model comprising importer and exporter gross domestic product (GDP) and series of trade costs. We develop the model with the key variables, namely, exporter TEs, importers PRs, and their interactions. Hence, our starting point for the analysis is the following equation:

$$EXP_{ijt} = C_1 + \alpha_{11}TE_{it} + \alpha_{12}PR_{jt} + \alpha_{13}TE_{it} * PR_{jt} + \alpha_{14}GDP_{it} + \alpha_{15}GDP_{jt} + \pi_i + \pi_j + \mu_t + \epsilon_{ijt} \quad (1)$$

Where EXP_{ijt} represents the bilateral exports from country i to country j in period t . TE denotes the technology effort index, PR is the index of patent rights. GDP, the gross domestic product per capita growth (% annual). π_i and π_j capture the cultural and geographical proximities such as bilateral distance, official common language, share a common border, and colonial relationship across exporting and importing countries. The detailed reasons for introducing these variables are given later along with the construction of the variables.

3.1 Estimation Challenges and Solutions

In estimating Equation (1), there is a need to address major challenges in order to obtain consistent estimates with the gravity model. We discuss and review all possible challenges and their solutions, which have been proposed in the literature, namely, multilateral resistance (MR), zero trade flows, heteroskedasticity of exports data, endogeneity issues and bilateral trade costs.

The MR is a noticeable challenge while estimating the Equation (1). It refers to the barriers that each of exporters (i) and importers (j) countries face in their trade with all their trading partners, such as domestic or internal trade.⁷ The bilateral trade resistance denotes the size of the barriers to trade between countries i and j , whereas MR focuses on the third-party effects that needs to be taken into account properly in an appropriate evaluation of the effect on trade flows (Anderson and van Wincoop, 2003; Baldwin and Taglioni, 2006; Adam and Cobham, 2007). Various solutions have been proposed to deal with such a challenge in the literature. In the beginning, iterative custom programming has been used to account for the multilateral resistances in a static setting, as developed by Anderson and van Wincoop (2003) in their original paper. Further, Baier and Bergstrand (2009) suggest a reduced form version, where a linear approximation of the MR called “remoteness indexes.”⁸ Such reduced form methods are criticised by Head and Mayer (2014). They suggest that such an approach has a little likeness to [their] theoretical counterpart. Hummels (2001) and Feenstra (2004) acclaim the use of exporter and importer (directional) fixed effects in cross-section estimations, Olivero and Yotov (2012) further extend such cross-section recommendations and validate that exporter-time and importer-time fixed effects will account for the MR in a dynamic gravity estimation.⁹ Against this backdrop, we proposed to use the exporter-time and importer-time fixed effects to deal with the MR.

In a gravity model framework, zero trade flows are obvious. Starting from Tinbergen (1962), ordinary least squares (OLS) regression technique has been employed extensively to estimate several forms of gravity equation enduring today. The OLS approach does not take care of the information contained in the zero trade flows. When the value of trade is transformed into a logarithmic form, such observations are simply dropped from the estimation sample. In this study, we utilise 6-digit disaggregated exports data, hence the problem with the zeros becomes more distinct with more disaggregated data. In our case, zeros account for around 16% of the pair trade links (see Figure 1). In the presence of zeros, studies suggest the use of Tobit estimators as an econometric solution (Eaton and Tamura, 1995; Martin and Pham 2008). Though, this technique is silent on the determination of the Tobit threshold, it roots the disassociation between theory and estimation.

To curb such problems, a two-step selection process has been proposed theoretically by Helpman, et al. (2008).¹⁰ With this approach, some difficulties arise for panel data estimations when dynamic considerations are taken into account. And it is also very hard to get good restriction for the first stage probit estimation. Finally, we consider the PPML estimator for gravity estimations¹¹ which is postulated by Santos Silva and Tenreyro (2006).

The PPML model provides consistent estimates under general conditions. Trade data often have heteroskedasticity issues that can also be dealt with by employing PPML method (Silva and Tenreyro 2006). To control the heteroskedasticity problem, Anderson and van Wincoop (2003) suggest transforming the dependent variable into size-adjusted trade, but this method has been criticised on the ground of zero trade flow challenge. PPML technique is an alternative and a more comprehensive approach. It effectively handles the of zero trade flow challenge in gravity model framework. The PPML model is consistent even when the variance function is mis-specified. The common assumption of the PPML estimation model is that the conditional variance is proportional to the conditional mean. If such assumption holds, the PPML estimator is likely to be more efficient than other estimators when heteroskedasticity increases with the conditional mean (Silva and Tenreyro, 2006).

While estimating Equation (1),¹² to account for the endogeneity issue, studies use instrumental variable approach. For example, Ivus (2010) utilises the colonial dummies in her study. However, such instrument is time-invariant; hence it is not appropriate to our analysis. Therefore, due to lack of reliable instruments, many studies suggest using country pair dummies that are a comprehensive set of dyadic-specific fixed effects, which control time-invariant characteristics as common to a country pair. In gravity model, it should be noted that the set of pair fixed effects or the first difference has been used in order to eliminate the unobservable association between endogenous covariate and error terms (Baier and Bergstrand, 2007; Rose and Spiegel, 2011). Bilateral trade costs are also crucial for a gravity model analysis. We use a robust gravity proxy for trade costs, namely, bilateral distance among trading partners i and j , presence of contiguous borders, common official language, and presence of colonial ties.

4. Data

In this study, we are interested in exports data at product level and further use it to construct the margins— extensive and intensive margins -- across 56 countries during 1996-2014. Export data are extracted at the Harmonised System (HS) 6-digit level of disaggregation from UN COMTRADE. We use different concordance tables¹³ to convert all the data to HS-0 classification, as the Harmonised System

(HS) classification has changed over time. Following Dalgado, Kyle and McGahan (2013) classification, we take high PRs sensitive products that are classified in the Standard International Trade Classification (SITC), then we made concordance between SITC and HS.

To build the margins of exports, studies apply different methods to decompose total exports into extensive and intensive margins (Hummels and Klenow, 2005; Bernard, et al., 2007; Helpman, et al., 2008; Dutt, et al., 2013). Following Dutt et al. (2013), we apply the count method to construct the margins. In a log- linear form, the decomposition of total exports (EXP) can be expressed as follows:

$$\ln \text{EXP}_{ij,t} = \ln(N_{ij,t}) + \ln\left(\frac{\text{EXP}_{ij,t}}{N_{ij,t}}\right) \quad (2)$$

where $\text{EXP}_{ij,t}$, the real total bilateral exports (sum of total exports for all products for a given year). Total exports between a country pair is decomposed into two different dependent variables, namely, the extensive margin of exports as a count of number of HS-0 products that exported from i to j in period t , i.e., $N_{ij,t}$, and the intensive margins as a simple average value of exports per product, i.e., $\text{EXP}_{ij,t}/N_{ij,t}$. The extensive margins of trade can account for a large share of the variation in imports and exports across countries. The well-known “gravity” relationship between trade flows and distance, for example, is driven almost exclusively by the extensive margin: while the number of firms and the number of traded products decline significantly with distance, the intensive margin of average import or export value per firm- product, if anything, increases.

To capture the technological capacity of countries, this study computes a technology efforts (TE) index by principle component analysis.¹⁴ Five variables are included to construct the index where three of them represent input indicators: R&D expenditure as percentage of GDP, researchers in R&D per billion population, number of patent application by non-residents. The remaining two variables, the number of the patent application by residents and the number of published scientific and technical journal articles, represent output indicators. The last three variables (publications, non-resident patents, and resident patents) are standardised by real GDP to adjust for the economic size of a country. All these variables are collected from the World Development Indicator (WDI) and the World Intellectual Property Organization (WIPO). The technology effort index ranges from 0 to 5.5, where higher values indicate intensive innovation activity. This study uses Ginarte and Park (1997) and Park (2008) PRs index¹⁵ that indicates the strength of PR protection in each country. GDP is taken from the WDI. All the gravity model variables including, bilateral distance, common border, common

official language, colonial dummy is taken from CEPPI database.¹⁶ We estimate both equations (1) and (2) for a full sample,¹⁷ and then estimate them by subgroups built on countries economic development high income and middle income countries, as based on the World Bank (2016) classification of economies.¹⁸

Before moving for the empirical analysis, Table 1 provides the summary statistics of the variables including the dependent and explanatory variables across 56 countries during 1996-2014. The total number of observations is 58,520, as there are 32 high-income countries and 24 middle-income countries. Exports values are in 1000 USD. Countries' TEs and PRs ranges from 0 to 5.5 and from 1.07 to 4.87 respectively. Panel B shows source countries' TEs across different exporters' income groups. As expected, all mean, and maximum level of TE surge simultaneously when we move from middle-income to the high-income countries suggesting that middle-income countries have lower technological capacity relative to high-income countries. Therefore, a significant component of our analysis is the development (namely, level of economic development, level of technological development) stage--dependent impact of TEs on exports, this make an argument to grasp the distribution of export flows and adoption of TEs across different development level. Figure 1 specifies the bilateral trade flow (both positive and zero trade flows) across income groups. Zero trades flows emerge more in middle-income countries (32%) as compare to high-income countries (10%), thereby highlighting that high-income countries are more likely diversified and have more positive trade with different countries as relative to middle-income countries.

Figure 1: Bilateral Trade flow and Income groups

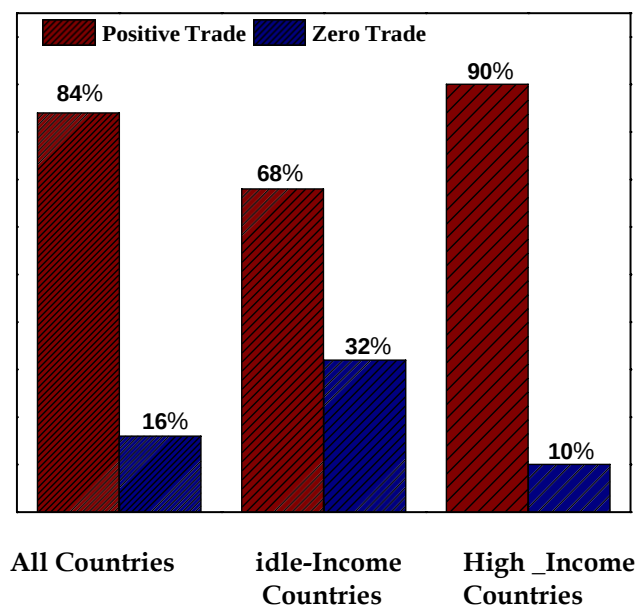


Table 1: Summary Statistics

	No. of Observation	Mean	Standard Deviation	Minimum	Maximum
Panel A = Full sample					
Total Exports (EXP)	58,520	532409.7	2574041	0	1.3E+08
Extensive Margins (EXT_M)	58,520	149.408	172.69	1	1254
Intensive Margins (INT_M)	58,520	1297.805	4708.142	0	214783
Log EXP	49,323	9.895	3.405	0	18.683
Log EXT_M	49,323	9.895	3.405	0	18.683
Log INT_M	49,323	5.550	2.009	0	12.277
Technological Efforts (TE _i)	58,520	1.398	1.234	0	5.509
PR _j	58,520	3.724	0.850	1.075	4.875
TE _i * PR _j	58,520	5.268	4.953	0	26.857
Log GDP	58,520	26.037	1.710	21.753	30.464
Log Distance	58,520	8.513	0.968	5.081	9.886
Common Language	58,520	0.084	0.278	0	1
Common Boarder	58,520	0.034	0.182	0	1
Colony	58,520	0.0	0.17	0	1
Panel B = TE Across Income Groups					
Middle-Income	25,080	0.41	0.45	0	1.999
High-Income	33,440	2.14	1.11	1.10E-09	5.509

Source: Authors' Calculation

5. Empirical Results

We present and discuss our empirical results for two categories, such as (a) full sample; (b) across incomegroups (level of economic development).

5.1 Technological Efforts and Exports - Full Sample

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Table 2 presents the impact of TEs on exports utilising disaggregated exports data for full sample. First, we discuss the empirical results for total exports in panel A. We utilise four econometric models with yearfixed-effects. Model (1) begins from an OLS regression model with exporters and importers time fixed- effects for adjusted MR terms as described in Section 3. Model (2) contains fixed effects (FEs) model with dyadic (pair) fixed-effects to account for pair-specific time invariant characteristics. Model (3) emerges when we utilise our preferred model, the PPML with only importer and exporter time fixed- effects. The final model, Model (4) comprises results when we implement the country's dyadic fixed- effects, the

Poisson fixed-effects model. Model 4 is our chosen model specification as we have discussed in detail in Section 3.

The empirical result shows that countries' TE index is highly significant and positive across all models. It implies that strengthening countries' TEs increase bilateral exports flows. We find that destination countries' PRs are also positive and significant in Model (2) and Model (4) suggesting that importing countries' strong PRs protection positively stimulate exporting countries' bilateral exports. However, it is negative in Model (3). Thus, we obtain a mixed result for PRs signifying that importers' strong PRs either do not affect bilateral exports or it could be unsystematic owing to the limited variation of high-income countries' PRs. Further, following Shin et al. (2016), this study also controlled for an interaction effect, to capture the combined effects of the TEs of a source country and the PRs of destination countries on the bilateral exports of source countries. We have discussed in Section 2 that there is an ambiguous relationship between the PRs of destination countries and the trade flows of source countries. This is due to two opposing effects such as the market expansion effects and market power effects. Our result indicates that interaction coefficient is negatively related to exports in all models; that is, holding TE constant, a higher level of destination PR is associated with a lower volume of source exports. Therefore, where the exportable product was propelled by higher technological efforts, the market power effect of destination PRs dominates the market expansion effects on exports in the specific case.

Concerning to our control variables, we find the expected sign with statistically significant coefficients. Specifically, empirical result illustrates that both importer- and exporter-countries' GDPs have a statistically significant positive sign and we find a negative sign for bilateral distance. This is one of the most robust empirical finding in the international trade: bilateral trade between two countries is proportional to size, measured by GDP, and is inversely proportional to the geographic distance between them. The COMLAN and COLONY are positive and significant inferring that trade between bilateral pair increases if they share an official language (COMLAN) and having colonial ties (COLONY) also increase bilateral trade. These results are consistent with empirical results in existing literature. However, we find a significant and negative sign for CONTIG suggesting a decrease of bilateral trade if they are adjacent to each other. A possible justification for this is that the border effect in trade refers to adjacent countries, but border effect is heterogeneous across region. Hence, such regions may not hold an economic coherent region.

In panel B, this study presents the empirical results of the decomposition of total exports (EXP), that is, extensive margin and intensive margin of exports. We follow

each estimation technique as discussed earlier in panel A. For both the extensive and intensive export margins, across all estimated models, we find a robust statistically significant positive effect of exporters' TEs. This result specifies that countries' TEs boost exports along with extensive and intensive margins to the extent that the finding of our study supports both export margin holds. We recommend that countries' TEs advocate product diversification along with a long-run export growth in order to realise the growth and improve the productivity of exporters.

The importer countries' PRs are positive and significant in the preferred models for extensive export margin. However, this is insignificant for intensive export margin. This result suggests that destination countries' strong PRs works mostly for new trading relationships and product varieties. Romer (1990), argues that product variety is the source of growth. Our result of positive effect of importers' PRs on total exports that works mostly along extensive margins and it has also important implication on growth and welfare.

Table 2: Empirical results of TEs and Exports: Full sample

VARIABLES	Panel A				Panel B							
	Total Exports				Extensive Margins				Intensive Margins			
	1	2	3	4	1	2	3	4	1	2	3	4
TE _i	0.949*** [0.108]	0.390*** [0.036]	0.237*** [0.013]	0.086*** [0.010]	0.692*** [0.032]	0.388*** [0.016]	0.599*** [0.053]	0.151*** [0.012]	0.751*** [0.086]	0.006 [0.032]	0.135*** [0.011]	0.045*** [0.011]
PR _j	-1.216 [1.387]	0.244*** [0.018]	-0.352*** [0.072]	0.040*** [0.006]	-1.216* [0.662]	0.273*** [0.008]	-0.998*** [0.114]	0.088*** [0.007]	0.006 [1.100]	-0.028* [0.016]	-0.054 [0.068]	0.008 [0.006]
TE _i *PR _j	-0.043*** [0.007]	-0.086*** [0.009]	-0.029*** [0.001]	-0.025*** [0.003]	-0.086*** [0.003]	-0.104*** [0.004]	-0.052*** [0.001]	-0.045*** [0.003]	0.043*** [0.006]	0.017** [0.008]	-0.012*** [0.001]	-0.012*** [0.003]
LGDP _i	1.470*** [0.053]	0.923*** [0.023]	0.229*** [0.014]	0.220*** [0.006]	0.752*** [0.018]	0.411*** [0.010]	0.533*** [0.062]	0.231*** [0.007]	0.683*** [0.042]	0.507*** [0.021]	0.199*** [0.011]	0.210*** [0.006]
LGDP _j	1.599*** [0.593]	0.793*** [0.023]	0.310*** [0.033]	0.086*** [0.005]	1.022*** [0.283]	0.266*** [0.010]	0.557*** [0.047]	0.065*** [0.006]	0.574 [0.470]	0.525*** [0.021]	0.169*** [0.031]	0.099*** [0.006]
LDistance	-1.525*** [0.011]		-0.162*** [0.002]		-0.750*** [0.005]		-0.188*** [0.002]		-0.780*** [0.008]		-0.141*** [0.002]	
COMLAN	0.672*** [0.027]		0.095*** [0.004]		0.390*** [0.013]		0.122*** [0.005]		0.289*** [0.021]		0.074*** [0.004]	
CONTIG	-0.300*** [0.036]		-0.099*** [0.005]		-0.331*** [0.017]		-0.152*** [0.007]		0.026 [0.029]		-0.056*** [0.005]	
COLONY	0.691*** [0.037]		0.071*** [0.005]		0.469*** [0.018]		0.108*** [0.007]		0.220*** [0.029]		0.039*** [0.005]	
Constant	-53.183*** [9.960]	-37.524*** [0.801]	-9.251*** [0.710]	-6.419*** [0.221]	-30.757*** [4.734]	-15.254*** [0.355]	-22.243*** [1.942]	-7.038*** [0.246]	-22.447*** [7.893]	-22.075*** [0.718]	-6.753*** [0.635]	-7.037*** [0.230]
Observations	49,195	49,195	58,520	58,520	49,323	49,323	53,222	56,677	49,195	49,195	58,520	58,520
R-squared	0.857	0.871	0.886	0.819	0.853	0.868	0.804	0.807	0.759	0.768	0.850	0.782
Year FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Exporters FE	yes		yes		yes		yes		yes		yes	
Importers FE	yes		yes		yes		yes		yes		yes	
Pair FE		yes		yes		yes		yes		yes		yes

Numbers in parentheses are standard errors.

*, ** and *** denote that coefficient is significant at 10, 5 and 1 percent levels respectively.

5.2 TEs and Exports: Level of Economic Development

We classify countries into two income groups, namely, middle-income (developing) countries and high-income (developed) countries based on the World Bank classification, as a proxy for level of economic development. We employ such four econometric models as discussed earlier in sub-section (5.1). First, we discuss the results for developing countries' total exports in panel A (see Table 3).¹⁹ The coefficient TE is positive and statistically significant, and robust to both exporter and importer fixed-effects, and country pair-fixed effects suggesting that developing countries' TEs significantly contribute to their bilateral exports. Hence, it indicates the significant importance of developing countries' TEs, and they involve in innovating at the frontier since countries are gaining significant weight in term of their bilateralexports of technology-sensitive products. Importer countries' PRs also are positive and highly significant which indicate that strengthening destination countries' PRs enhance bilateral exports of the developing countries. The empirical result which shows that, interaction effect is negative and statistically significant, suggests the dominance of market power as discussed earlier.

Panel B depicts the empirical results of the decomposition of total exports into extensive and intensive export margins. For the extensive export margins, the results indicate that a unit increase in the TEs index boosts exports along with the extensive export margin by 30-32%²⁰. However, for intensive export margin, it accounts only for 10-11%. Hence, this result depicts that the adoption of technological capacity augments more varieties of products between country pairs for the developing countries. Interestingly, we find that destination countries' PRs are highly significant with positive signs across all model specifications, notwithstanding, they are insignificant for intensive margin in most models. It argues that the destination countries' strong PRs motivate developing countries' diversification of product, but it does not explain for its exports volume. This also suggests those destination countries' strong PR matters for exporters' product varieties. The interaction coefficient is negative and significant showing that the dominance of market power impacts for developing countries' bilateral exports along with trade margins in the preferred models.

Table 4 shows developed countries' empirical results.²¹ We find that TE coefficient is positive and statistically significant in the preferred model which indicates that developed countries' TEs significantly contribute to their bilateral exports. We find a mixed result for destination countries' PRs for high-income countries' total exports, as discussed earlier, the mixed evidence suggests that importers' strong PRs either do not affect bilateral exports or affect along this total export could be unsystematic owing to the limited variation of high-income countries' PRs. The

interaction coefficient is negative and significant, it shows that the existence of market power effects in high-income countries as discussed earlier.

Panel B shows the results of trade margins. The empirical result shows that if TEs index rise by one unit increases exports along with extensive export margin by 9-21%, however, for intensive margin of exports, it is insignificant across the chosen models. We also find a mixed result for destination countries' PRs for developed countries' bilateral exports along with extensive export margin. As we discussed earlier, importers' strong PRs either do not affect bilateral exports or it could be unsystematic owing to the limited variation of high-income countries' PRs. For intensive export margin, the PRs coefficient is negative and significant highlighting the fact that importers PRs do not contribute to high countries' exports volume. We find that an interaction coefficient is negatively related to extensive exports margins, but positively related to intensive export margin. It reveals that the market expansion effect of destination PRs dominated the market power effects on exports in this specific case, where the exportable product was not driven by higher technological efforts and vice-versa. We also find the same signs and significance level for the control variables across models along with trade margins in Tables 2 as discussed in the earlier subsection(5.1).

Table 3: Empirical results of TEs and Exports: Middle-income countries

VARIABLES	Panel A				Panel B							
	Total Exports				Extensive Margins				Intensive Margins			
	1	2	3	4	1	2	3	4	1	2	3	4
TE _i	0.117	0.306*	0.191***	0.160***	0.125	0.496***	0.329***	0.303***	-0.038	-0.189	0.119***	0.096*
	[0.200]	[0.186]	[0.033]	[0.048]	[0.082]	[0.077]	[0.043]	[0.055]	[0.166]	[0.165]	[0.033]	[0.050]
PR _j	0.282	0.322***	0.023	0.033***	0.202*	0.265***	0.108*	0.077***	0.081	0.058*	0.024	0.010
	[0.291]	[0.038]	[0.040]	[0.012]	[0.120]	[0.016]	[0.060]	[0.014]	[0.241]	[0.034]	[0.038]	[0.012]
TE _i *PR _j	-0.105***	0.009	-0.072***	-0.029**	-0.097***	-0.154***	-0.122***	-0.086***	-0.007	0.164***	-0.044***	-0.000
	[0.038]	[0.046]	[0.007]	[0.012]	[0.016]	[0.019]	[0.009]	[0.014]	[0.031]	[0.040]	[0.007]	[0.012]
LGDP _i	2.291***	0.625***	0.234***	0.047***	0.974***	0.136***	0.248***	0.016	1.256***	0.480***	0.220***	0.065***
	[0.067]	[0.052]	[0.011]	[0.014]	[0.030]	[0.022]	[0.011]	[0.016]	[0.055]	[0.046]	[0.013]	[0.014]
LGDP _j	1.172***	0.800***	0.182***	0.111***	0.704***	0.319***	0.178***	0.113***	0.469***	0.474***	0.163***	0.105***
	[0.196]	[0.054]	[0.021]	[0.014]	[0.081]	[0.022]	[0.023]	[0.016]	[0.163]	[0.047]	[0.019]	[0.015]
Ldistance	-2.077***		-0.279***		-1.052***		-0.353***		-1.031***		-0.224***	
	[0.023]		[0.004]		[0.009]		[0.005]		[0.019]		[0.004]	
Comlang	0.731***		0.171***		0.529***		0.260***		0.210***		0.110***	
	[0.056]		[0.009]		[0.023]		[0.012]		[0.046]		[0.009]	
Contig	-0.155*		-0.092***		-0.037		-0.126***		-0.121*		-0.067***	
	[0.083]		[0.012]		[0.034]		[0.015]		[0.069]		[0.011]	
Colony	0.855***		0.090***		0.587***		0.137***		0.263***		0.047***	
	[0.081]		[0.011]		[0.033]		[0.014]		[0.067]		[0.011]	
Constant	-59.917***	-30.869***	-5.986***	-3.116***	-29.452***	-9.936***	-6.667***	-3.417***	-29.045***	-20.572***	-6.249***	-3.896***
	[5.091]	[1.785]	[0.604]	[0.488]	[2.115]	[0.737]	[0.769]	[0.552]	[4.219]	[1.579]	[0.572]	[0.502]
Observations	16,986	16,986	25,080	25,080	17,114	17,114	20,418	23,351	16,986	16,986	25,080	25,080
R-squared	0.816	0.831	0.869	0.737	0.860	0.860	0.793	0.730	0.679	0.697	0.820	0.685
Year FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Exporters FE	yes		yes		yes		yes		yes		yes	
Importers FE	yes		yes		yes		yes		yes		yes	
Pair FE		yes		yes		yes		yes		yes		yes

Note: Numbers in parentheses are standard errors.

*, ** and *** denote that coefficient is significant at 10, 5 and 1 percent levels respectively.

Table 4: Empirical results of TEs and Exports – High-income countries

	Panel A				Panel B							
	Total Exports				Extensive Margins				Intensive Margins			
VARIABLES	1	2	3	4	1	2	3	4	1	2	3	4
TE _i	0.189*** [0.054]	0.286*** [0.032]	0.088*** [0.008]	0.043*** [0.009]	0.455*** [0.028]	0.298*** [0.015]	0.207*** [0.018]	0.086*** [0.010]	-0.266*** [0.043]	-0.012 [0.029]	-0.005 [0.010]	0.011 [0.011]
PR _j	-1.311 [1.109]	0.160*** [0.019]	-0.429*** [0.078]	0.019*** [0.006]	-1.386** [0.570]	0.240*** [0.009]	-1.159*** [0.113]	0.060*** [0.007]	0.076 [0.883]	-0.079*** [0.017]	-0.078 [0.072]	-0.011* [0.006]
TE _i *PR _j	0.022*** [0.008]	-0.065*** [0.008]	-0.010*** [0.001]	-0.010*** [0.002]	-0.066*** [0.004]	-0.074*** [0.004]	-0.031*** [0.002]	-0.021*** [0.003]	0.088*** [0.006]	0.009 [0.007]	0.006*** [0.002]	-0.001 [0.003]
LGDP _i	1.352*** [0.028]	1.177*** [0.029]	0.137*** [0.007]	0.204*** [0.007]	0.685*** [0.015]	0.650*** [0.014]	0.218*** [0.014]	0.241*** [0.008]	0.666*** [0.023]	0.527*** [0.027]	0.119*** [0.008]	0.174*** [0.007]
LGDP _j	1.532*** [0.450]	0.802*** [0.022]	0.361*** [0.045]	0.081*** [0.004]	1.020*** [0.231]	0.250*** [0.010]	0.791*** [0.065]	0.055*** [0.005]	0.512 [0.358]	0.552*** [0.020]	0.151*** [0.042]	0.101*** [0.005]
Ldistance	-1.306*** [0.011]		-0.120*** [0.002]		-0.592*** [0.006]		-0.125*** [0.002]		-0.714*** [0.009]		-0.115*** [0.002]	
Comlang	0.514*** [0.027]		0.050*** [0.003]		0.262*** [0.014]		0.059*** [0.004]		0.253*** [0.021]		0.043*** [0.004]	
Contig	-0.179*** [0.035]		-0.059*** [0.004]		-0.288*** [0.018]		-0.097*** [0.006]		0.109*** [0.028]		-0.027*** [0.004]	
Colony	0.540*** [0.036]		0.054*** [0.005]		0.386*** [0.019]		0.084*** [0.006]		0.154*** [0.029]		0.029*** [0.004]	
Constant	-48.776*** [7.295]	-43.862*** [0.912]	-8.081*** [0.883]	-5.696*** [0.223]	-29.393*** [3.747]	-20.856*** [0.439]	-19.333*** [1.322]	-6.858*** [0.253]	-19.380*** [5.806]	-23.004*** [0.835]	-4.118*** [0.840]	-5.973*** [0.238]
Observations	32,209	32,209	33,440	33,440	32,209	32,209	32,804	33,326	32,209	32,209	33,440	33,440
R-squared	0.889	0.906	0.876	0.850	0.863	0.879	0.804	0.834	0.813	0.829	0.839	0.826
Year FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Exporters FE	yes		yes		yes		yes		yes		yes	
Importers FE	yes		yes		yes		yes		yes		yes	
Pair FE		yes		yes		yes		yes		yes		yes

Note: Numbers in parentheses are standard errors.

*, ** and *** denote that coefficient is significant at 10, 5 and 1 percent levels respectively.

5.2.1 TEs and Exports – Across Income Groups

This study further classifies the bilateral export flows across different income groups, such as bilateral export flows from middle-income (MI) to MI countries, from MI to high-income (HI) countries, from HI to MI, and from HI to HI countries, respectively in Table 5. We apply the Poisson fixed-effect model year fixed-effects, i.e., the PPML model with country pair fixed-effects. Table 5 shows the results of bilateral export flows across different income group combinations. We find that TEs positively influence the bilateral export flows across different income combinations. TEs coefficient is highly significant for export flow from developing countries to developed countries. It depicts that the developing countries' high-technology products are more exported to developed countries. India's exports of generic drug and Chinese dominance in exporting of solar panels are a spot of such exporting. Moreover, we find that high-income countries' TEs also is positively influence bilateral export flows to developing countries, but not to the developed countries. Evidently, the share of high-income countries' exporting to middle-income countries, the case of China, is more compare to high-income countries. It also indicates that developed countries are already in the frontier of technology; hence they are not exporting the high-tech exports products as compared to developing countries. The companies for developed countries may be facing stiffer competition for their product which may not be the case in other pairs. Destination countries' strong PRs positively stimulate the bilateral export flows from MI to MI, from MI to HI, and from HI to HI, however, it is negatively influencing the bilateral exports from HI to MI. A possible reason for this result is that developing countries' innovation is based on weak threat of imitation and there is weak PRs protection, hence developing countries TEs is negatively related to high-income countries' exports. We find the interaction coefficient is negatively related to bilateral export flows across all combinations.

Panel B shows the impact of TEs on extensive and intensive export margins. The positive TEs encourage the quality of exports (product varieties) across all combinations except bilateral export flows from HI to HI. Export volume is positively influenced by countries' TEs across all income groups' combination except bilateral export flows from MI to MI. We find that enforcement of strong PRs has a positive impact on export margins, when we move the bilateral exports from MI to MI and MI to HI, yet in contrary, when we move the bilateral exports from HI to MI and HI to HI across the extensive and intensive export margins. The possible reason could be the less variability in the strength of PRs in developed countries. The interaction effects are also negative and significantly different across bilateral export flows and across export margins, the possible reasons are discussed in earlier sections.

Table 5: Empirical results of TEs and Exports – across-income groups

	Panel A					Panel B							
VARIABLES	Total Exports				Extensive Margins				Intensive Margins				
	MI to MI	MI to HI	HI to MI	HI to HI	MI to MI	MI to HI	HI to MI	HI to HI	MI to MI	MI to HI	HI to MI	HI to HI	
TE _i	0.116*	0.467***	0.025***	0.013	0.248***	0.829***	0.033***	-0.004	0.062	0.275**	0.020**	0.026*	
	[0.059]	[0.109]	[0.007]	[0.012]	[0.069]	[0.124]	[0.007]	[0.012]	[0.062]	[0.112]	[0.008]	[0.013]	
PR _j	0.035**	0.100***	-0.023***	0.004***	0.083***	0.175***	-0.009***	-0.006***	0.011	0.063**	-0.015***	0.001	
	[0.017]	[0.026]	[0.001]	[0.001]	[0.020]	[0.031]	[0.001]	[0.001]	[0.017]	[0.027]	[0.001]	[0.001]	
TE _i *PR _j	-0.019	-0.098***	-0.006***	-0.002	-0.088***	-0.199***	-0.011***	0.002	0.015	-0.044*	-0.003	-0.004	
	[0.017]	[0.025]	[0.002]	[0.003]	[0.020]	[0.028]	[0.002]	[0.003]	[0.018]	[0.025]	[0.002]	[0.003]	
LGDP _i	0.024	0.066***	0.229***	0.192***	-0.005	0.044**	0.311***	0.208***	0.046**	0.077***	0.164***	0.177***	
	[0.022]	[0.018]	[0.010]	[0.009]	[0.026]	[0.020]	[0.012]	[0.010]	[0.023]	[0.018]	[0.012]	[0.010]	
LGDP _j	0.084***	0.125***	0.080***	0.077***	0.104***	0.120***	0.030***	0.066***	0.070***	0.122***	0.117***	0.085***	
	[0.023]	[0.026]	[0.007]	[0.008]	[0.026]	[0.029]	[0.008]	[0.009]	[0.024]	[0.027]	[0.008]	[0.009]	
Constant	-1.235	-4.240***	-6.336***	-5.201***	-1.942**	-4.702***	-8.151***	-6.045***	-1.990***	-4.881***	-6.141***	-5.722***	
	[0.756]	[0.800]	[0.338]	[0.336]	[0.881]	[0.881]	[0.388]	[0.370]	[0.772]	[0.825]	[0.372]	[0.353]	
Observations	10,488	14,592	14,592	18,848	9,462	13,889	14,497	18,829	10,488	14,592	14,592	18,848	
R-squared	0.763	0.718	0.873	0.817	0.759	0.709	0.869	0.785	0.695	0.676	0.817	0.818	
Year FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	
Pair FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	

Note: Numbers in parentheses are standard errors.

*, ** and *** denote that coefficient is significant at 10, 5 and 1 percent levels respectively.

6. Synthesis of the empirical results

Based on the preferred model, Table 6 presents the synthesis of the empirical results. TEs augment the bilateral exports along with trade margins across countries. Countries technological efforts increase the likelihood that countries become motivated to export high technology products along with product varieties and volume of exports. Destination countries' PRs protection enhances bilateral exports along with extensive margins of exports. Our result indicates that interaction coefficient (between TE_i and PR_j) is negatively related to exports that is, holding TEs constant, a higher level of destination PRs is associated with a lower volume of source exports. Therefore, where the exportable product was propelled by higher technological efforts, the market power effect of destination PRs dominates the market expansion effects on exports.

In case of developing countries, the results indicate that a unit increase in the TEs boosts exports along with extensive export margin by 30-32%. However, for intensive export margin, it accounts only for 10- 11%. Hence, this result depicts that the adoption of technological capacity augments more varieties of products between country pairs for the developing countries. For high-income countries, we find that if TEs rise by one unit it increases exports along with the extensive export margin by 9-21%, however, for intensive margin of exports, it is insignificant across the chosen model. Interestingly, we find that importers' PRs positively influence bilateral exports along extensive margins when exporting from MI to HI countries, however, when from HI to MI, it is negatively related. This result shows that developed countries have strong threat to imitation along with market expansion effects, but developing countries pose weak threat to imitation as well as the existence of market power effects.

We find that TEs positively influence the bilateral export flows across different income combinations. TEs coefficient is highly significant for export flow from developing countries to developed countries. It depicts that the developing countries' high-technology products are more exported to developed countries. We find that high-income countries' TEs also positively influence bilateral export flows to developing countries, but not to the developed countries. As developed countries are already in the frontier of technology, hence they are not exporting the high-tech exports products as compared to developing countries. The companies for developed countries may be facing stiffer competition for their product which may not be the case in other pairs. Based on the results, we suggest that countries should support exporters in marketing of the products, brand creation through various schemes including participation in international trade fairs. Devise schemes to reduce the cost of exporters for patenting in different countries and ensure that market power enjoyed by the HI countries' exporters is not abused.

Table 6: Synthesis of the empirical results

Full Sample	Total Exports	Extensive Margin	Intensive Margin
TE _i	+ve and significant	+ve and significant	+ve and significant
IPR _j	+ve and significant	+ve and significant	Not significant
IPR*TE	-ve and significant	-ve and significant	-ve and significant
Middle Income			
TE _i	+ve and significant	+ve and significant	+ve and significant
IPR _j	+ve and significant	+ve and significant	Not significant
IPR*TE	-ve and significant	-ve and significant	Not significant
High- Income			
TE _i	+ve and significant	+ve and significant	Not significant
IPR _j	+ve and significant	+ve and significant	-ve and significant
IPR*TE	-ve and significant	-ve and significant	Not significant
Across Income Group: MI-HI			
TE _i	+ve and significant	+ve and significant	+ve and significant
IPR _j	+ve and significant	+ve and significant	+ve and significant
IPR*TE	-ve and significant	-ve and significant	-ve and significant
Across Income Group: MI-MI			
TE _i	+ve and significant	+ve and significant	Not significant
IPR _j	+ve and significant	+ve and significant	Not significant
IPR*TE	Not significant	-ve and significant	Not significant
Across Income Group: HI-MI			
TE _i	+ve and significant	+ve and significant	+ve and significant
IPR _j	-ve and significant	-ve and significant	-ve and significant
IPR*TE	-ve and significant	-ve and significant	Not significant
Across Income Group: HI-HI			
TE _i	Not significant	Not significant	+ve and significant
IPR _j	+ve and significant	-ve and significant	Not significant
IPR*TE	Not significant	Not significant	Not significant

7. Sensitivity Analysis

In this study, we analyse the impacts of exporting countries' TEs on their bilateral exports and further on the decomposition of total exports – extensive and intensive export margins. To check the robustness of our results, we are interested to utilise the “distance to frontier” as a proxy variable for TEs. On the premise that it would be able to measure the technological gap of the exporters where low technology gap more high-tech exports and vice-versa.

In Table 7, by utilising the Poisson fixed-effect model, we find that countries' technological gap is negatively related to their bilateral exports along with extensive and intensive margins for full sample. We also find that not only countries' product varieties, but long-run export growth is also negatively influenced by exporters' technological gap. We also have observed that importing countries' PRs is negatively related to their bilateral exports along with extensive across income groups. Interestingly, we have found an opposite sign of our main results for the interaction effects due to the distance to frontier of countries' TEs. We also find that the interaction effect is positive and statistically significant across income groups along with export margins. Thus our main results are robust to having distance to frontier as a proxy variable for technology efforts.

Table 7: Empirical results of Technological Gap and Exports – Full sample, HI and MI countries

VARIABLES	Full Sample			Middle-Income			High-Income		
	Total Exports	Extensive Margin	Intensive Margin	Total Exports	Extensive Margin	Intensive Margin	Total Exports	Extensive Margin	Intensive Margin
Tech_Frntri	-0.105*** [0.010]	-0.123*** [0.011]	-0.096*** [0.010]	-0.160*** [0.048]	-0.303*** [0.055]	-0.096* [0.050]	-0.043*** [0.009]	-0.086*** [0.010]	-0.011 [0.011]
PRj	-0.072*** [0.008]	-0.076*** [0.009]	-0.074*** [0.008]	-0.025 [0.020]	-0.095*** [0.023]	0.009 [0.022]	-0.033*** [0.009]	-0.058*** [0.009]	-0.015 [0.010]
TechFrntri*PRj	0.030*** [0.002]	0.039*** [0.003]	0.024*** [0.002]	0.029** [0.012]	0.086*** [0.014]	0.000 [0.012]	0.010*** [0.002]	0.021*** [0.003]	0.001 [0.003]
LGDPi	0.221*** [0.006]	0.236*** [0.007]	0.207*** [0.006]	0.047*** [0.014]	0.016 [0.016]	0.065*** [0.014]	0.204*** [0.007]	0.241*** [0.008]	0.174*** [0.007]
LGDPj	0.090*** [0.005]	0.074*** [0.006]	0.100*** [0.006]	0.111*** [0.014]	0.113*** [0.016]	0.105*** [0.015]	0.081*** [0.004]	0.055*** [0.005]	0.101*** [0.005]
Constant	-6.150*** [0.232]	-6.880*** [0.259]	-6.675*** [0.240]	-2.795*** [0.492]	-2.812*** [0.554]	-3.704*** [0.508]	-5.459*** [0.233]	-6.383*** [0.263]	-5.915*** [0.250]
Observations	58,410	56,559	58,410	25,080	23,351	25,080	33,440	33,326	33,440
R-squared	0.819	0.807	0.782	0.737	0.730	0.685	0.850	0.834	0.826
Year FE	Yes	yes	yes	yes	yes	yes	yes	yes	yes
Pair FE	Yes	yes	yes	yes	yes	yes	yes	yes	yes

Note: Numbers in parentheses are standard errors.

*, ** and *** denote that coefficient is significant at 10, 5 and 1 percent levels respectively.

8. Conclusion

This study examines the impact of technological efforts on bilateral exports along with the margins of trade. In this study, we have implemented the Poisson Pseudo-Maximum Likelihood (PPML) estimation technique proposed by Silva and Tenreyro (2006) as an appropriate methodology to estimate the impact of technological efforts (TEs) on bilateral exports along with the extensive and intensive margin of trade across 56 countries during 1996-2014. To analyze the TEs, this study constructs a technology effort index using principal component analysis using both input and output indicators of innovation, made by a country that contributes toward its bilateral export across countries. Furthermore, we have split our samples into two categories, such as (a) full sample; and (b) across income groups (based on level of economic development).

We have found strong evidence that countries' TEs contribute to bilateral exports along with trade margins. Countries' technological capacity increases the likelihood that countries become motivated to export high technology products along with product quality and export volumes. Importing countries' PRs protection stimulates bilateral exports along with product variety; however, it does not contribute to exports volume. This result indicates that countries' patent rights enhance quality of imports rather than quantity/volume of exports. We have also examined the interaction between source countries' TEs and the destination countries' PRs environment. The fact that the interaction effect has a negative influence on exports in high-income countries suggests that stronger destination PRs enable source country firms to exploit market power better, if they possess greater technological capacity.

Based on the level of economic development, this study reveals strong evidence that technological level augments bilateral exports only along with only extensive margins. It implies that technological capacity plays a significant role for countries' product diversification and exports quality across income groups. Interestingly, we find that importers' PRs positively influence bilateral exports along extensive margins when exporting from MI to HI countries; however, when from HI to MI, it is negatively related.

This study recommends that TEs advocate the product diversification along with a long-run export growth in order to improve exporters' productivity, improve allocative efficiency, and realise the economic development. Hence, these findings have implications for research on the effects of source countries' TEs, and destination countries' PRs on economic development. In future research, scholar

can investigate the impact of higher technological efforts in the source country and higher destination PRs on foreign direct investment (FDI). Another avenue for future work is to integrate source country exports with source country outward foreign direct investment (FDI) activities. Under theories of internalization, it is well- known that firms choose among different modes of entry into foreign markets, with exporting and FDI being the key modes.

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Notes

¹ Countries' TEs capture the inputs and outputs associated with innovation activities.

² World Development Indicators (2018).

³ For instance, few such economies are engaged in adaptive R&D for high-technology products in the second or third stage of product cycle development. A few may even export such products if they are not protected or are off-patent in the international markets. India's exports of generic drugs are an example of such exported products. Some other developing countries may have evolved up the technology ladder in a few sectors to produce and export patented products in the first stage of their product cycle development. Patenting and exporting of Chinese solar panel is a case in point

⁴ Griliches (1990) establishes R&D as an input into the knowledge production function that leads to output in the form of patents.

⁵ Kim (1997) defines technological capability as "the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt and change existing technologies." (p. 4). Capability can be grouped under three broad headings, such as physical investment, human capital, and the technological effort of a country.

⁶ There is a considerable trade-off between the quality of exports data and their variances in disaggregated trade flows. Usually, the first order condition of the Poisson model gives the same weight to all observations, hence, in presence of heteroskedasticity, the Poisson model performs extraordinarily better than other models (Silva and Tenreyro 2006).

⁷ See Anderson and van Wincoop (2003) who develop the "new" version of the gravity model with the presence of multilateral trade resistance.

⁸ That is constructed as weighted averages of bilateral distance, with GDP used as weights

⁹ This approach will also absorb the size variable's frameworks with panel data while accounting for the unobservable multilateral resistance terms, see Anderson, Larch and Yotov (2015), and Larch and Yotov (2016) for further discussions.

¹⁰ This model is estimated in two stages, estimation of Probit model in the first stage that determine the probability to exports. OLS technique will use for positive sample of trade flows in the second stage estimation.

¹¹ For detailed discussion see Santos Silva and Tenreyro (2006 and 2011) and Head and Mayer (2014).

¹² The sources of endogeneity are model misspecification, measurement error, and simultaneity. An endogeneity problem occurs when there is a reverse causality where the policy variable may be associated with the unobservable cross-sectional trade costs variables.

¹³ Available at https://wits.worldbank.org/product_concordance.html

¹⁴ Principal component analysis (PCA) is a statistical procedure which converts an original set of observations, possibly correlated variables, into a substantially smaller set of uncorrelated variables that represent most of the information in the original set of variables (Hotelling 1933). Moreover, PCA reduces the dimensionality of the variable set and decomposes the total variance.

¹⁵ Park and Ginarte (1997) develop the PRs' index that indicates the strength of PR protection in each country. The index ranges in value from 0 to 5, higher values of the index reflect stronger levels of protection. Further, Park (2008) extends the index to more countries and longer time.

¹⁶ Available at <http://www.cepii.fr>

¹⁷ 56 countries are included in this study based on data availability

¹⁸ Middle-income economies are those whose gross national income (GNI) per capita is more than \$1,026 but less than \$12,475 and high-income economies are those whose GNI per capita is \$12,476 or more (World Bank 2016).

¹⁹ This study includes 24 middle-income countries as the exporters, and all 56 countries are the importer countries.

²⁰ The range is the coefficients of different models (Model 3 and 4)..

²¹ This study includes 32 high-income countries as the exporters, and all (56) countries are the importer countries.

Exploring Opportunities for Science and Technology Collaboration in Agriculture: Why Caribbean scientists collaborate with international partners?

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Abstract

The nature of global science is changing and experts suggest that the present scientific and technical revolution is truly unprecedented, particularly in areas of expansion and integration of global networks which is most evident in global spending on R&D, information communication technologies, transport, and others. Most of these networks are initiated on collaborations with international organisations, multinational corporations, major foundations, and cross-national structures. So, building technological capacity through knowledge creation in developing countries is significantly linked to the globalisation of science. This is evident in the growing number of researchers and increased scientific publications that are initiated through collaborations with cross-national structures and organisations. Developing countries of the Caribbean Community have recently witnessed increasing rates in publications written with scientists from other regions of the world and technical projects initiated at the governmental level. This study attempts to analyse two research questions: a) what are the mechanisms for building science and technology with far-flung reasons and b) why researchers and scientists collaborate with far regions. Through the deployment of detailed questionnaires, the study analyses the responses from 25 Caribbean practitioners from the Caribbean Agricultural Research and Development Institute; University of the West Indies; University of Guyana; and the CARICOM Secretariat to understand the hierarchical nature and power structure of collaboration. Based on empirical data, collaboration activities involve sharing knowledge on the context of a particular innovation or the critical scientific knowledge embedded in the innovation. For the first research question, three dominant mechanisms account for almost 75 per cent of all collaborations: joint research activities with universities; in-house R&D; and joint research activities with government R&D

centres. This is because efforts are geared towards developing scientific infrastructure that is conducive to local user characteristics and environmental conditions. For the second research question, optimising resources and mutual beneficial technology arrangements, are the significant factors that Caribbean practitioners consider for engaging with far regions. A gradual change in this direction is evident with the shift from the large-scale transfer of agricultural products from the advanced countries to fostering South partnerships to promote food and nutrition security cooperation. These emerging trends are significant drivers for South to South collaboration representing the links between developing countries to build science and technology capacity.

1. Introduction

Agriculture continues to be a dominant role in the economic and social development of many Member States countries. The sector remains an integral contributor to gross domestic product, employment generation and foreign exchange earnings. As such, there exist a direct link between agriculture and the improvement of the Caribbean economy and the sustainability of rural livelihoods. For example, Jamaica's agricultural sector generates employment for about 20 per cent of the labour force (FAO, 2003; Josling et al., 2018). Agriculture also remains a vital area of regional and international collaboration for agro-processing and nutritional security and is a potential opportunity to be unlocked in the Caribbean. However, globalisation and trade liberalisation have compelled CARICOM's leaders to confront difficult decisions about the Region's policy orientation, particularly concerning mechanisms to ensure collaboration between the public and private sector and the creation of an enabling environment favourable to food industry and agricultural growth and development. Previous experiences indicate that competitiveness in the agriculture sector cannot be achieved solely through improvements in productivity, plant efficiency and product development (Caribbean Community Secretariat, 2012). Such scientific endeavours must be facilitated by a policy framework and the ability of nations to engage and sustain productive partnerships with other nations to foster investment and research within the sector (Gibbons et al., 1994). To support international collaboration between universities, private sector, and government institutions, many nations have to adopt policies to promote collaboration within their Science, Technology and Innovation system in priority sectors and with other nations (Luukkonen, 2001).

However, innumerable challenges confront the agriculture sector in the Member States, where the population is heavily dependent on the sector for employment and meeting increased demand in the food supply. Crop yields have fallen, input costs have increased, food costs to consumers are high, and incomes of

farmers – the majority of producers – are low. These changes in agricultural productivity and income are adversely affected by market uncertainties and investment in technological practices by developing countries to drive competition in agricultural products, which are in turn related to the weak coordination between vested stakeholders in both domestic and regional settings. Globalisation is also changing the marketing channels of the food industry; there is high transportation cost between the island States, vulnerability from adverse climate conditions, and the small economy size of member states, meaning the drive for domestic productivity for local producers are small (Josling et al., 2018). Also, policy challenges relating to harnessing the contributions of macro-economic impacts of tourism, oil exploration and development, and other major industry is causing complex and structural change where the labour force is leaving agriculture, particularly producers, and switching to other sectors (FAO, 2019). The confluence of these challenges has tremendous effect on the economic and social stability of the agri-economy in Member States.

1.1. Emerging trends in agricultural development in the Caribbean

The agriculture sector lags behind other sectors in terms of R&D development. The rapid growth of new industrial and service sectors in many of the Member States has put agriculture on the lower end of the scale. Figure 1 shows the share of GDP of the major industry group for the Caribbean Community for the year 2018. The service sector accounts for almost 70 percent of GDP for most member states and agriculture contributing not more than 4 percent. This is obvious from an economic standpoint and because structural transformation prescribes a smaller share of the agricultural sector in the national GDP as an economy develops. However, the demand for agricultural products in the region is increasing with simultaneous tightening of government expenditure on agricultural R&D. A historical contribution of the share of agriculture in Member States is provided in Figure 2. In few Member States – The Bahamas, St. Kitts and Nevis, and Trinidad and Tobago – agriculture represents about one percent of national GDP. The situation is different for countries like Belize, Guyana, Haiti, Dominica, and Suriname, where agriculture is an important industry for the economy. It contributes around 8 percent to 19 percent of GDP with a mean of 13 percent over the last five years. Additionally, these economies continue to attract a significant share of employment between

10 percent to 25 percent in those countries (FAO, 2019). Being producer economies, agriculture has suffered by accounting for a smaller share of total output than in earlier years. In 2020, share of agriculture GDP accounted for about 8 percent of GDP in the Caribbean Community and in 1980 it accounted for 12 percent. For 8 of the 15 member states, share of agricultural GDP accounted for no more than 10 percent in 2020 for which data is available; it was less than 5 percent in Grenada, St. Lucia, Antigua and Barbuda, St. Kitts and

Nevis, and Bahamas. Agriculture is still an important sector in few member states, especially in Haiti, Guyana, Dominica and Belize. In contrast, most of the countries in Sub-Saharan Africa and South Asia invest more in agricultural research on average, than most of the countries in the LAC region to offset the population dependency on food and nutrition.

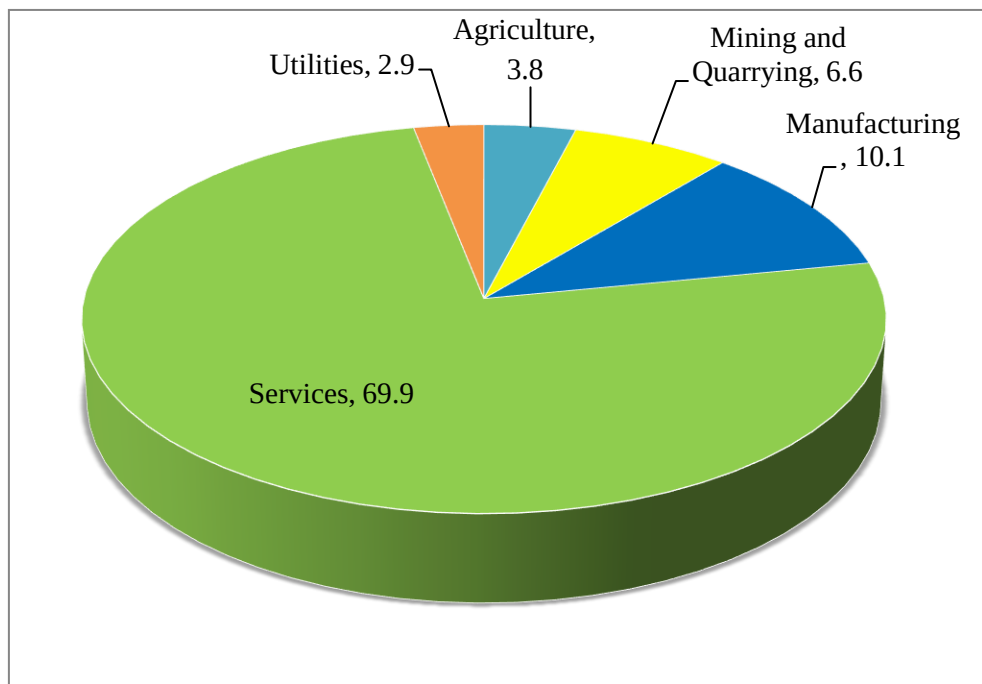


Figure 1. Structure of CARICOM GDP (in percentage) by major industry group.
Source: Compiled by author from (Caribbean Community Secretariat, 2020)

The result of declining agricultural share seems to be linked to the tremendous growth in other economic sectors rather than the shrinking agricultural production, although population demand for food would have increased over the years. As such, what is required is a more integrated information flow to be put in place along with infrastructural improvements to offset the historical emphasis on traditional crop production varieties. If the right configuration is achieved between stakeholders and policy infrastructure, many Member States, or even the Caribbean Community could be a massive Agri-Hub of the world as there is untapped natural resources and crop-tolerant climatic conditions.

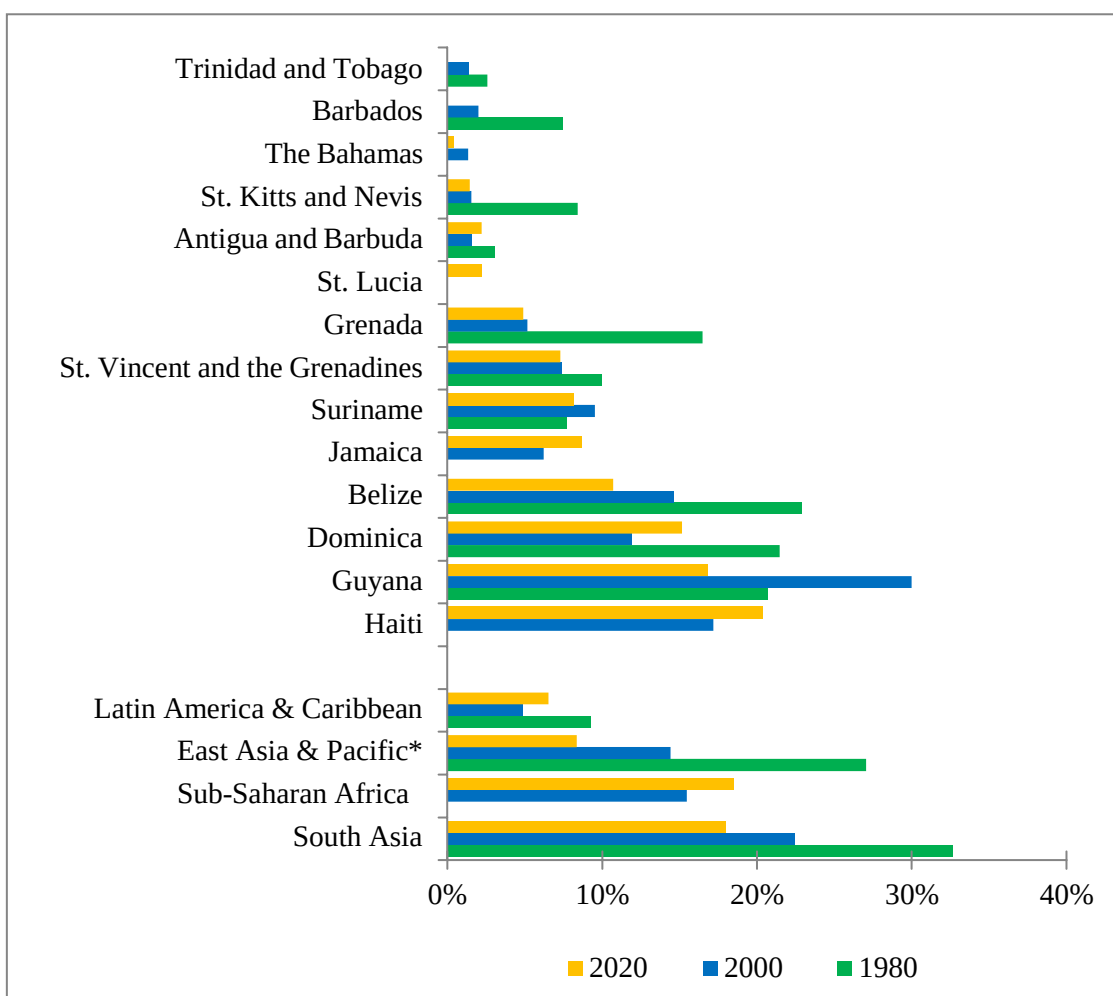


Figure 2. Historical patterns in the share of agriculture to GDP for the period 1979 to 2019. Source: Compiled by author from World Bank national accounts data, and OECD National Accounts data files, 2021.

1.2. International partners for agricultural research

At the regional level, rapidly changing market channels associated with globalisation of the food industry is gradually displacing historically built collaboration patterns dominated by the U.S., Canada, U.K., France, Germany and Norway. The emerging trends in Table 1 shows that Latin America and East Asia regions are highly preferred for collaborating in areas of food and nutrition security; root and tuber crop production systems; genetic and molecular studies and value chain studies. In contrast, collaboration with North American regions – Texas in the U.S. and Canada – involve root crops such as butternut squash, scotch bonnet peppers and coconuts; E- Agriculture, food and nutrition security, SPS Measures, and food safety. Europe remains the region for financial aid having strong collaboration links to Caribbean institutions as indicated by a

mean of 1.79 (most preferred). This is because most of the ECLAC donors are from Europe; of interest to Caribbean practitioners include Germany, United Kingdom, Ireland, Norway, Netherlands and France. The ECLAC or by Spanish acronym CEPAL, is a UN organisation based in Chile with a sub-regional office in Trinidad and Tobago. It is tasked with contributing to the social, economic and environmental development of the Latin American and Caribbean through continuous international cooperation, by undertaking research and development activities and providing technical cooperation at the regional level. Similarly like collaboration activities in North America region, activities with ECLAC donors extend to disaster risk resilience, food and agriculture and the environment. What needs to be understood is whether there has been a change or on-going transitions whereby scientific collaborations are shifting towards developing countries. This would hold significant implications as it would suggest that the outcomes or priorities of the collaboration process are not in the interest of Caribbean practitioners. However, based on field data, collaboration with neighbouring countries in Latin America – Brazil, Costa Rica, Mexico, Chile and Dominica Republic – are the strongest in terms of countries of preference.

Table 1. Significant collaborating partners of CARICOM countries when establishing international S&T collaboration in agriculture

Regions	Collaborating Partners	% Freq.	Mean	Median (p50)	Highest Score (Percent)	Lowest Score (Percent)
Caribbean Community	Trinidad and Tobago; Suriname; Barbados; Jamaica; St. Vincent and the Grenadines; Belize; Antigua and Barbuda; Dominica; Guyana; Grenada; CARDI 14 country offices; (French Guiana, Guadeloupe, Martinique, U.S. Virgin Islands)	100	1.82	2	1 (35.71)	3 (17.86)
North America	United States (Texas, Florida, Alabama); Canada; Mexico; USA/ Puerto Rico	75.00	2.33	2	1 (28.57)	5 (9.52)
Latin America	Costa Rica; El Salvador; Dominican Republic; Colombia; Brazil; Chile; Venezuela; Cuba; Argentina	71.43	1.15	1	1 (60.00)	5 (5.00)

East Asia and Pacific	PR China; Thailand; Malaysia;Fiji; Japan; Pacific SIDS; Singapore; South Korea; Australia	71.43	2.25	2	1 (30.00)	5 (10.00)
	Europe and Central Asia	67.86	1.79	1	1 (57.89)	5 (5.26)
South Asia	United Kingdom; Netherlands;France; Norway; Germany; Ireland	67.86	2.63	3	1 (26.32)	5 (10.53)
	Philippines; Pakistan; Sri Lanka; Maldives	60.71	2.53	3	1 (23.53)	5 (5.88)
Middle East and North Africa	Morocco; Egypt; Algeria	46.43	3.23	3	1 (7.69)	5 (15.38)
Sub-Sahar anAfrica	South Africa; Nigeria; Mali;Kenya					

A weighted 5-point matrix/rating scale was used to evaluate each statement by a given set of choices, 1 being most preferred, 2 being moderately preferred, 3 being slightly preferred, 4 being somewhat preferred, and 5 being least preferred.

2. Analytical Framework

Collaboration is regarded as a need-driven activity with the aim of attracting the best talents and expertise to conduct scientific investigations and enquiry. Many times, these collaborations are usually motivated around economic needs, historical interactions such as colonial relationships, economic ties or similarities in linguistics and culture, and geographic proximity (Wagner, Brahmakulam, Jackson, Wong, & Yoda, 2001). The impact of these drivers on the structure of a country's collaboration pattern can be long lasting and even deter national governments from making their own scientific investigations. More importantly, what needs to be investigated pertains to whether the objectives of collaboration and the resulting socio-economic benefits are suitable and appropriate for all collaborating partners and not just in the interest of selective partners. In fact, Wagner et al. (2001) provided a rather revealing analysis regarding the ranking for engaging in collaboration by developed countries scientists. Their extensive study concluded that 54 percent of the surveyed scientists collaborate due to previous interactions stemming from visits or meeting by the international collaborator. This was followed by the expertise of the foreign partner and only around 20 per cent scientists collaborate in the international area to optimize equipment and facilities. Though not surprising as developed countries are heavily endowed with resources, the situation for developing countries and

low-income developing countries warrant a similar analysis. Most of the time, interest for collaboration grew out of diplomatic ties with scientific and socio-economic motivations taking a back seat, reaping international funding and low S&T capacity building.

The process for building technological innovations in developing countries depends to a large extent on the diffusion and absorption of scientific and technical knowledge as well as the conversion of these into new products and production processes. This paints an interactive and complex system involving science, technology, learning, policy, and demand (Edquist, 1997). The use of the system of innovation approach to the study of knowledge exchange is not new (Carlsson, 2002; Edquist, 1997). The system of innovation approach is compatible with the notion that processes of innovation are, to a large extent, characterized by interactive learning (Edquist, 1997). The fact that successful innovations are not isolated events (Schumpeter, 1939) but occur in collaboration and interdependence with other organization gives rise to the emergence of the System of Innovation (SI) approach (Edquist, 2004). This position is also important for multinational and transnational corporations that aims to accelerate the pace of S&T innovations, seek out the best S&T talent and gaining access to new markets for high- margin products (National Research Council, 2014). Many scholars have analysed these trends to understand how they shape and reshape the S&T landscape. However, these frameworks places emphasis on understanding how innovations emerge without considering what precedes the interaction for networking as well as the socio-economic implications of collaboration. Recently, scholars suggest an international system of innovation, for which we have adopted in this study. Desai (2009) in dissecting international technology transfer channels in developing Asian countries generated three underpinnings of the international system of innovation: dynamic, hierarchical and power structure. These three descriptive foundations of the international system of innovation can be captured visually by an inverted triangle depicting the hierarchical S&T resource chain where countries try to harness and acquire technological capabilities. As developing countries tries to acquire technical competence and build S&T capabilities through R&D research, scientific collaboration, and strategic alliances among others, they shift upwards the S&T resource chain. Those countries, while progressively strengthening their core scientific competence, could displace actors (high endowment) who once dominated that particular domain through technological competence and competitiveness. Thus, the system can be considered as non-static and gradually changing as actors' moves up and down the S&T resource chain. A critical point to note here is that building technical competence and having high concentration of S&T resources also peddles the kind and magnitude of scientific collaboration an actor forms with another actor at the bottom or any other position of the resource chain. Contrary of research efforts that employ innovation system approaches and system analysis actually provide any detailed analysis of international scientific collaboration by focusing entirely

on corporate R&D (Fromhold-Eisebith, 2007), internationalization of S&T should extend to include global scientific and technological policies and strategic alliances (Chesnais, 1992, 2010).

2.1. A decade of international and regional collaboration activities

In 2016 there was the conclusion of the EU funded APP with the Inter-American Institute for Cooperation on Agriculture (IICA) being the implementation agency. The APP comprised of three components namely- i) the CARICOM secretariat leading the regional agricultural development policy and strategy empowerment; ii) Caribbean Agricultural Research and Development Institute (CARDI) spearheading improvement in transfer and/or adoption of research and/or technology and iii) IICA leading the charge for agricultural enterprise development and improved market linkages. The major success registered by the APP included supporting member states to develop their national agriculture policies and capacity building for the policy makers. Also in the same year, the Ministers of Agriculture rectified the 'Resolution of the Ministers/Representatives of Agriculture within CARICOM to commit to work together and unify towards addressing the issue of chronic hunger, poverty and food nutrition security for the people of Haiti' which was supported by 11 CARICOM member states at the 34th FAO Regional Conference for Latin America and the Caribbean held in Mexico (Caribbean Community Secretariat, 2021a).

During the COTED-Agriculture meeting in 2017, a Regional Policy on Bio-safety was also adopted with the underlying objective of achieving efficient and balanced biosafety regime in the region. The adoption process of the policy involved consultation with the member states as a component of a 2012 Regional Biosafety Project funded by UNEP/ Global Environment Facility (GEF) and executed by the University of West Indies (Caribbean Community Secretariat, 2021b). In 2011, COTED Ministers adopted the Community Agricultural Policy (CAP) which included food and nutritional security, product-trade/value chain, sustainable development of natural resources (natural resources, forest and fisheries), rural modernisation and youth programmes and modern agricultural knowledge and information system as its key focus areas. A Regional Policy on Food and Nutrition Security and Action Plan was formulated to promote regional food and nutritional security. It aims to facilitate access to regionally produced nutritious food with remunerative market prices ensuring increment in production, productivity and profit to farmers.

With similar focus, the region collaborated with the EU and the UNDP to create an online agriculture portal termed as Caribbean agribusiness. It is a platform of institutions and individuals in agribusiness as Ministry of Agriculture, producers' organisations, farmers and agri-business associations and equipped with information pertaining to policy issues, trade and investment opportunities in the sector. Additionally, in the fisheries sector, a revision of the Common

Fisheries Policy was undertaken in order to facilitate collaboration in conservation, management and utilisation of the living marine and aquatic resources; to provide a chance to the member states to look into sub-regional arrangement of concerned fishing stocks and which are not managed under any regulatory regime. The Policy also undertook to impart a framework to ensure the economic interests and welfare of fishing communities through coordinated policy interventions (Caribbean Community Secretariat, 2018a). In 2012, a collective decision to endorse a Plan of action to build up ties between agriculture and tourism was taken. The plan included steps to increase trade of agricultural goods into tourism and hospitality sector and also emphasis on rural/culinary tourism product development and promotion (Caribbean Community Secretariat, 2018b).

During the 10th EDF Intra-ACP Agriculture policy Programme for the Caribbean (CARICOM members plus the Dominican Republic), a contribution agreement between the European Commission and the Inter-American Institute for Cooperation on Agriculture was signed to support the agriculture sector in the region. The programme was aimed towards empowering policy regimes and incentive schemes for small scale farmers, increment in production and productivity of select commercially and nutritionally valuable agricultural produce to ensure food security and building regional institutions' capacities. Under the 10th EDF itself, a contribution agreement for a Programme on Sanitary and Phyto-sanitary (SPS) measures was also signed which was a part of an umbrella programme to fulfil the commitments under CARIFORUM-EU Economic Partnership Agreement. The programme was intended towards gaining the access to European market by complying with their SPS measures and also focused on helping countries in the region to better develop their own regionally harmonised SPS measures. The program with its 3 components namely legislation, national and regional SPS coordination and capacity building was aimed towards promoting trade in agriculture and fisheries while being sustainable (Caribbean Community Secretariat, 2018c). While the CARICOM oversaw the legislative functions, the Caribbean Regional Fisheries Mechanisms (CRFM) acted as collaborating partner accompanied by a designated agency belonging to the Dominican Republic.

The promotion of trade in agriculture was also a priority area. The Regional Policy on Biotechnology, Genetically Modified Organisms was being undertaken by the GMO Working Group set up by the 13th Council of Trade and Economic Development (COTED). Furthermore the Trade Capacity Enhancing Project which was financed by the Multilateral Fund of the Inter-American Development Bank (IADB), has executed the Caribbean Agri-business Association (CABA) strategic plan. In 2007, a pledge of investment of US\$ 11.3 was undertaken in the Agriculture Donor Conference held in Trinidad which resulted in various projects including submissions of 39 national and 14 regional projects. As a key outcome of the conference, funding by the

Governments of Italy and Spain was secured for introduction of innovative technology in agriculture sector to up the production scale in many member states. Preparations were also made for an Agriculture Investment Forum to be organised in Guyana in 2008. The CARIBVet network which works as the animal health surveillance network for early information in animal pests and diseases, was also strengthened. The CARICOM secretariat also acted as coordinator for various agencies of member states, regional and international organisations to deal with Avian influenza in the Caribbean region (Caribbean Community Secretariat, 2008).

In 2010, efforts were targeted towards achieving international competitiveness of the agriculture sector with ability to contribute to the development of vibrant CSME (Caribbean Single Market and Economy). In the same efforts, the Draft Community Agricultural Policy was formulated. Many other steps were also undertaken as- CRICOM Regional Policy for Food and Nutrition Security (RPFNS) was formalised and endorsed and a draft action plan to implement it was also chalked out; an Agri-business Development Strategy was adopted; integration of primary products into value-added and other agri-business was promoted by incorporating value chain approach. RPFNS was endorsed in a special meeting of COTED in Grenada in 2010 (Caribbean Community Secretariat, 2011) and its blueprint was also approved by the Council for Human and Social Development (COHSOD).

3. Methodology

The study is based predominantly on empirical data as well as secondary data. To collect primary information on the patterns and reasons for engaging in international collaboration related to agriculture we deployed structured questionnaires. The questionnaire was designed and comprised of 26 questions which captured information about areas of collaboration, conditions for initiating collaboration, preferred institutions when establishing international collaboration, among others. In addition, interviews were held with experts, policy officials and prominent people of the Caribbean Secretariat, such as Deputy Programme Managers, Scientists and Organisational Heads to collect additional information. The basis for selecting these persons is their knowledge about their areas, especially the deputy programme managers under the Council for Trade and Economic Development, were able to provide valuable information on the current collaboration projects and initiatives in their areas of work. In this study we analyse the twenty five (25) responses from Caribbean policy makers, scientists and academicians in the area of science and technology for agriculture.

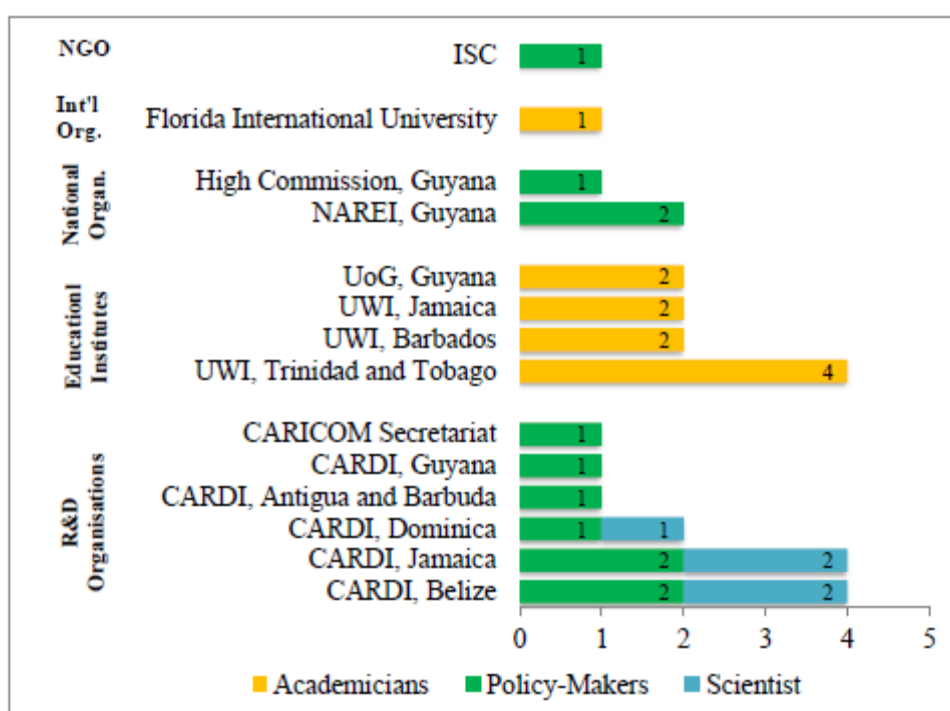


Figure 3. Distribution of experts by organisational affiliation

4. Discussion and Findings

This section brings together knowledge of experts and officials from the Caribbean Community Secretariat, Caribbean Agricultural Research and Development Institute, National Agricultural Research and Extension Institute, University of the West Indies, and the University of Guyana. The data analysis below is derived from the research design in conducted from April 2021 on international collaboration for innovation in agriculture. Responses from the questionnaire indicate the interest of experts and officials to exchange knowledge and experiences at the international level with Latin America, Europe and North America, particularly, US government institutions and public universities in agricultural research and development.

4.1. Drivers of collaboration

More than often, collaboration involves the sharing of knowledge on the context a particular innovation can be used or what are the critical scientific knowledge embedded in the innovation. From our analysis, there are three major approaches across all organisations for developing and strengthening science and technology capacity: joint research activities with universities and technical institutes; in-house research design and development; and joint research activities with government R&D centres. These dominant mechanisms account for 75percent of the international collaboration. This is because efforts are geared towards developing scientific infrastructure that is conducive to local user

characteristics and environment conditions. For the less-scientific countries, establishing collaboration for developing technologies and innovative products requires developing countries to carefully assess the selection and utilisation of technologies and to identify the relevant local weaknesses and

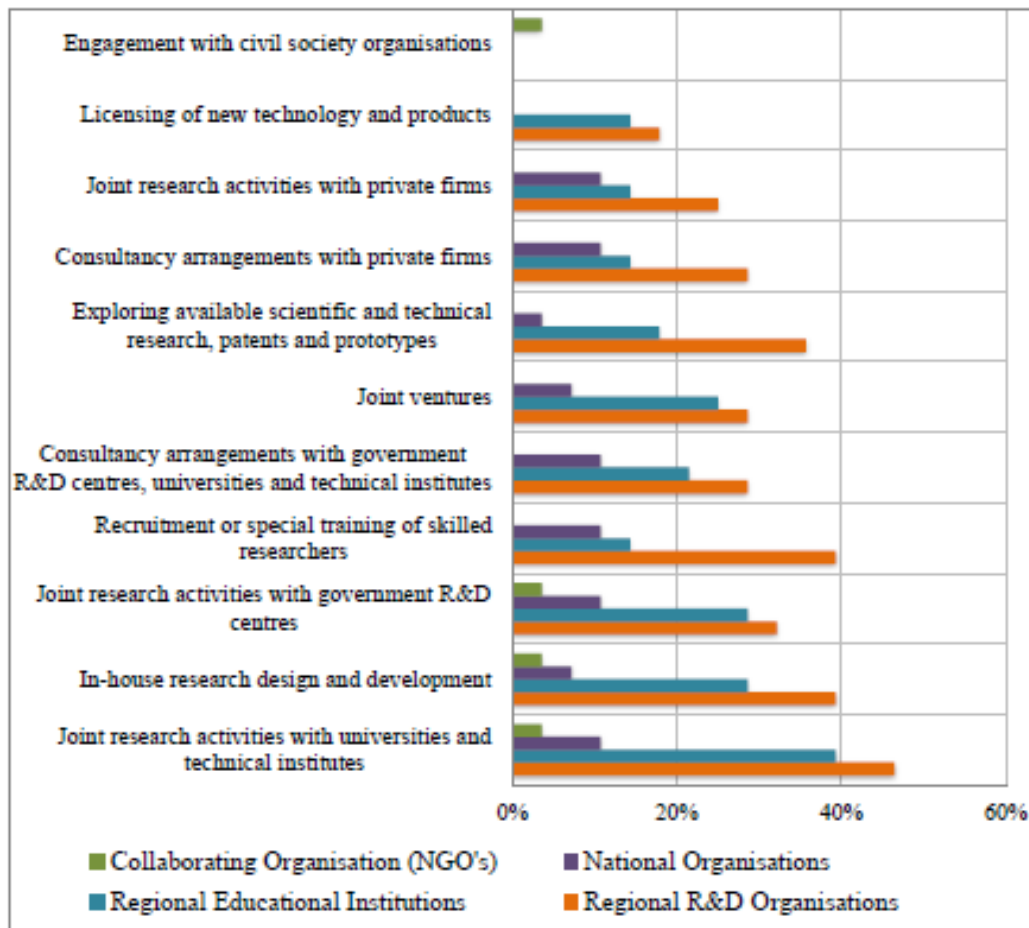


Figure 4. Mechanisms for building science and technology capacity by different categories of organisation

advantages in order to minimise the adaptation period (Cohen, 2004). A significant step towards this direction is visible in Figure 4 where there is a break from traditional approaches of adopting imported innovations from the developed world that is not suited for the production and process system of Member States. Several attempts in the past to assist Member States to boost agricultural related production have generally focused on the transfer of large-scale transfer of agricultural products and machinery from the advanced countries. For example, the Skeldon Sugar Factory was constructed during 2004-09 by the People's Republic of China in Guyana. The project represented the single largest investment in the history of Guyana with the transfer of technology from China to the Caribbean, involving the provision of technical assistance from one country to another. The project sought to establish a state-

of-the-art sugar factory and cogeneration facility, with the intention of increasing sugar production and lowering operational costs in the Berbice region of Guyana (Stabroek News, 2009). However, the modernise Skeldon Sugar Factory experience revealed the un-eventfulness of poorly planned technology collaboration that depends on the similarities and environmental conditions of the collaborating/contractor country and the destination country. The production, growing system and delivery of sugar in Guyana is different from China. While Guyana still utilize hands and light equipment for sugarcane cultivation, this severely affects the factory production capacity and operation cost, leading to re-design measures costing US\$ 60 million (Wilburg, 2017) in addition to the project cost.

Many efforts in Member States are now directed towards modifications to local conditions of S&T collaboration. For example, licensing of new technology and research arrangements with private firms are on the lower rank of the preferred method of collaboration, particularly for regional R&D organisations, educational institutions and national organisations. Another implication for the channels of international collaboration and the mechanisms that induce accumulation of technological skills rests with budgetary allocations that have potential to derail project priorities depending on the funding partner or institution. For instance, 50 percent of experts, when asked about the source of funding for international collaboration, pointed out that collaboration is usually initiated with the international partner providing full funding for the research activity. Almost 60 percent of experts from CARICOM R&D organisations and educational institutions indicate that they need to secure their own funding or source third party sponsors (international organisations, banks) for partnering in international collaborations. At the central level, government expenditure in the form of national budgetary allocation for international research and development was the most negligible as only few regional institutions like CARDI (Belize and Dominica), representing 14 percent of the sample organisations, have access to provisions in National Budget for S&T collaboration. Around 36 percent of experts (majority from R&D organisations) indicate that government ministries with responsibility for science and technology generally provide funding for supporting projects with an international partner.

Table 2. Considerations necessary by Caribbean practitioners for confirming commitment to international S&T collaboration in agriculture-related areas

Variables	Mean	Highest Score (Percent)	Lowest Score (Percent)
To access technical knowledge, facilities, and equipment one does not have	1.79	1 (39.29)	3 (17.86)
To pool knowledge to find innovative solutions for global problems	1.58	1 (57.69)	3 (15.38)
To maintain diplomatic aims and international relations	2.31	1 (7.69)	5 (3.85)
To develop specialization in a particular scientific area	1.68	1 (39.29)	4 (3.57)
To secure access to funding mechanisms	1.25	1 (85.71)	4 (3.57)
To facilitate the commercialization of new technologies	2.14	1 (35.71)	4 (7.14)
To build and strengthen S&T human resource	1.5	1 (53.57)	3 (3.57)

Note: A weighted 5-point matrix/rating scale was used to evaluate each statement by a given set of choices, 1 being extremely important, 2 being very important, 3 being somewhat important, 4 being not so important, and 5 being not at all important.

Table 3. Important conditions that shape Caribbean practitioners' decision in advancing and sustaining international S&T collaboration in agriculture and food

Variables	% Freq.	Mean	p50	Lowest Score (%)
Huge financial aid would be made accessible through this project	100	1.64	1	5 (3.57)
Collaborating partner(s) have already acquired the ability to advance research in the particular area of collaboration	100	1.82	2	5 (3.57)
Ability to develop new areas of scientific capabilities that are part of CARICOM strategic plan	100	1.96	2	5 (7.14)

Need to secure own funding to engage in collaboration	100	2.04	2	5 (7.14)
Collaboration area depend on funding partner(s) priorities	100	2.29	2	5 (3.57)
Collaboration project involves complex global problems that would improve all partner(s) visibility in the world	100	2.54	2	5 (3.85)
Only field data and observations are to be provided to the collaborating partner(s) to conduct out extensive research	100	2.89	3	5 (3.57)
Close geographic proximity of the collaborating partner(s)	100	3.36	3.5	5 (3.57)

Note: A weighted 5-point matrix/rating scale was used to evaluate each statement by a given set of choices, 1 being a great deal, 2 being a lot, 3 being a moderate amount, 4 being a little, and 5 being none at all.

The confluence of these indicators has a tremendous effect on the economic and social stability of the agri-economy in Member States. Thus, targeted and holistic policy interventions are required to achieve long-lasting solutions in the changing environment of the Caribbean Community. Also, proper alignment of the reasons for engaging in cross-border knowledge exchange can be exploited as significant drivers for South to South collaboration representing the links between developing countries to build science and technology capacity.

5. Conclusion and policy implications

The Caribbean Region has long relied on traditional partners – the U.S. and Europe – for much of its technological needs. However, as the share of S&T outputs of the U.S. shrinks (National Research Council, 2014) and the shifting of priorities of traditional partners to take account of critical social development issues (training in STEM education, climate change, unemployment, agriculture and tourism, critical telecommunication systems, etc.) of the Region, the Caribbean Community must re-examine its strategy for maintaining scientific collaboration and keeping awareness of emerging S&T developments. To fully reposition itself in the major trends occurring around the world – growing share of developing countries in high-tech exports, foreign direct investment flows, technological capabilities and global value chain networks – and to make strategic research investments, the Caribbean Community must assess with whom and in which areas it should collaborate.

To examine more deeply into the implications of the globalisation of S&T and of international collaboration in S&T for the Caribbean Community, it was decided to limit the scope of the research to selective regional, functional and associate

institutions to assess the Community strategies in agriculture for leveraging S&T engagement and for coordinating and implementing these strategies across institutions. In doing so, emphasis was placed on the first Strategic Plan (2015-2019) prepared by the Caribbean Secretariat and those institutions within the Community and its departments for which relates to the sectors defined in the study.

In the agricultural sector where technology relates to constructing and operating large-scale plant, knowledge is transferred internationally mainly through know-how agreements. However, recent trends indicate that specialised knowledge is now being channelled through, in addition to agreements, local linkages with production engineers and researchers. In the sectors of new and renewable energy and information communication technologies, knowledge emerges mainly from collaborative R&D activities and academic research. The five major channels of international collaboration include joint research activities with universities and technical institutes, joint research activities with government R&D centres, consultancy arrangements with government R&D centres, universities and technical institutes, in-house research design and development, and recruitment or special training of skilled researchers. Given these mechanisms of international collaboration, it faces up against several challenges.

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Structural Changes in The Global Pharmaceutical Industry and the Persistence of Global Asymmetries in The Pharmaceutical Industry

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Abstract

The global pharmaceutical industry has experienced critical structural changes since the previous decades regarding transformations in demand patterns, new technological opportunities related to biotechnology, and the diffusion of innovative technologies in the search procedures, and the emergence of new business models, impacting the growth patterns of pharmaceutical firms. The intensification of mergers and acquisitions involving pharmaceutical and biotechnology companies stands out as one of the most significant outcomes of the changes in the current pattern of competition and productive organization of this industry. Based on extensive microdata, this paper aims analyzes the mergers and acquisitions in the global (bio)pharmaceutical industry between 1997 and 2015 to observe new patterns of growth in the pharmaceutical industry in developed and emerging markets. Mergers and acquisitions involving pharmaceutical companies reflected the structural changes in the pharmaceutical markets. The results confirmed the hypothesis that the patterns of M&A involving pharmaceutical companies in traditional markets are substantially different from the patterns of M&A in pharmerging markets. In the group of countries classified as traditional markets that represent important markets of developed countries, deals directed to acquire targets with core capabilities in biotechnology or R&D activities, highly associated with intangible assets, prevailed. However, biotech or R&D targets were scarce in the group of developing countries with growing pharmaceutical markets. Pharmerging markets presented high growth expectations in the last decades, especially during the 2000s. The growth of these markets opened new spaces of

accumulation in the industry, creating opportunities for market consolidation, which reflected in horizontal majority acquisitions in the industry. As the market grew, companies could increase their scale and market power by acquiring smaller competitors. The growth and the higher appropriability conditions in these markets also attracted the entry of new transnational competitors. The findings in the article reinforced that, despite the structural changes in the pharmaceutical industry, global asymmetries in knowledge creations and innovation between advanced and developing countries remained. The analysis of M&A activity also revealed that deals involving targets with core capabilities in biotech or R&D activities in the traditional markets are not homogeneous. Most of these deals were minority acquisitions led by financial companies, with lower value deals and smaller target companies. On the other hand, there was also an expressive group of majority acquisitions led by pharmaceutical companies, presenting higher deal values and acquiring more mature targets. These findings corroborate the literature that points to increasing fragmentation and specialization in the innovation chain of the pharmaceutical industry and to the growing role of intangible assets in the growth strategies of firms.

1. Introduction

The global pharmaceutical industry has experienced critical structural changes since the previous decades regarding transformations in demand patterns, new technological opportunities related to biotechnology, and the diffusion of innovative technologies in the search procedures, and the emergence of new business models, impacting the growth patterns of pharmaceutical firms.

The growth of a firm depends both on their resources and characteristics of their environment (PENROSE, 2009; RAHMEYER, 2007). The set of resources covers the stock of knowledge, skills, competencies, as well as the capital available to firms (RAHMEYER, 2007). The individual characteristics of firms are associated with their ability to observe, learn, and exploit opportunities created by changes in their environment (COHEN; LEVINTHAL, 1990). Based on their set of resources and immersed in a specific environment, firms adopt strategies to grow. This process results in the transformation of the set of resources at the disposal of the firms. At the same time, this changes their environment, modifying the growth trajectory of the firm in a co-evolutionary way (GUENNIF; RAMANI, 2012; NELSON; WINTER, 1982; RAHMEYER, 2007).

This paper analyzes mergers and acquisitions involving pharmaceutical firms between 1997 and 2015. The analysis shows the emergence of two pathways of growth among pharmaceutical companies, reflecting structural changes in the industry. The first comprises the higher technological opportunities in traditional pharmaceutical market¹ generated by the emergence of biotechnology and new technologies in the innovation process in the pharmaceutical industry. The second pathway of growth comprises opportunities derived for new geographical frontiers of growth in the global pharmaceutical industry, which has been called pharmerging markets².

This research is aimed at contributing to the literature of the Health Economic-Industrial Complex (TEMPORÃO, GADELHA, 2019) by generating new evidence on global asymmetries between the pharmaceutical industry of developed and developing countries. Second, it emphasizes that mergers and acquisitions carry useful information to reveal the development pattern of the firms in the pharmaceutical industry, as the patterns observed were consistent with what the literature shows. Third, it brings attention to the need to deepen the comprehension of the role of minority acquisitions in the growth of the firm.

The paper is structured as follows. The second section reviews the literature. The third section reviews the structural changes in the global pharmaceutical industry and presents the reasons for pharmaceutical firms to engage in M&A. The fourth section proceeds with the methodology, and then, the fifth section analyzes M&A data of the pharmaceutical industry. The last section presents the main conclusions of the study.

2. Theoretic Framework

There is extensive literature about mergers and acquisitions. Several studies have concluded that there is no precise definition of the term “mergers and acquisitions” in the literature (FAULKNER; TEERIKANGAS; JOSEPH, 2012; HALEBLIAN et al., 2009;

JUNNI; TEERIKANGAS, 2019). Therefore, this paper defines M&A deals as the broad set of transactions where one firm acquires equities of another company, like shares or parts of it (e.g., division, business units), the creation of new companies with equities shared by two or more former companies of similar size that cease their existence (the most precise definition of a merger), takeovers, buy-outs, minority acquisitions, and joint venture formations (FAULKNER; TEERIKANGAS; JOSEPH, 2012; HALEBLIAN et al., 2009; JUNNI; TEERIKANGAS, 2019).

The perspective of the resource-based firm argues that a company engages in M&A to obtain resources, which thereby will produce competitive or dynamic advantages (BARNEY, 1986, 1991; GRANT, 1991; WERNERFELT, 1984). These resources assume forms of physical or intangible assets,

technological capabilities, and relevant knowledge (CONNER; PRAHALAD, 1996; GRANT, 1996; LEVITT; MARCH, 1988; NONAKA, 1991). New related

pieces of knowledge or complementary capabilities can enhance the innovative outcomes of the firm. "Acquiring diverse external knowledge bases and making proper use of this new knowledge are found to be relevant contributions to a firm's post-M&A innovative performance" (CLOODT; HAGEDOORN; VAN KRANENBURG, 2006).

Minority acquisitions account for almost one-third of M&A operations (BOSTAN; SPATAREANU, 2018) in the USA. Some reasons why firms engage in minority acquisitions are: to facilitate cooperation between two independent firms; to preserve or enhance target's management; to provide finance directly to target; to increase information about target firms; and avoid dilution of earnings per share (ALLEN; PHILLIPS, 2000; BOSTAN; SPATAREANU, 2018; OUIMET, 2013). In this sense, minority acquisition could be understood as an alternative to small and medium firms to finance its projects, increase cooperation to absorb knowledge and capabilities, and promote their growth with access to external resources without losing its formal independence. However, more research based on the evolutionary approach and resource-based view of the firm should be done on this topic.

According to the evolutionary theory, understanding the opportunities and limits that constrain industry dynamics requires considering not only the internal organization of the firm, but also the environment. There are several important factors within the environment that must be considered, including demand expectations, institutional settings (such as intellectual property right regimes and market regulation), uncertainty, and the technological environment (MALERBA; ORSENIGO, 1997; 2015).

The concept of technology regimes comprises the main characteristics of innovation patterns, describing the technological environment in specific sectors. The combination of the opportunity and appropriability conditions, the degree of cumulativeness of the technological knowledge, and the characteristics of the relevant knowledge base describe the sectoral technological regime (MALERBA; ORSENIGO, 1997).

The technological opportunity refers to the shared belief of agents about the chance that innovation efforts in some direction will lead to successful innovations. "Appropriability conditions summarize the possibilities of protecting innovations from imitation and of extracting profits from innovative activities" (MALERBA; ORSENIGO, 1997). The cumulativeness degree of technological knowledge refers to the incremental nature of the technological search. It measures the likelihood that successful innovation efforts will increase success in future innovation efforts in a cumulative way, and it is associated with the existence of dynamic increasing returns of exploring the knowledge

base. The characteristics of the knowledge base describe the nature and means of transmission of the knowledge required to conduct the innovative process in specific technology trajectories (DOSI; NELSON, 2010; MALERBA; ORSENIGO, 1997).

Firms can grow in two ways: exploring its set of resources in new ways or absorbing new resources externally. "Growth, by definition, implies that the firm takes into itself the activities associated with the opportunities for production and marketing that it perceives in its capabilities and its environment" (PENROSE, 2008). Therefore, two determinants are crucial to understand the potential and limits to the growth of firms: their set of resources and characteristics of their environment.

The set of resources covers the stock of knowledge, skills, competencies, as well the capital available to firms (PENROSE, 2009; RAHMEYER, 2007). Based on their set of resources and embedded in a specific environment, firms adopt strategies aimed at promoting their growth. Firms, however, do not consciously optimize strategies on efficient markets. Based on bounded rationality and immersed in Knightian uncertainty, firms adopt routines and conventions to figure out their strategies (NELSON; WINTER, 1982; RAHMEYER, 2007). From this perspective, the growth of M&A deals since the 2000s is, therefore, associated not with rational optimal procedures of decision making, but rather with the diffusion of M&A deals as an "important strategy" to promote firm growth.

3. Structural Changes in the Global Pharmaceutical Industry and Reasons for the Engagement of Pharmaceutical Firms in M&A

This article uses evolutionary theory to investigate patterns that emerged in the M&A activity of the pharmaceutical industry between 1997-2015. We now explore characteristics of the global pharmaceutical industry, considered as the environment where firms grow, internally or externally, using mergers and acquisitions. Then, we advance to the structural changes that have been transforming the pharmaceutical industry environment in the previous decades, focusing on the changes in its technological regime. Finally, we introduce some reasons for the engagement of pharmaceutical firms in M&A.

The competitive structure of the pharmaceutical industry comprises a differentiated oligopoly based on innovation and marketing (MAZZUCATO; DOSI, 2006; VARGAS et al., 2012). The introduction of new or improved products is one of the main strategies in the pharmaceutical and biopharmaceutical industry dynamics, demanding high investments in research and development (MALERBA; ORSENIGO, 2015). R&D expenditure of the pharmaceutical industry as a percentage of worldwide sales reached 20,4% in 2016 (EVALUATE PHARMA, 2017). Given the proximity of the innovative process to scientific advancement and the high codification of knowledge in the

sector, patents are the main form of appropriation in the industry. Marketing is also crucial in this industry. In 2013, the sales and marketing expenditures of the largest pharmaceutical firms reached 23% of its revenues, while R&D expenditures reached 15,3% (PRASAD; DE JESÚS; MAILANKODY, 2017).

The global pharmaceutical industry is dominated by a quite small and stable core of innovative firms (big pharma) from few developed countries. Despite the elevated levels of expenditures on marketing and R&D and the significant temporary monopolistic position provided by patents, the pharmaceutical industry shows reduced concentration ratios when seen as a unified sector. In 2016, the twenty largest companies in the sector accounted for 64.5% of prescription sales³ and the CR4 index was equal to 21,2% (EVALUATE PHARMA, 2017). Three reasons explain this: the fragmented nature of pharmaceutical markets, the high and the reduced cumulativeness of the innovation process, and the importance of imitation (MALERBA; ORSENIGO, 2015). The reduced or lack of possibility of substituting products of different therapeutic classes is the leading cause that explains the fragmented nature of pharmaceutical markets. In the sub-markets associated with therapeutic classes, the concentration levels are higher. The CR4 index on Oncology and Anti-Diabetics and Vaccines markets in 2016 was 45.6%, 74%, and 89,3%, respectively (EVALUATE PHARMA, 2017). Second, despite the monopolistic power given by patents, the innovation process on the industry is highly uncertain and presents low cumulativeness (MALERBA; ORSENIGO, 2015). The innovation process was commonly referred to as a quasi-random process guided by trial and error. Besides, the fragmented nature of pharmaceutical markets reflects also in the knowledge base of the industry, generating barriers to translate the knowledge accumulated in one submarket to another. Imitation also plays a crucial role in the pharmaceutical industry, reducing monopolistic positions throughout time with the introduction of generic drugs (MALERBA; ORSENIGO, 2015; MAZZUCATO; DOSI, 2006). Finally, as credence goods, market share in national markets are strongly linked to marketing efforts and distribution chains, creating a group of domestic/regional pharmaceutical firms that reduce the concentration in global terms.

In the past decades, the pharmaceutical industry has shown structural changes that affected its productive and innovative conditions, and, therefore, created opportunities and obstacles to the growth of its firms. The emergence of molecular biology and its promises, stringent sanitary regulations, changes in the intellectual property right regimes, the growth of generics markets, the demographic and epidemiologic transition, and the growth of developing markets all together impacted the pharmaceutical industry and its firms. New strategies emerged alongside with this new environment.

Since the 1980s, with the emergence of molecular biology and new techniques of experimentation, data processing has dramatically increased

technological opportunities and changed the knowledge base of the industry (HENDERSON; ORSENIGO; PISANO, 1999), which has drastically impacted the pharmaceutical industry and its technological regime.

The emergence of these new technological platforms generated a high expectation for the development of new therapeutic classes, and biological products had increased the technological opportunities, by opening new frontiers of growth in the industry. Since then, biotech drugs (vaccines, biologics) had increased its relevance in the innovative efforts of the pharmaceutical industry. Biotech Drugs accounted for 25% of the sales of prescription and OTC drugs in 2016 and nearly half of the sales of the top 100 products⁴ (EVALUATE PHARMA, 2017). Monoclonal antibodies and recombinant products ranked on the top 10 pharmaceutical products by sales. Furthermore, the growing focus on orphan drugs, the high- performance therapeutic areas, and personalized medicine are attracting more investment to biotech companies to finance the newest blockbuster drug.

The incorporation of molecular biology and new techniques of experimentation and data processing also led to hopes that the pharmaceutical industrial innovative process would move away from the trial and error search process (based on random screening) to a pattern guided by “targeted search.” The industrialization of the innovative process (NIGHTINGALE; MAHDI, 2006) would reduce the quasi-random characteristic of pharmaceutical industry innovation, increasing the degree of cumulativeness and the chances to approve new lucrative drugs.

This process has modified the relevant knowledge base of the industry, increasing the diversity and complexity of the knowledge involved in the search for innovations. Historically, big pharmaceutical companies (big pharma) have had its roots in the fine chemicals industry. However, the new opportunities in the industry depended heavily on molecular biology and computational knowledge generated in the academia and other sectors related to life sciences (HENDERSON; ORSENIGO; PISANO, 1999; NIGHTINGALE; MAHDI, 2006).

Consequently, pharmaceutical companies had to acquire and absorb the diverse and complex knowledge externally, using new strategies.

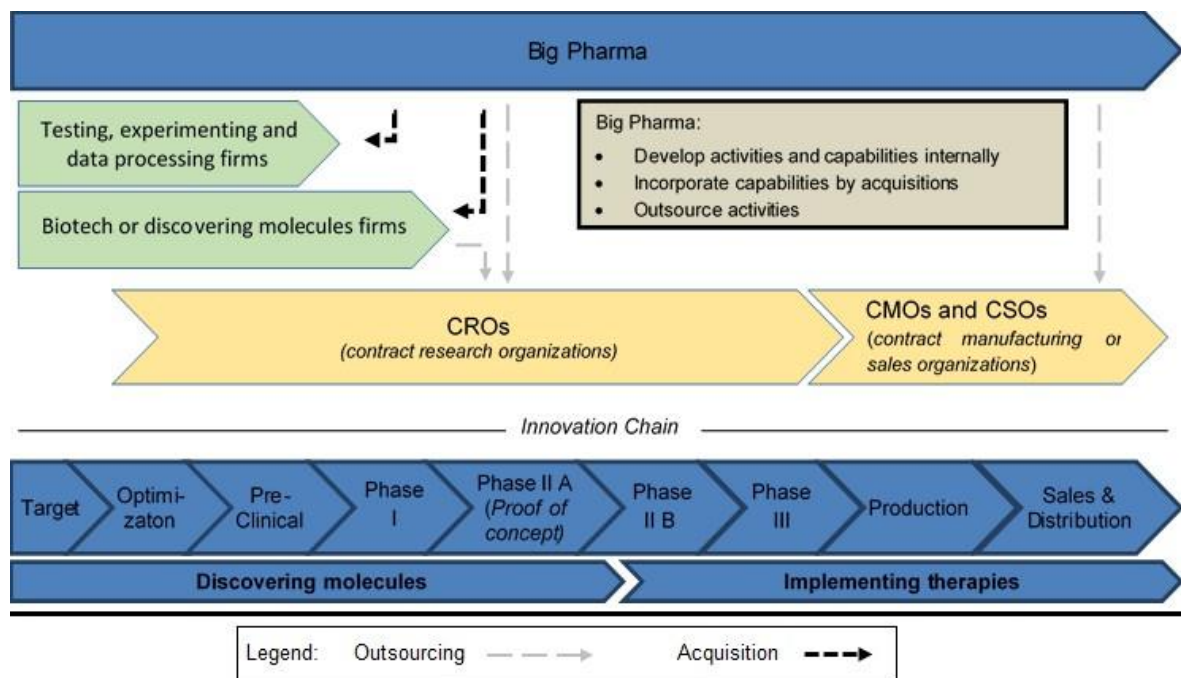
A significant consequence of the knowledge base transformation was the deepening of labor division in the pharmaceutical industry and fragmentation of its research and development chain. Therefore, the process of drug discovery and the development of new instruments and experiments have been increasingly fostered by startup companies, usually generated by spin-offs of promising research conducted by scientific institutions.

Changes in the institutional environment also affected the technological

regime of the pharmaceutical industry. The rise in the use of knowledge generated by the academia was supported by the incentives and regulations that promoted university and industry partnerships by governments (MAZZUCATO; DOSI, 2006). Stricter sanitary rules for the approval of new medicines also impacted the pharmaceutical industry, increasing the development costs of drug innovation. It increased the time needed to approve new drugs and had been pushing for stricter sanitary conditions to manufacture drugs (laboratory and manufacture good practices). Despite the controversy around estimates on the real costs to develop original drugs (CHIT et al., 2014; DIMASI; GRABOWSKI; HANSEN, 2016; MORGAN et al., 2011), it is consensual that costs had increased on the previous decades. The higher costs increased the barrier to move from drug discovery to drug development and production, reinforcing the division of labor and fragmentation of the R&D chain (MALERBA; ORSENIGO, 2015).

The literature shows that small innovative companies have been specializing in drug discovery and early drug development stages. Big pharmaceutical companies, on the other side, had been specializing in the final stages of drug development since these stages require significant productive and regulatory capabilities and capital requirements (COCKBURN; HENDERSON, 2001; MAZZUCATO; DOSI, 2006). Fragmentation of the R&D innovative process also induced the emergence of new specialized firms to execute services, as the Contract Research Organizations (CROs) and Contract Manufacturing Organizations (CMOs).

Figure 1 – Value chain fragmentation in the pharmaceutical industry⁵



Source: Prepared by the authors based on (VARGAS, 2016a)

These transformations generated optimism regarding the discovery of new drugs with high sales potential (blockbusters), but they also triggered a significant increase in the development costs of new drugs. The industry R&D productivity, measured by the number of drugs launched in the market divided by the R&D expenses required to launch these drugs declined in the 2000s.

Simultaneously, the industry witnessed the patent expiration of lucrative drugs (patent cliff). The decreasing productivity and the patent cliff stimulated questions about the business model of the pharmaceutical industry, intensified competition among large transnational pharmaceutical groups, and created the need for innovative financial approaches to support more productive drug development. In order to maintain or increase their competitive position in the global market, pharmaceutical firms have changed their business strategies (LO; NARAHARISETTI, 2013; VARGAS, 2016b).

The technological regime of the pharmaceutical industry has also been impacted by the level of appropriability of the industry, especially with the approval of the Trade-Related Aspects of Intellectual Property Rights (TRIPS). The TRIPS agreement sought to harmonize intellectual property rights among World Trade Organization (WTO) countries. These countries had to implement IPR minimum standards, converging their IPR regimes to that observed in advanced countries, like the enforcement of the patentability of drugs and active pharmaceutical ingredients, and extended the duration of patent protection to twenty years (CORIAT; ORSI; D'ALMEIDA, 2006). Developing and least developed countries were able to sign TRIPS with extended deadlines, to allow for the gradual convergence of the IPR regimes to TRIPS standards.

The main argument to support the TRIPS agreement was that stricter IPR regimes would create incentives for innovation in both developed and developing countries and that it would increase the availability of new drugs in developing countries (KYLE; QIAN, 2014). However, it reduced opportunities for imitation using reverse engineering practices and increased the appropriability conditions for innovators in these markets (MALERBA; ORSENIGO, 2015). Evidence suggests that, while implementation of the TRIPS agreement increased the launch of new drugs in developing countries (KYLE; QIAN, 2014), it reduced domestic innovation in these countries (QIAN, 2007), increased prices, and created negative consequences on access (CORIAT; ORSI; D'ALMEIDA, 2006; MALERBA; ORSENIGO, 2015). According to this article, the critical consequence of the TRIPS agreement was a sharp rise in the appropriability conditions of pharmaceutical products in developing countries, which opened new frontiers of accumulation and growth in the industry, creating incentives for the investment from pharmaceutical companies in these countries.

From an evolutionary perspective, the characteristics of the demand also play a crucial role. There was a substantial change in the growth vectors of the global pharmaceutical market from the 2000s, as the pharmaceutical market growth of advanced countries slowed down and accelerated in a group of developing countries. Between 2008 and 2013, this group of developing countries contributed to 46% of the global pharmaceutical market growth. According to expectations, between 2012 and 2017, two-thirds of global pharma growth would come from these markets (IMS HEALTH, 2012, 2013).

Another dimension that played a crucial role in the evolution of the pharmaceutical industry was the spread of financialization, understood as “a systemic pattern of wealth that implies the predominance of financial logic in the decision-making process of relevant players in the capitalist system” (BRAGA et al, 2017). Some of the main impacts of financialization on the firm behavior was the dissemination of M&A as a tool to appropriate value and constraint competition by acquiring strategic assets, and the increased importance of knowledge and intangible assets in the valuation of assets (SERFATI, 2008; HIRATUKA et al, 2022).

The structural changes in the pharmaceutical industry over the last decades have created opportunities and challenges. In an environment with higher technological opportunities, but higher knowledge base complexity, and rising costs of the innovative processes, companies reorganized their business strategies. Pharmaceutical companies had been adapting their strategies to current market dynamics, positioning themselves to grow through portfolio transformation, targeted deal-making, cost-cutting measures, and a sharpened focus on high- performance therapeutic areas and dynamic domestic markets. Engaging in mergers and acquisitions, especially M&A, has been crucial to implement their strategies.

Therefore, there are significant reasons for pharmaceutical firms to engage in mergers and acquisitions: the acquisition of relevant knowledge, intangible assets, and promising innovative projects, the reduction of R&D costs, and the entrance in new markets by acquiring firms with a portfolio of products and distribution capabilities, especially in pharmerging markets.

However, pharmaceutical firms are not the only ones that had been engaging in mergers and acquisitions in the pharmaceutical industry. Institutional investors have acquired increased role in the corporate decision-making process, “regardless of the magnitude of their ownership, given the high amount of capital they manage in capital markets” (FONSECA et al, 2019).

The next section describes the hypothesis, procedures, and methods used in this investigation.

4. Methodology

This research focuses on mergers and acquisitions involving companies related to the pharmaceutical industry between 1997 and 2015, in the context of structural changes in the industry. It is argued that the mergers and acquisitions that occurred in the pharmaceutical industry can shed light on the patterns of growth that emerged along with these structural changes.

The article's hypothesis is that the patterns of M&A involving pharmaceutical companies in traditional markets are substantially different from the patterns of M&A in pharmerging markets. These differences reflect the global asymmetries in the innovation and development stages of the pharmaceutical firms and pharmaceutical markets in these regions.

Advanced countries accounted for more than 95% of cumulative five-year sales of new chemical entity (NCEs) launches on the market between 2004 and 2011(IMS HEALTH, 2013)⁶. Moreover, pharmaceutical companies from developed markets are the leaders in the innovation efforts to produce new brand products in the global pharmaceutical industry (EVALUATE PHARMA, 2014, 2015). Therefore, it is expected that acquisitions oriented to incorporate innovation pipelines of drugs or new instruments, techniques, or services related to the innovation process will be concentrated in the advanced countries.

However, the fragmentation of the innovation chain tendency of the pharmaceutical industry suggests that there will be two distinct patterns in deals involving biotech or R&D services firms. It is expected that the need to finance its activities and projects induces smaller biotech or R&D service companies to engage in minority acquisition with financial companies. However, the incorporation of innovation pipelines of drugs or new instruments, techniques, or services related to the innovation process by pharmaceutical firms tends to be associated with majority acquisitions.

Although the importance of developing countries is increasing in the global pharmaceutical market, their product mix is substantially different from that of advanced countries. While generics sales accounted for 17% of sales in the 8 largest pharmaceutical markets of advanced countries, they accounted for almost half of the sales in the pharmerging markets (IMS-HEALTH, 2013). Consequently, it is expected that M&A activity in the developing countries will be concentrated in targets related to pharmaceutical manufacturing activities, and that will be observed substantially fewer acquisitions of firms related to biotechnology or R&D activities related to the pharmaceutical innovation process.

The growth of pharmaceutical markets in the developing countries have opened spaces for market consolidation. The broader markets and competition

in prices have put pressure for larger scales, which could be accomplished by the acquisition of smaller competitors. Besides, this growth induces the emergence of new international competitors. It could take many years for new competitors to accumulate a product portfolio, distribution capabilities, and develop market relationships to compete in these markets. The acquisition of established companies, then, is an alternative to enter these markets.

This paper uses a comprehensive and extensive dataset of worldwide M&A transactions involving firms in the pharmaceutical industry, completed between 1997 and 2015, to reveal the emergence of patterns of growth in the industry. The data was extracted from the Orbis database, provided by the bureau van Dijk.

The initial extraction selected M&As carried out by companies classified by Orbis as companies in the pharmaceutical, biotechnology, or life sciences sectors as a buying company or as a target company. Using the broad definition of M&A (FAULKNER; TEERIKANGAS; JOSEPH, 2012), we selected completed or presumably completed deals comprising the majority and minority acquisitions, mergers, joint venture formations, and institutional or management buy-outs or buy-ins. The first extraction resulted in a sample with 28,417 equity transactions.

The article uses the North American Industry Classification System (NAICS) to identify the sectors of firms. Orbis provided NAICS primary activity codes (core business) and secondary activity codes (other activities) to acquirers and targets. Firms were classified as “pharmaceutical companies” if their core business were related to pharmaceutical and medicine manufacturing⁷, research, and development in biotechnology⁸, distribution of drugs⁹ or firms with core business in R&D¹⁰ activities and other activities in pharmaceutical and medicine manufacturing, research and development in Biotechnology or distribution of drugs. According to their core business, “pharmaceutical companies” were further classified into three different groups: “Manufacturing firms (excluding biotech firms)¹¹”; “Biotech or R&D firms”¹², and “Distribution firms”¹³.

The two first digits of NAICS designate the economic sector of the firms. Firms with core business in activities under the digit 52 were classified as financial companies. Firms with their core business identified in ORBIS and that were not classified as pharmaceutical companies or financial companies were grouped in the “other” group.

Orbis database provides a broad set of information about the deals and companies involved with them. Besides the info about the industry classification of firms, types, financing, stakes involved, values, and dates of the deal, some legal, geographical, and financial characteristics of firms were explored to create categorical variables. The Orbis database also provides information about the

financial motivations of deals. Using textual analysis on STATA 14, we identified M&A deals that were associated with “venture capital,” “angel investment,” and “development capital” motives to create a variable signaling “financing motivations.”

The database provided information about the nominal values of deals in US dollars and the potential value of the target if deals acquired 100% of the company. Values were deflated using 2015 consumer price values (USA, 2020). Targets and acquirers of the deals were classified into four groups according to the country of their main legal address: traditional markets, pharmerging markets, other developed markets, and other countries.

The traditional pharmaceutical markets are Australia, Belgium, Canada, Denmark, France, Germany, Ireland, Italy, Japan, Netherlands, South Korea, Spain, Switzerland, the United Kingdom, and the United States. The selection followed the group of countries identified as the traditional markets by IMS-Health (2013) or countries that were one of the top ten leading exporters of pharmaceutical products in any year between 2010 and 2016¹⁴, but were not classified as traditional markets or as pharmerging markets by the IMS-Health (2013). This additional step included Switzerland, Belgium, Netherlands, and Denmark as traditional pharmaceutical markets.

Pharmerging markets are defined as pharmaceutical markets located in developing countries with forecasts of high growth potential. The group includes China, Brazil, India, Russia, Poland, Argentina, Turkey, Mexico, Venezuela, Romania, Saudi Arabia, Colombia, Vietnam, South Africa, Algeria, Thailand, Indonesia, Egypt, Pakistan, Nigeria, and Ukraine. “These 21 (...) countries will together add \$187 bn in annual sales between 2012 and 2017. This increase represents two-thirds of global pharma growth and will increase the pharmerging markets global share from 23% in 2012 to 33% in 2017” (IMS HEALTH, 2013).

The other developed countries are members of the OECD, except for those present in the major pharmaceutical markets or the emerging pharmaceutical market group. Finally, the other countries are all those that were not included in any other previous group.

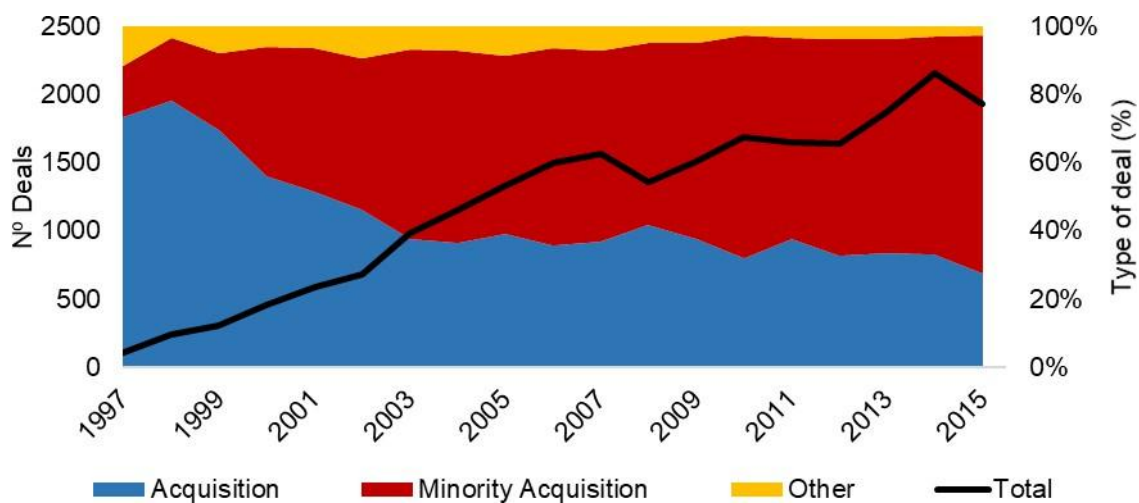
After creating these categorical variables, the data were treated to keep only transactions that involved pharmaceutical companies as targets or acquirer firms, ending with a database with 22,719 M&A transactions. Then, we proceed with exploratory analysis of the database in order to reveal the patterns of growth that emerged in the pharmaceutical industry. The next section will provide the results and explore the hypothesis presented.

5. Results

The initial data analysis showed a continuous growth of equity transactions from 1997 to 2015, despite the impact of the 2008's crisis. From 1997 to 2015, the number of annual operations grew from 115 to 1,934, reaching a compound annual growth rate (CAGR) of 17.5%. The analysis of the evolution of equity operations according to the deal type (acquisition, minority acquisition, mergers, joint venture formation, and institutional or management buy-outs or buy-ins) revealed details for these transactions. The main types of deals were minority acquisitions (58%) and majority acquisitions (37%). All other types of deals accounted for 5% of the deals in the period.

Majority acquisitions and minority acquisitions tended to grow in the period, but at different paces. The number of annual deals on the former grew steadily until 2007, then stabilized near 600 deals per year until 2014, then grew again. Despite showing a more volatile trend, the growth of minority acquisitions was marked higher. While majority acquisition operations reduced their share from 73% in 1997 to 37% in 2007 and 28% in 2015, minority acquisition operations went from 15% in 1997 to 56% in 2007 and 70% in 2015.

Figure 2 - M&A evolution according to the year and type of deal (1997-2015)



Source: Prepared by the authors based on Bureau van Dijk (2019)

The values of deals were informed in 16,349 transactions (72%), with an average value per operation of US\$ 150 million. However, the high coefficient of variation of the average value recorded indicated heterogeneity in the operations. The segregation of operations by ranges of values denotes this heterogeneity. About 75% of the equity transactions carried out in the period studied presented values between US\$ 1 and US\$ 100 million, and only 0.3% (41 operations) had values above US\$ 10 billion. The transactions with values

between US\$ 1 and US\$ 10 million accounted for 8.4% of the total amount spent. The 39 operations above US\$ 10 billion accounted for 42% of that amount.

Large equity transactions (above US\$ 100 million) accounted for almost 75% of the traded value, despite representing less than 2% of the total amount of operations. Majority acquisitions are the primary type of operations related to large equity transactions (83%). On the other hand, a large group of small financial operations emerged during the 2000s, from which approximately 90% involve values below US\$ 100 million, representing less than 9% of the trade value. In these operations, minority acquisition prevails, accounting for 75% of the operations

Table 1 - Value ranges of M&A deals involving the pharmaceutical industry according to the type of deal (1997-2015)

Value ranges (US\$ millions)								Total
		Less than 1	1-10	10-100	100-1,000	1,000 - 10,000	Greater than 10,000	
Majority acquisition	No.	445	1,407	1,675	949	241	37	4,754
	%	9.4%	29.6%	35.2%	20%	5.1%	0.8%	100%
	(row)							
Minority acquisition	% (col)	19.4%	22%	28.3%	67.8%	82.5%	90.2%	29.1%
	No.	1,799	4,850	4,072	356	32	1	11,110
	%	16.2%	43.7%	36.7%	3.2%	0.3%	0,0001%	100%
All other deals*	(row)							
	% (col)	78.4%	75.7%	68,8%	25.4%	11%	2.4%	68%
	No.	52	149	168	94	19	3	485
Total	%	10.7%	30.7%	34.6%	19.4%	3,9%	0,06%	100%
	(row)							
	% (col)	2.2%	2.3%	2.9%	6.7%	6.5%	7.3%	2.9%
	No.	2,296	6,406	5,915	1,399	292	41	16,349
	%	14%	39.2%	36.2%	8.6%	1.8%	0.3%	100%
	(row)							
	% (col)	100%	100%	100%	100%	100%	100%	100%

Source: Prepared by the authors based on Bureau van Dijk (2019)

Table 2 shows the geographical distribution of M&A deals involving firms of the pharmaceutical industry between 1997 and 2015. There were 17,217 deals with information of the acquirer and target countries. Seventy two percent of these deals were classified as domestic, which means that at least one of the acquirers and targets were from the same country. The group of countries classified as traditional markets had the highest proportion of deals involving the pharmaceutical industry, being followed by the group of countries classified as Pharmerging Markets.

Table 2 - Regional distribution of M&A deals (1997–2015)

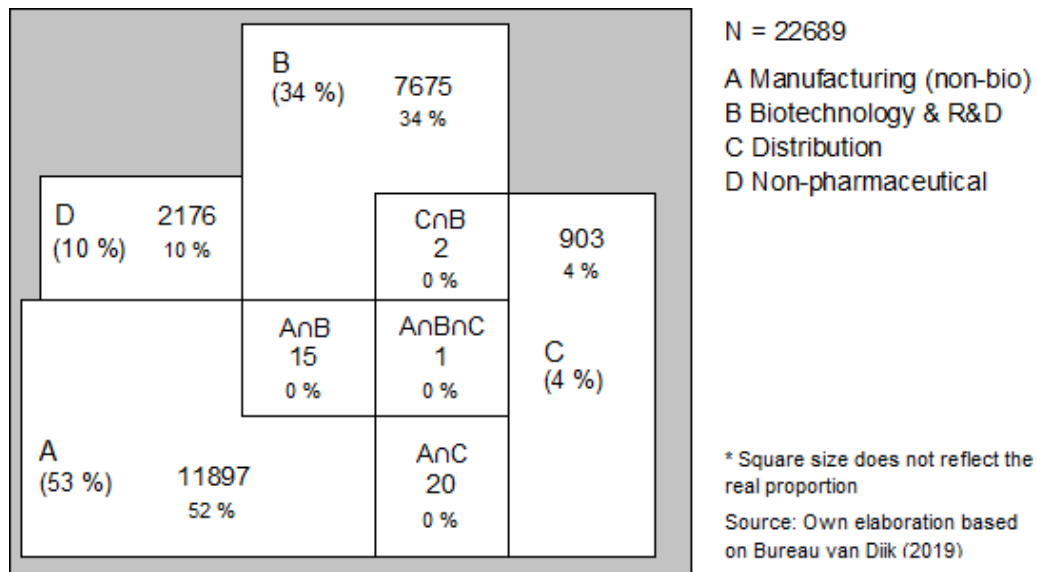
Deals (n= 17,217)	Acquirer			
	Traditional Markets	Pharmerging Markets	Other Developed Countries	Other
Traditional Markets	64%	1%	2%	1%
Target Pharmerging Markets	3%	17%	0%	1%
Other Developed Countries	2%	0%	5%	0%
Other	2%	1%	0%	3%

Source: Prepared by the authors based on Bureau van Dijk (2019)

Almost all M&A deals (99,87%) provided information about the target's core business. The deals were divided into four groups: Manufacture of pharmaceutical products (Manufacture), Distribution of pharmaceutical products (Distribution), Biotechnology, and other R&D activities related to the pharmaceutical industry (Biotech or R&D), and other activities non-related to the pharmaceutical industry (Non-Pharmaceutical). Manufacturing activities accounted for 53% of the deals, while Biotech or R&D accounted for 34%, distribution accounted for 4% of the deals, and non-pharmaceutical targets appeared in 10% of the deals.

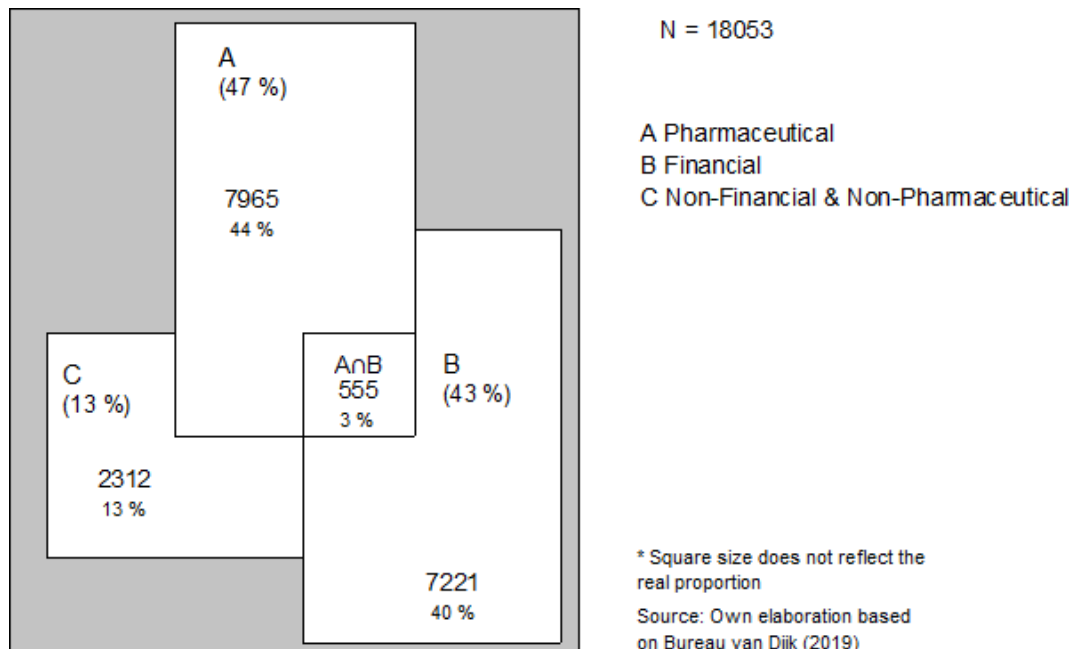
More than eighteen thousand deals had information about the acquirer's core business. The Acquirer's companies were grouped into three sectors: firms related to the pharmaceutical industry (Pharmaceutical), Financial companies (Financial), and Non-Financial & Non- Pharmaceutical companies. Disregarding those deals where the acquirer core business was missing, pharmaceutical companies were acquirers in 47% of deals, while financial companies and "non-financial companies and non-pharmaceutical" were present in 43% and 13% of the deals.

Figure 3 - Distribution of deals according to the target's core business (1997–2015)



Source: Own elaboration based on Bureau van Dijk (2019)

Figure 4 - Distribution of deals according to acquirer's core business (1997–2015)

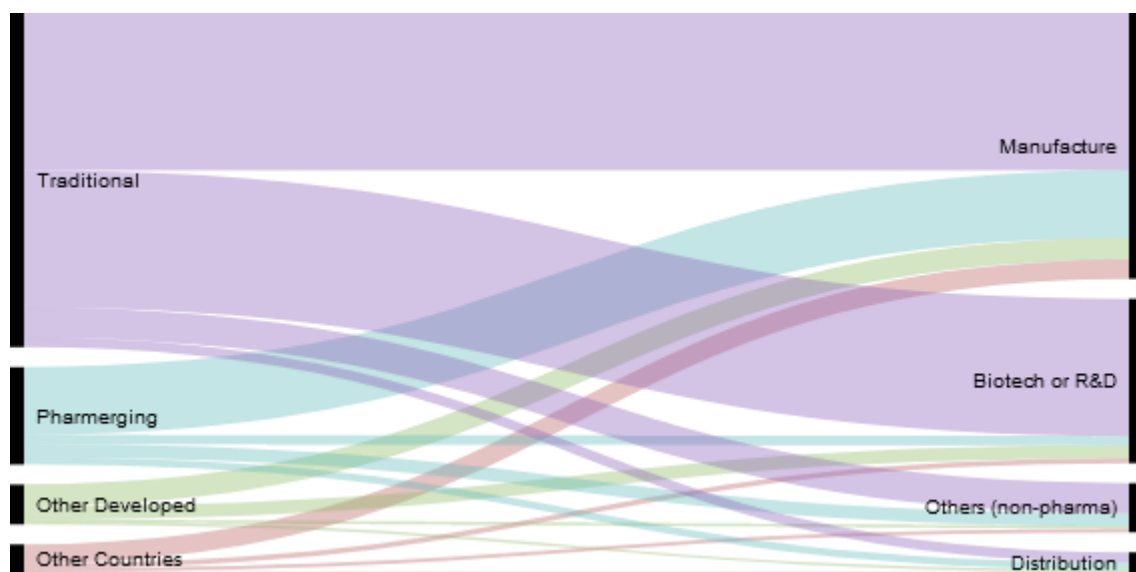


Source: Prepared by the authors based on Bureau van Dijk (2019)

Figure 5 crosses information about regional characteristics of M&A deals and

the core business of targets. The height of the left and right block represents the proportion of deals according to their regional dimension and the target's core business, respectively. The size of the streams represents how these two dimensions are associated. Results in figure 3 show that 41% of the deals in traditional countries are related to targets with core business in biotechnology or R&D activities. Besides that, 70% of the deals involving firms in countries classified as pharmerging markets are related to targets with core business in manufacturing activities.

Figure 5 - Association of deals according to their target's core business and their regional characteristics - (1997-2015)



Source: Prepared by the authors based on Bureau van Dijk (2019)

Table 3 - Distribution of deals according to their target's core business and their regional characteristics - (1997-2015)

	Manufacture	Biotech or R&D	Distribution	Others (non-pharma)	Total	N
Traditional	47%	41%	3%	9%	100%	16,805
Pharmerging	70%	10%	7%	13%	100%	4,894
Other Developed Countries	55%	33%	5%	7%	100%	2,001
Other Countries	65%	16%	7%	12%	100%	1,487

Source: Prepared by the authors based on Bureau van Dijk (2019)

The article hypothesizes that the regional characteristics of deals are essential to understand the heterogeneities observed in M&A deals involving the pharmaceutical industry between 1997 and 2015. Transactions involving companies from traditional markets tend to be more associated with targets with biotech or R&D core business, and transactions involving companies from pharmerging markets tend to be more associated with manufacturing capabilities. Moreover, it is expected that transactions related to biotech and R&D with minor values (as a proxy of the startup growth) are more associated with financial acquirers, while biotech and R&D targets with higher values would be more associated with pharmaceutical acquirers. As the fragmentation of the R&D chain in pharmaceutical increased, biotech and R&D companies had to increasingly rely on the financial market to finance its activities. When they reach more mature stages of drug development, they are acquired by big pharma, which monitors for new capabilities, competencies, and prospects of innovations externally.

The next sessions investigate these hypotheses. First, it looks further into deals that occurred with companies from traditional markets. Then, it examines the deals on the pharmerging markets.

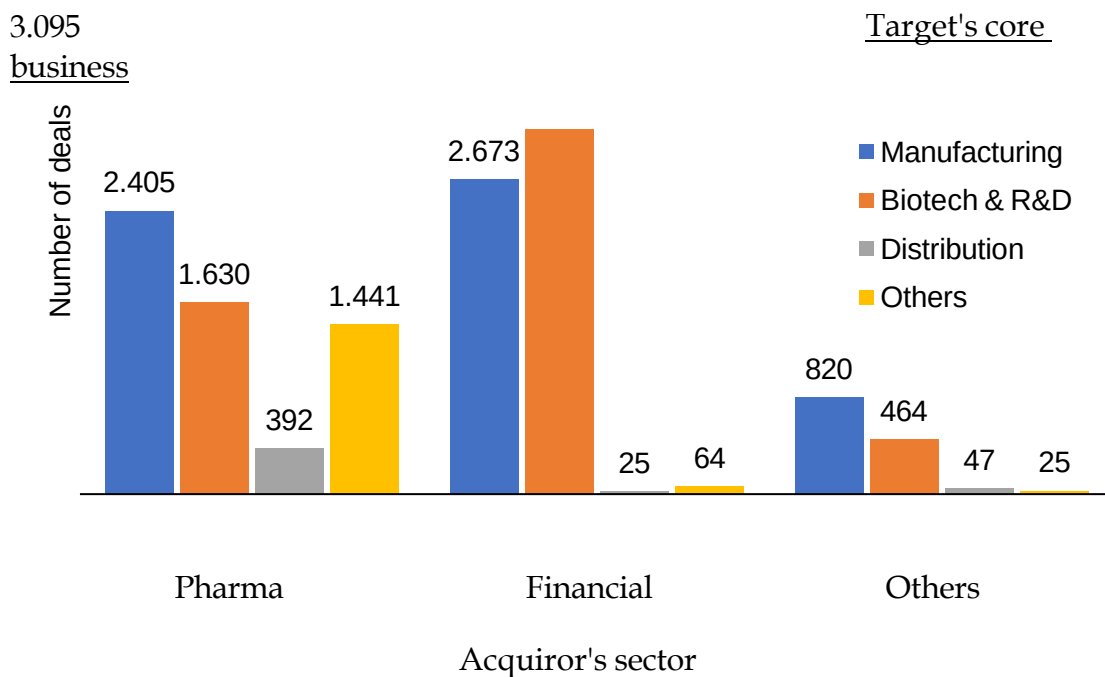
M&As Deals in The Pharmaceutical Industry in Traditional Markets

This section examines the hypothesis that emerged in the group of countries classified as traditional markets' M&A transactions related to the new technological opportunities derived from biotechnology and new technologies in the innovation process of the pharmaceutical industry.

There were 12,631 deals involving acquirers or targets in countries classified as traditional markets with information about the target's and acquirer's core business and country. Acquirers from the financial sector and the pharmaceutical industry led to a total of 5,854 (46%) and 5,549 (46%) deals involving firms from the pharmaceutical industry in traditional countries between 1997 and 2015 ¹⁵.

However, there are substantial differences between deals led by financial companies and firms in the pharmaceutical industry. More than 92% of the acquisitions from financial firms were classified as minority acquisitions, and 77% of the acquisition led by pharmaceutical firms were majority acquisitions. The participation of financial firms on minority acquisition deals is not a surprise, as it is adherent to their financial investment strategies. From the perspective of firms from the pharmaceutical industry (firms classified in manufacturing or biotech & R&D) these transactions could be viewed as financial instruments to raise capital to firms.

Figure 6 - Distribution of Deals on Traditional Markets According to the Core Business of Acquirer and Target - (1997-2015) - (N:12,631)



Source: Prepared by the author based on Bureau van Dijk (2019)

Table 4 shows that there were 3,095 M&A and 2,673 deals with acquirer firms from the financial market and targets classified as “biotech or R&D” or “manufacturing,” respectively. Deals classified as “angel investment,” “venture capital,” or “development capital” motives accounted for 79% of biotech or R&D deals, and 40% of deals aimed at targets with manufacturing activities.

Pharmaceutical firms on traditional markets were acquirers in 2,405 deals related to targets with core business on manufacturing, 1,630 deals related to “biotech or R&D”, and 1,441 deals related to other targets. Deals associated with “angel investment,” “venture capital,” or “development capital” motives accounted for less than 16% of targets with biotech or R&D activities, and around 3% of targets were related to manufacturing activities, and 4,4% of targets involved other activities. From another perspective, 82%, 68%, and 80% of deals with acquirer from the pharmaceutical market with manufacturing, biotech or R&D, and “other activities,” respectively, were majority acquisitions.

It is worth noting that acquisitions by pharmaceutical companies of targets that are not associated with pharmaceutical manufacturing, biotech, or R&D directly related to the pharmaceutical industry or distribution of pharmaceutical products accounted for 24.6% of the deals led by pharmaceutical companies on traditional markets. A closer look revealed that 46.6% of these deals had targets with core business in non-pharmaceutical “chemical manufacturing activities” (18.7%), “professional, scientific, and technical

services” (15,2%), and “medical equipment and supplies manufacturing activities” (12.6%).

Table 4 - Means of selected variables of biotech or R&D targets, according to the acquirer’s sector and type of deal on traditional markets (US\$ millions) - (1997-2015)

		Pharma (majority acquisition)	Financial companies (development capital, venture capital or angel investment)
<u>Frequency</u>	N	1,104.00	2,446.00
	%	8.7%	19.4%
<u>Value deal</u>	N	703	2,182
	Mean	527.25	22.83
	SD	123.85	0.51
	N	686	340
<u>Potential Value*</u>	Mean	551.57	89.38
	SD	134.38	23.04
<u>Revenues</u>	N	1,280	1,671
	Mean	7,310.64	3,810.84
	SD	21,846.60	12,031.22
<u>Employees</u>	N	1,176	1,662
	Mean	13,838.00	4,618.71
	SD	33,874.50	20,239.81

Source: Prepared by the authors

Note: * (PV) Potential value of deal if 100% of equities were acquired. $PV = \text{“Value deal”} * 100 / \text{“stakes acquired”}$

Table 4 shows data about values of deals involving biotech or R&D targets and their revenues and number of employees, according to two types of transactions: majority acquisition of biotech or R&D firms by pharmaceutical companies and minority acquisitions, associated with “development capita,” “venture capital,” or “angel investment,” of biotech or R&D firms by financial companies. The findings in Table 4 support the hypothesis that deals led by financial companies are associated with lower values, even when we weigh the value of the transaction in relation to the percentage acquired by the acquirer company. Moreover, biotech or R&D companies acquired by financial companies present lower means of revenues and employees, suggesting that financial companies tend to acquire smaller biotech or R&D companies¹⁶ in comparison to pharmaceutical firms.

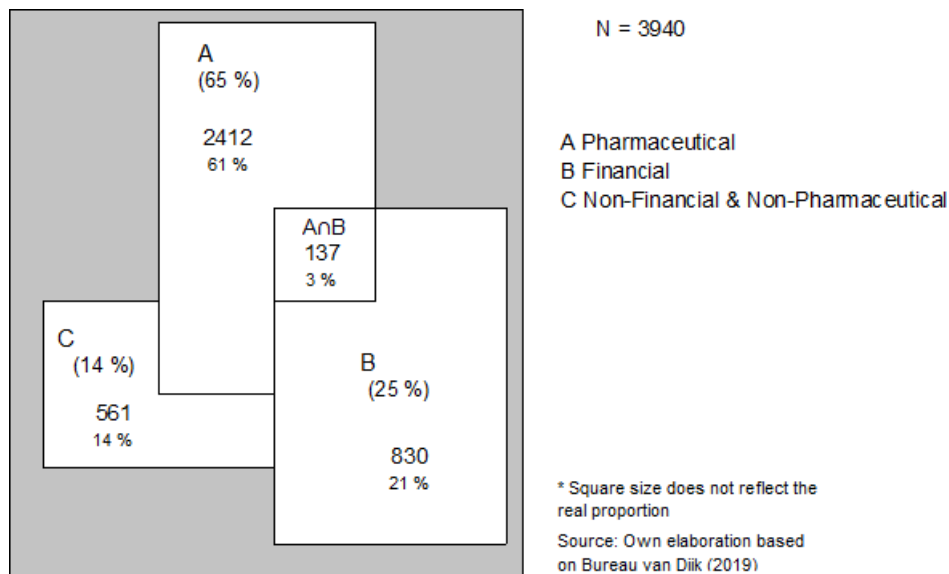
These results support the hypothesis that acquisitions oriented to incorporate innovation pipelines of drugs or new instruments, techniques, or

services related to the innovation process will be concentrated in the advanced countries. The data reports a large group of M&A associated with targets with activities within these activities. Moreover, the findings are compatible with the argument that there is a tendency of fragmentation and specialization in the pharmaceutical industry innovation chain. The findings suggest that biotech or R&D companies had engaged in minority acquisitions with financial companies to finance its activities without losing their independence and that acquisitions by pharmaceutical companies concentrate on majority acquisition of more mature targets with biotech or R&D activities.

M&A Deals in The Pharmaceutical Industry of Pharmerging Markets

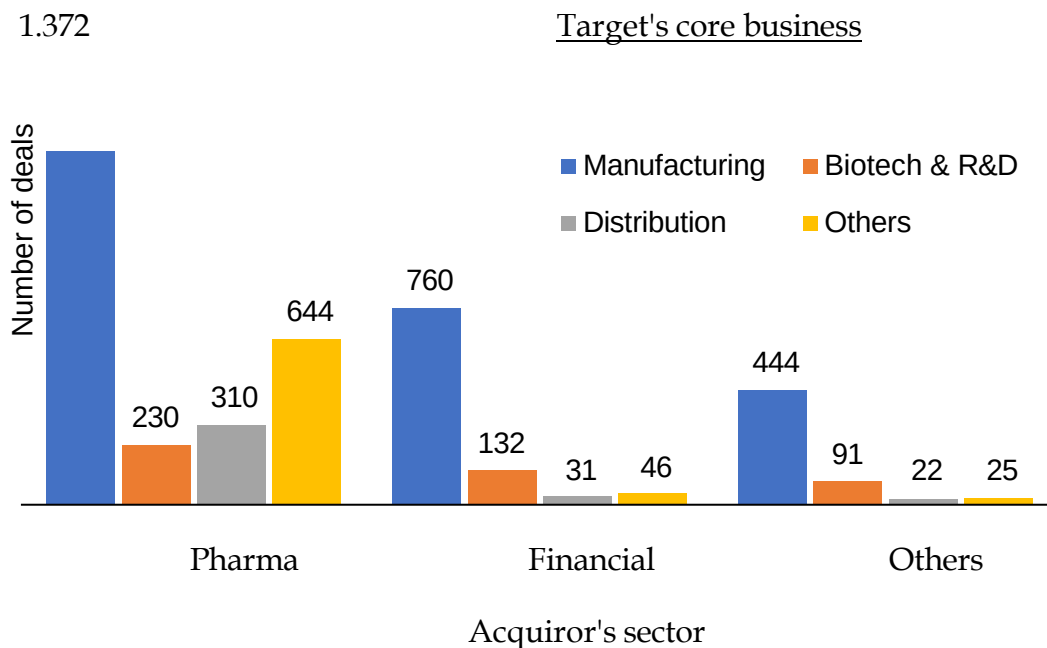
This section examines the M&A deals involving pharmaceutical companies in the pharmerging markets. The “Pharmerging Market” is a group consisting of 21 countries that presented, in the first half of the 2010s, pharmaceutical markets with high growth potential, increasing GDPs, expanding access to healthcare and drugs, and, in many cases, more robust intellectual property regimes, despite the high heterogeneities between its members in terms of GDP, per capita income levels, and healthcare system sophistication (IMS, 2012; 2013). Between 2008 and 2013, the pharmerging markets contributed to 46% of the global pharmaceutical market growth. Expectations in 2013 where that “these 21 Pharmerging countries [would] together add \$187bn in annual sales between 2012 and 2017, two-thirds of global pharma growth, and [would] increase the pharmerging markets’ global share from 23% in 2012 to 33% in 2017” (IMS, 2013). Projections of IMS (2015) pointed that the group of pharmerging markets would account for 25% of global pharmaceutical market in 2020¹⁷.

Figure 7 - Distribution of deals in pharmerging countries according to acquirer's core business (1997-2015)



Source: Prepared by the authors based on Bureau van Dijk (2019)

Figure 8 - Distribution of deals on Pharmerging Markets according to the core business of acquirer and target - (1997-2015) - (N:3,940)



Source: Prepared by the authors based on Bureau van Dijk (2019)

The distribution of deals on pharmerging markets according to the acquirer's sector shows substantial differences in comparison to deals in traditional markets. Table 3 (see initial results) reported that almost 70% of the deals involving companies from the pharmerging markets were related to targets with core business in pharmaceutical manufacturing activities.

As table 3 shows, just 10% of M&A in pharmerging markets were related to biotech or R&D. This proportion remains low even when we restrict the analysis to deals with acquirers from the financial sector (13,6%), as shown in figure 8, and suggests that this kind of deals are not frequent in pharmerging markets. This sharp contrasts with M&A in traditional markets where 56% of deals led by financial firms targeted firms with biotech or R&D activities.

Figures 7 and 8 show that financial companies led 25% of the deals in pharmerging countries. Furthermore, while deals associated with "venture capital," "angel investment," or "development capital" motives led by financial firms and targets with biotech and R&D activities motivations accounted for 56% of deals in pharmerging markets, it accounted for 79% in traditional markets. This finding could be explained by the global asymmetries in the generation of innovative pharmaceutical products between advanced and developing countries, but also by the lack of strong financial markets, especially in terms of risk capital.

The article hypothesis concerning transactions on pharmerging markets is that the growth of pharmaceutical markets in the group of countries labeled pharmerging markets induced a market consolidation in these countries. It would translate into majority acquisition of firms with core business in pharmaceutical activities located in the pharmerging markets to obtain economies of scale and market power.

Figure 8 corroborates the hypothesis by showing that more than one-third of M&A transactions in the pharmerging markets were associated with acquirers from the pharmaceutical industry and targets with core capabilities in the pharmaceutical manufacturing activities. If we also consider targets with core capabilities in the distribution of pharmaceutical products, the participation increases to 43% of deals. Almost 75% of these deals are majority acquisitions.

The growth of pharmaceutical markets would also induce the entry of new transnational competitors. It is expected that transnational firms would acquire more mature and larger companies in comparison with domestic deals.

Table 5 shows some characteristics of targets from the pharmaceutical industry involved in majority acquisitions by pharmaceutical companies in deals that occurred in the pharmerging countries. The table presents differences between the means of the values of deals, revenues, and the number of employees of targets involved in these transactions. The results confirm the

hypothesis that transnational firms tend to acquire larger firms, as these deals present higher values and acquire targets with more employees and revenues¹⁸.

Table 5 - Means of targets selected variables of M&A involving pharmaceutical industry of pharmerging markets with acquirers from the pharmaceutical industry and targets with core business in pharmaceutical activities

		Domestic deals	Transnational deals
<u>Frequency</u>	N	936	450
	%	23.8%	11.4%
<u>Value deal</u>	N	688	242
	Mean	44.49	112.62
	SD	6.51	20.47
<u>Revenues</u>	N	767	355
	Mean	849.49	3,151.63
	SD	126.41	523.11
<u>Employees</u>	N	530	256
	Mean	3,234.33	9,122.74
	SD	346.65	1,472.88

Source: Prepared by the authors based on Bureau van Dijk (2019)

The findings suggest that the pattern of M&A deals involving pharmaceutical companies in pharmerging markets presents substantial differences in comparison with the patterns of M&A deals in the traditional markets. First, the scarcity of deals directed to acquire targets with biotech or R&D activities is striking in comparison with traditional markets. Moreover, the growth of the pharmerging markets induced a consolidation in the pharmaceutical market, which reflected in a high proportion of deals led by pharmaceutical companies directed to buy firms with core capabilities in manufacturing and, at a lesser extension, in the distribution of pharmaceutical activities.

6. Conclusion

Global pharmaceutical industry has experienced critical structural changes since the previous decades related to transformations in the characteristics of the demand, new technological opportunities related to biotechnology, and the diffusion of innovative technologies in the search procedures, the increasing role of pharmaceutical markets from developing countries, and the emergence of new business models. This article analyzed M&A in the industry since the 2000s, looking to reveal new growth patterns in the pharmaceutical industry, derived from these structural changes.

One of the main structural changes that impacted global pharmaceutical markets was the emergence of molecular biology and new techniques of experimentation and data processing, which transformed the technological regime of the industry. This emergence opened new technological opportunities in the industry and changed the relevant knowledge base of the industry. Another crucial structural change was the fragmentation of the innovation chain in the industry, with the emergence of new biotech and R&D service firms focusing on the first steps of the innovation process or in specific services in the innovation chain. Finally, another structural change was the opening of new spaces of accumulation in the pharmaceutical industry, with the growing importance of the pharmerging markets.

Mergers and acquisitions involving pharmaceutical companies reflected the structural changes in the pharmaceutical markets. The results confirmed the hypothesis that the patterns of M&A involving pharmaceutical companies in traditional markets are substantially different from the patterns of M&A in pharmerging markets. In the group of countries classified as traditional markets that represent important markets of developed countries, deals directed to acquire targets with core capabilities in biotechnology or R&D activities, highly associated with intangible assets, prevailed. However, biotech or R&D targets were scarce in the group of developing countries with growing pharmaceutical markets. The findings in the article reinforced that, despite the structural changes in the pharmaceutical industry, global asymmetries in knowledge creations and innovation between advanced and developing countries remained.

The analysis of M&A activity also revealed that deals involving targets with core capabilities in biotech or R&D activities in the traditional markets are not homogeneous. Most of these deals were minority acquisitions led by financial companies, with lower value deals and smaller target companies. On the other hand, there was also an expressive group of majority acquisitions led by pharmaceutical companies, presenting higher deal values and acquiring more mature targets. These findings corroborate the literature that points to increasing fragmentation and specialization in the innovation chain of the pharmaceutical industry and to the growing role of intangible assets in the growth strategies of firms.

The analysis of M&A deals in the pharmerging markets shows a different picture in comparison to the traditional markets. Pharmerging markets presented high growth expectations in the last decades, especially during the 2000s. The growth of these markets opened new spaces of accumulation in the industry, being responsible for a substantial share of the global pharmaceutical market. The finding in the article supports the hypothesis that the market growth in pharmerging markets created opportunities for market consolidation, which reflected in horizontal majority acquisitions in the industry. As the

market grew, companies could increase their scale and market power by acquiring smaller competitors. The growth and the higher appropriability conditions in these markets also attracted the entry of new transnational competitors.

To obtain a comprehensive understanding of mergers and acquisitions (M&A) in the growth pharmaceutical industry, future research should investigate national trends and associate them with each country's specific industry development trajectory. This approach will allow us to examine more thoroughly the relationship between a nation's pharmaceutical industry growth and its M&A patterns. Future research should also update the microdata to capture the experience of China and India on the previous decade. From an alternative standpoint, future research should also address the correlation between various types of institutional investors and their merger and acquisition (M&A) strategies in emerging pharmaceutical markets.

Finally, it is crucial to examine the policy implications of persistent global disparities in knowledge production between developed and developing nations. The perpetuation of these knowledge asymmetries in the pharmaceutical industry has profound ramifications for the advancement of science, technology, innovation, and production, with profound impacts on health access (TEMPORÃO, GADELHA, 2019), as the COVID-19 showed.

The findings reinforce the hypothesis that both developed and emerging countries faces distinct challenges regarding industry and innovation policies in the pharmaceutical sector. In developed countries, the challenge lies in directing innovation efforts towards the well-being of the population and to ensure a more equitable appropriation of benefits generated by the collective efforts, especially those driven by public institutions. Conversely, National Innovation Systems of emerging countries still faces the challenge of building productive and innovation capabilities.

Nevertheless, the existence of global knowledge asymmetries does not imply an impossible barrier to convergence and progress. The need to build these capacities represents, on the one hand, an immense challenge, since the distance in relation to the central countries becomes greater. On the other hand, international experience offers insights about the building of institutional arrangements, policies, and instruments different from the model observed in central countries and better adapted to national needs and specificities.

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Notes

¹ As shown in detail in the methodology section, the traditional markets are Australia, Belgium, Canada, Denmark, France, Germany, Italy, Ireland, Japan, South Korea, Spain, Switzerland, the United Kingdom, and the United States.

² As shown in detail in the methodology section, the Pharmerging markets are defined as pharmaceutical markets located in developing countries with forecasts of high growth potential. The group includes China, Brazil, India, Russia, Poland, Argentina, Turkey, Mexico, Venezuela, Romania, Saudi Arabia, Colombia, Vietnam, South Africa, Algeria, Thailand, Indonesia, Egypt, Pakistan, Nigeria, and Ukraine.

³ However, the concentration in the twenty largest companies are almost twelve percent higher than the observed in 1996.

⁴ Treatments for rheumatoid arthritis, Hepatitis C, and cancer figures most prominently in the list of the most sales-generating drugs.

⁵ The innovation chain presented in a linear fashion is a simplification aimed at showing in which activities the new specialized firms arose in the past decades in the pharmaceutical industry

⁶ IMS Health (2013) analyzed the sales in 16 countries, which accounted for 80% of global pharmaceutical markets. Country contribution was calculated based on the accumulative sales (up to 5 years) of these launches in each of these countries

⁷ 3254 – “Pharmaceutical and medicine manufacturing”; 32541 – “Pharmaceutical and medicine manufacturing”; 325411 – “Medicinal and Botanical Manufacturing”; 325412 – “Pharmaceutical Preparation Manufacturing”; 325413 – “In-Vitro Diagnostic Substance Manufacturing”; 325414 – “Biological Product (except Diagnostic) Manufacturing”.

⁸ 541711 – “Research and Development in Biotechnology”.

⁹ 424210 – “Drugs and Druggists' Sundries Merchant Wholesalers”; 446110 – “Pharmacies and Drug Stores”.

¹⁰ 10 5417 – “Scientific research and development services”; 54171 – “Research and development”; 541712 – “Research and Development in the Physical, Engineering, and Life Sciences (except Biotechnology)”.

¹¹ 3254 – “Pharmaceutical and medicine manufacturing”; 32541 – “Pharmaceutical and medicine manufacturing”; 325411 – “Medicinal and Botanical Manufacturing”; 325412 – “Pharmaceutical Preparation Manufacturing”; 325413 – “In-Vitro Diagnostic Substance Manufacturing”,”

¹² 325414 – “Biological Product (except Diagnostic) Manufacturing”; 541711 – “Research and Development in Biotechnology”

¹³ 424210 – “Drugs and Druggists' Sundries Merchant Wholesalers”; 446110 – “Pharmacies and Drug Stores”

¹⁴ Export data was extracted from “The atlas of economic complexity” (THE GROWTH LAB AT HARVARD UNIVERSITY, 2019).

¹⁵ Deals without information about the core business of target and acquirer firms, and the information of the countries of targets and acquirers’ firms were excluded.

¹⁶ The two sample Students T test for means with unequal variances rejected the null hypothesis that all means of deals led by pharmaceutical companies are lower or equal to the means of deals led by financial companies, with 95% confidence interval.

¹⁷ Projections of IMS (2015) pointed that, in 2020, China would account for 11% of global pharmaceutical market by medicine spending, India and Brazil would account for 6% and all the other pharmerging market would account for another 8%.

¹⁸ The “two sample Students T test for means with unequal variances” rejected the null hypothesis that the means of value deals, the mean of the revenues and employees of acquired firms in transnational deals are higher than the means in domestic deals, with 95% confidence interval.

Analysis of the impact of the national policy on the private partnership between foreign firms and domestic tech startups in developing- Evidence of startups in Rwanda-

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Abstract

In the last decade, a new model of international cooperation has emerged involving new actors in Africa (startups) and international actors (private foreign firms and venture capital firms). An understanding of the relationship between this new model of international cooperation and national policy in developing countries is essential because the traditional market creation argument is only relevant to Europe and Asia. However, a clear understanding of how this relationship might be applied to the African context, where it is essential to create many markets to move the digital agenda and startup ecosystem forward, will enable policy toward economic growth. This study examines Rwanda's national policy in order to identify means by which national policy can prompt the formation of private partnerships between foreign private firms and domestic startups in developing countries. In 2000, Rwanda instituted a series of national innovation policies to promote innovation and diversification in firms investing in the country. This case illustrates the need for flexible, agile policies for knowledge transfer in private partnerships between foreign firms and domestic startups and concludes that institutional factors such as flexibility and agility of a policy could shape economic activity across economic sectors and attract foreign knowledge in private sector.

Keywords: Mission-oriented innovation policy; national innovation policy; knowledge transfer; Startups; private partnership; international cooperation; developing countries, Rwanda.

1. Introduction

In the last decade, a new model of international cooperation has emerged involving new actors in Africa (startups) and international actors (private foreign firms and venture capital firms). An understanding of the relationship between this new model of international cooperation and national policy in developing countries is essential because the traditional market creation argument is only relevant to Europe and Asia. However, a clear understanding of how this relationship might be applied to the African context, where it is essential to create many markets to move the digital agenda and startup ecosystem forward, will enable policy toward economic growth. In this regard, recent studies suggest that to address grand challenges such as attracting investment from private and public actors, creating jobs, and solving modern care problems, government should adopt innovation policies (Kattel & Mazzucato, 2018). Moreover, public capability to structure and implement policy development are essential for attracting investment from bilateral partners and private foreign firms in developing countries (OECD, 2019). In other words, public policies play a vital role in attracting the investment necessary for the promotion of the growth of startups critical for the addressing of local agenda through training, or job creation. In fact, tech startups are becoming an object of private and public impetus policies in middle-income developing mixed countries (e.g., Brazil) because of their capacity to attract foreign investment and technologies (Audy & Piqué, 2016; Wolff, 2022).

Without startups or Small and Medium Enterprises (SME), some developing nations would be less able to exploit opportunities and attract investors. In recent times, the governments of certain developing countries have made a significant shift in their approach towards national policies. They are now looking beyond the conventional role of correcting market and institutional failures by reframing their strategies to accommodate the reality and prepare their respective economies for the challenges since innovations are somehow related to incertitude (Kattel & Mazzucato, 2018). Basically, governments are creating and shaping markets that could increase business expectations around future growth opportunities, in turn driving private investment (Kattel & Mazzucato, 2018).

According to a recent investment report on climate reform facilities (Climate Reform Facility et al., 2021), in 2021 at least 16 African countries had feed-in Small Business Acts (SBAs) that promote the establishment and development of startups and SMEs. These SBAs foster the development of a suitable environment for the development of startups and the attraction of external knowledge.

However, the literature on knowledge transfer is mainly concerned with large organizations; only recently have some studies begun to emphasize the small to

medium enterprise (SME) context (Eze et al., 2013; Massaro et al., 2016; Serenko & Bontis, 2017; Thorpe et al., 2005). Although it has been argued that knowledge flow in startups promotes innovation by creating new organizational learning through the adoption of new collaborative and innovative technologies (Andrade et al., 2022; Centobelli et. al, 2017), and there is little discussion in the literature of the ways in which startups in developing countries are exposed to knowledge transfer from international sources.

Moreover, the literature on discussion between multinational enterprises and suppliers has focused mainly on the flow of knowledge from MNCs to recipients in developing or emerging countries (Rui et al., 2016), largely ignoring the flow of knowledge from foreign private firms to startups and knowing that the startups have an impact on the training of various people and job creation in developing countries.

Further, in the era of emerging technology, private foreign firms, in need of scaling up and market access, and facing legal barriers in their home countries or confronted with rigidity of regulation in their home countries (Iizuka & Ikeda, 2019), are generally looking for locations where they can test their technology. In that light, developing countries eager to achieve economic growth are now considering the promotion of agile and flexible policies and regulatory institutions to attract new knowledge and emerging technology that can enable them to overcome local obstacles (Featherston et al., 2016).

In this scenario, there is a need for a deeper understanding of how national policy prompts private partnerships between foreign firms and domestic startups, and of the factors of national policy that help to trigger private partnerships between foreign firms and startups in developing countries.

This study sets out to address these needs and consists of the following sections: introduction; a review of the literature concerning national and mission-oriented innovation policy and its influence on private partnerships between foreign firms and domestic startups in developing countries; a research questions of the study and the conceptual framework; description of the methodology; examination of the case of Rwanda; and discussion and conclusions.

2. Literature review

There is currently an academic debate centered around the critical role of national policy in developing countries growth and facilitating knowledge flow from private foreign firms and domestic startups. Most of this debate was focused on knowledge flow through FDI and MNC from developed foreign countries in

newly industrialized countries in Asia and emerging economies such as Brazil, India, and South Africa, and to a limited extent in less developed economies in sub-Saharan Africa (Watkins et al., 2015); and more recently on the contribution of SME in the process of knowledge flow (Anand et al., 2020) .

However, in the last decade, a new model of international cooperation has emerged involving new actors in Africa (startups) and international actors (private foreign firms and venture capital firms). Studies on startups observed that startups are becoming an object of private and public incentive policies in middle-income developing mixed countries (e.g., Brazil) because of their capacity to attract foreign investments and technologies (Audy & Piqué, 2016; Wolff, 2022)

On one hand only a few studies have examined the role of national policies in prompting private partnerships between foreign firms and domestic startups (domestic startups refer to startups in developing countries). To that end, there is a need to examine the mechanism by which national policy prompts private partnerships between foreign firms and domestic startups and understand the factors of the national policy involved in the process. The literature has identified three main theoretical frameworks essential in prompting international private partnership: (1) mission- oriented innovation policy; (2) national policy; (3) international cooperation.

2.1. Missions-oriented innovation policy

Most nations around the world are eager to achieve economic progress that is both innovative and sustainable, while also being inclusive of all members of society (Kattel & Mazzucato, 2018). This aspiration to attain a specific type of economic development has been the objective of many developed and developing countries. However, such aspirations require changing or reconsidering the role of public policies and the government in the market and institutions.

Studies suggest that government and public policies should reframe their strategies to accommodate the reality and prepare their respective economies for the challenges since innovations are somehow related to incertitude (Kattel & Mazzucato, 2018). Instead, they should ask about what policy mechanisms precisely lead to the development of economic growth (Pierson, 2004) or determine which direction aligns with desired goals and create markets that increase business expectations for future growth opportunities that can drive private investment (Kattel & Mazzucato, 2018). They may adopt an innovation policy such as a mission-oriented innovation policy to address grand challenges such as attracting investment by both private and public actors, creating jobs, or tackling modern care problems.

The mission-oriented innovation policy (MOIP) is, by definition, a market-shaping public investment and policy framework that concentrates on moving the direction of the innovation system (Kattel & Mazzucato, 2018). Burlamaqui (2006) argues that mission-oriented policies are instruments in the (Schumpeterian) market-shaping framework to focus policy debate on which direction public efforts should enlarge firm-level search activities. Other studies argue that mission-oriented policies offer a framework that enables the public sector to overcome endemic policy coordination failures (Ergas, 1987, p. 194) and that public investments created a technological frontier that coincided with private sector developments, thus creating multiple new search opportunities for firms (Dosi, 1981, p. 10-11). Therefore, mission-oriented policies are usually coupled with radical technological advancements closely tied to a linear approach to science, technology, and innovation (Jensen et al., 2007).

Historically, there is old and new MOIP, old mission focused adopted top-down policy decision through the creation of government agency, new mission, according to some scholars should promote bottom-up stakeholders-based initiatives (Alves & et., 2020; Mazzucato & Penna, 2016). While literature on the implementation of MOIP mostly focuses on leading countries (Ergas, 1987; Foray et al., 2012). The first strand concerns socioeconomics issues and relies on expert meritocracy in public organizations accompanied by constant renewal and rejuvenation of organizational configurations (Karo & Kattel, 2015; Kattel et al., 2019).

The second strand of mission-oriented concerned technological issues and had a much more courageous vision of dynamic alteration. Single national/public laboratories often implemented policies with a tangible mission to resolve specific technological problems (Weinberg, 1967). The third strand concerns socio-technological missions and is driven by purpose from 'intractable' socio-economic challenges and social movements connected to these challenges with citizens or users of public service as the primary focus (Mazzucato & European Commission, 2018; OECD, 2017). Despite the above, there are some criticisms of the mission-oriented policy. For instance, Markusen (2003) argues that MOP represents a fuzzy policy-making with considerable opaque, needs more details, and fails to conform with the nature of the regional innovation and connected entrepreneurial ecosystem. Edler and Boon (2018) claimed that MOP, usually take less consideration of major demand condition inside economies and can be ill-fitting and ineffective in some case (Brown, 2021).

However, in the case of developing countries, some authors argue that MOIP is well fit for because of the embryonic level of the market (Alves et al., 2020). Therefore, despite these few criticisms, the MOIP remains an appropriate concept that can be

used to understand how national policy prompts private cooperation between foreign firm and domestic startups. I argue that the flaws of this concept can be addressed by combining it with other complementary concepts like national industrial policy and international cooperation.

2.2. Effect of national industrial policy on the promotion of catching up and learning in developing countries

In discourse concerning the broad faction of policies related to education, technologies, and trade, many governments around the world have used the terminology of industrial policy. While the term may differ across cases, the national industrial policy may be defined as any government policy that modifies the allocation of resources regarding promising activities that guarantee economic development (Pack & Saggi, 2006). National industrial policy has been a major driver of the industrialization of many developing and emerging countries. Some studies argue that governments have been using industrial policies to attract foreign direct investment from multinational companies because they would generate employment (Joseph et al., 2019). Others observed that a lack of policy dedication could make a country more inclined to step into international agreements because a nation facing a domestic commitment issue has comparatively more to benefit from securing well-organized policies (Conconi & Perroni, 2009). Industrial policy in the current literature has been the subject of debate centered around three points:

First, do national policies help lower-income countries achieve economic development and catching up, and if so how? Traditionally, trade theory has held that to compete, a nation behind the curve should focus more on the low labor costs approach (Hunt & Morgan, 1995). In addition, the current literature on economic development holds that lower-income countries can capitalize on their comparative advantage by using wage advantage to drive resources to the creation of products for export (Foster & Azmeh, 2019). However, some authors, e.g., Stiglitz (2003), believe that this economic approach is not suitable for developing countries because in developing countries it has not always led to economic and structural transformation. As a solution to the criticism of Stiglitz, Lall (1992) and Mathews & Cho, (2000), propose that for developing countries to reach economic growth, government policies should focus more on technology transfer and technological capability building to attain structural transformation. Similarly, Featherston et al. (2016) underlined that developing countries eager to achieve economic growth may consider promoting agile and flexible policies and regulatory institutions to attract new knowledge and emerging technology to help them overcome local obstacles. Also, (Mathews & Cho, (2000) observed that government could play an enormous role by facilitating the acquisition of human

capabilities, technologies, and skills or using the national fund to generate or gain access to new technologies and support the acquisition.

Second, should governments orientate inward or outward policies toward industrial policies? (Foster & Azmeh, 2020). The system and dependency theory supports that breaking away from their adverse position in the international division of labor to achieve industrialization and development is essential for developing countries (Wallerstein, 1974). For instance, the industrial transformation of East Asian countries was achieved through the outward policy initiated by the government (World Bank, 1993). The government used foreign direct investment attraction industrial policy as a tool to attract multinational companies because they will generate employment Joseph, Dhar, (2019). The critical aspect of that policy was the government protecting the domestic market by imposing a tariff on imported goods to promote domestic industrialization. Third, to what extent should government intervention be to shape and put a country in the global economy? (Foster & Azmeh, 2020). Studies have given evidence that initiating good institutions could strengthen firms in exports and internal and external policies leading to economic development.

Moreover, the role of government in organizing the business environment is prevalent (Coad, 2014; Davidsson & Henrekson, 2002), and earlier studies have examined numerous aspects of government intervention. For example, some scholars have emphasized that institutional factors can shape economic activity across economic sectors, such as intellectual property rights, taxation, labor market legislation, or financial and legal obstacles to business creation (Coad, 2014; Davidsson & Henrekson, 2002). Others have examined the intervention of government in a specific sector or activity, including the ratification of different forms of laws or different forms of industrial policy (Delmas, Russo, and Montes-Sancho n.d.; Dobbin & Dowd 1997; Russo 1991). However, recently in their efforts to attract foreign private investment and promote innovation in developing countries in Sub-Saharan Africa, governments in some poor and small developing countries have initiated their startup and innovation policies. According to a recent investment report on reform climate facility (ICReport, 2021

¹⁾, besides Tunisia and Senegal, which have startup act, at least 16 African countries had feed-in- Small Business Act (SBAs) which promote the development and the establishment of startups. Such policies have successfully promoted inter-firm cooperation between private foreign firms and African startups and induced technological innovation.

2.3. International cooperation and knowledge transfer

With the continuous internationalization of economics and politics, governments must be more gratified in interaction with the world (Yanez, Magnier, and Ramirez 2008). To respond to the need for economic development, government nation worldwide put policies promoting private cooperation (partnerships) between local companies and local firms with foreign firms. Indeed, a partnership or is defined as a continued multi-organizational relationship with jointly decided objectives and exchanging or sharing resources or knowledge to generate research outputs (new knowledge or technology) or foster innovation (use of new ideas or technology) for practical ends (Horton et al., 2009). Only a few strands of literature have discussed international cooperation and its influence on firms. The first strand starting with Cohen (1990), emphasized the importance of external factors to firms capability. The second strand of studies focused on the strategic technological alliances (Hagedoorn 1994, Archibugi and Iammarino 2002; Tether 2002). The third group focused on the internationalization of innovation (Archibugi & Michie, 1995), identified three principal kinds of internationalization for innovation:

- 1) International firm exploitation of innovation involving know-how and technologies via patents, reverse engineering, and technological collaboration.
- 2) International cooperation in global value chain involving firms of more than one country, sharing know-how to develop scientific and technological knowledge, where each partner keeps its institutional identity and ownership remains untouched (Edwards-Schachter et al., 2011).
- 3) The international creation of knowledge and innovation by multinational corporations (MNC) generates innovation across borders by creating research networks involving (a) the implementation of R&D units in the host country, and (b) the accession of foreign R&D units, i.e., Foreign Direct Investment (FDI) in R&D (Edwards-Schachter et al., 2011).

Traditionally in the third type of internationalization for innovation mentioned above, international cooperation is mostly attached to FDI and MNC in the case of transfer knowledge to firms in developing countries (Rui et al., 2016). However, with the emergence a new model of international cooperation involving new actors in developing countries (startups) and international actors (private foreign firms and venture capital firms). We assist to the new type of knowledge transfer, flowing from private foreign firm into domestic startups in developing countries.

3. Research questions

In the previous section, the literature review revealed some significant findings as well as areas that require further investigation. First, the importance of the role of the government through national policy in creating a new market, attracting foreign investment, and helping countries achieve economic development and catching up; however, few pieces of literature refer to its role in prompting private partnerships between foreign private firms and domestic startups in developing countries, where foreign firms in the quest of ground to test or develop their innovation before commercialization are confronted to the rigidity of institutional conditions that prevent companies from developing because they represent barriers (Iizuka & Ikeda, 2019); these barriers force the firms to go in the countries with more adaptative and flexible institutional conditions (Dietz et al., 2003). Second, the literature showed that national policy could foster the transfer of knowledge from MNCs in developed countries to the recipients in developing countries or emerging countries (Rui et al., 2016); nonetheless, existing studies failed to document the factors of national policy that contribute to attracting private foreign investment and knowledge in startup in developing countries.

Based on the above understanding, this paper address following questions:

- How national policy prompts private partnerships between private foreign firm and startups in the area of emerging technology?
- What are the factors of the national policy that contribute to attracting private international firm in developing countries?

3.1. Conceptual framework/ operationalization

The literature has identified several important factors and gaps in the research promoting partnerships between foreign firms and domestic startups. One of the most significant factors is the need for policies or institutions that support and facilitate such partnerships. Another critical factor is a legal framework that provides the right conditions for foreign private companies to operate effectively in the domestic market. This could also include broader institutional setups, such as how the rule of law works in the country.

Another important factor is the need for policies that can change depending on the situation and adapt to the moving reality of the market. This kind of dynamic targeting is essential because it allows existing policies to accommodate new opportunities and changing circumstances. Furthermore, providing basic physical facilities such as roads, electricity, banks, and internet connectivity is crucial for the success of foreign firms and domestic startups.

Finally, knowledge acquisition, human resource training, and access to funds and equipments are also crucial factors that can help promote successful partnerships between foreign firms and domestic startups. By addressing these gaps in the literature, policymakers and researchers can develop better strategies for promoting economic development and growth.

To operationalize the above concepts, they have been framed as follows:

1. Promoting private interfirm cooperation means the policies or institutions promote partnership between a foreign firm and a domestic startup.
2. A conducive environment means the legal framework provides the right conditions for foreign private companies to come to Rwanda.
3. The flexibility and agility of policy mean that the existing policies can change depending on the situation and adapt based on the opportunity.
4. Infrastructure means the availability of basic physical facilities (road, electricity, bank, and internet).
5. Learning & capability building means knowledge acquisition, human resource training, and access to funds and equipment.

This paper examines the case of Rwanda's national policy framework, which has been able to maintain an exciting Gross Domestic Product (GDP) and attract private foreign tech companies to invest in domestic companies after adopting an agile and flexible policy framework and regulation essential to the adoption of emerging technology and innovation (Featherston et al., 2016). Indeed, after adopting the Rwanda Vision 2020 in 2000, Rwanda grew rapidly compared to other African countries, and its growth stemmed from the knowledge economy and digital technology.

The following section presents the methodology used to analyze the growth of Rwanda's economy, identify the motivation behind selecting Rwanda as the case study for this analysis, examines the chronology of the policy adopted by Rwanda to achieve rapid growth, and explores the Startup ecosystem in Rwanda and the role played by the national policy in supporting the growth of this sector.

4. Methodology

This study applied qualitative case study methodology, which is appropriate for identifying with rich perceptions from the case of Rwanda in achieving rapid growth after adopting a series of policies (Yin, 2009). It utilizes primary and

secondary data gathered via semi-structured interviews and a structured review of official documents. To begin our observational study, we relied on secondary data collected from various policy documents and official public report that examine startup ecosystems at various levels, including national, regional, and international. This information served as a solid foundation for our research and provided valuable insights into the dynamics of these ecosystems. Along with our secondary data, we also conducted semi-structured interviews with key stakeholders to gather primary data. These stakeholders included government organizations such as ministries, policymaking institutions, academic and research organizations, private sector firms such as startups and incubators, and bilateral agencies. This allowed us to gain a comprehensive understanding of the topic at hand, and we gathered valuable insights and perspectives from various sources. We selected various institutions for our study based on several criteria. The institutions were chosen because they are mandated to work with startups, design policies that touch the startup ecosystem and growth or regulate research related to startup growth and innovation. Additionally, we selected representatives of these institutions for interviews based on specific criteria. We interviewed senior researchers, CEOs managing startups, project managers managing startups, and senior national policies officers in charge of STI startups who were involved in projects related to startups.

According to Table 1, the interviews were conducted between January 2023 and February 2023. Fourteen individuals were interviewed, each lasting 30 to 60 minutes. Before the start of each interview, interviewees were asked for their consent, which they provided formally. The interview guide consisted of an introductory section explaining the study's purpose and requesting their consent. The interviews were conducted conversationally with the help of approximately ten (10) questions, which can be found in the annex. These questions were focused on the stakeholder perception of the Rwandan national policy promoting international cooperation or collaboration and the effect of international cooperation on the innovation capability of startups..

Mission-oriented innovation policy, national policy, and international cooperation were chosen as the primary analytical frameworks for this paper (Coad, 2014; Davidsson & Henrekson, 2002; Joseph et al., 2019; Lundvall, 1992; Mathews & Cho, 2000; Mazzucato, 2017). We used thematic analysis to examine our interview notes during our data analysis process. Our research question guided us in identifying key parameters we used to extract relevant text segments and analyze them according to the main themes. Through this process, we could identify common trends and differences in our interviewees' responses. National policy existence, the influence of national policy on international partnerships, investment attraction, new technology introduction, innovation, and resources were some of

the parameters we used to explore the factors that influence interfirm international cooperation. Overall, our thematic analysis allowed us to gain valuable insights into the role of national policy in shaping international business relationships and driving innovation.

Table 1: Data collection and analysis

Primary data: Interviews	Interviewees	Secondary data	Data treatment and analysis
Ministries (MINICT) ²	1	National Policies, Official public reports. Online articles	Analysis of qualitative data: parameters identification and keywords Classification: Thematic analysis, combination of perceptions Chart, graphs and figures presentation
Policy Making Public Agencies (RDB, NCST)	2		
Private Sector: 250STARTUP, Leap Lab, WiredIn Inc.	4		
University (UR, RP)	2		
Bilateral cooperation Agency (SEAD West Project, GIZ, Expertise France, JICA)	4	Reports	
Private Foreign firm (Rexvirt)	1		

4.1. Motivation for studying national policy of Rwanda.

According to data from reports (2008 to 2022) of the IMF publication *Regional Economic Outlook: Sub-Saharan Africa*³, Rwanda was one of the fastest-growing countries in Sub Saharan Africa. Rwanda's development strategy, since 2000, focused on establishing a knowledge-based economy to deal with limited natural resources. In regard to the World Bank's International Governance Indicators database, fast-growing countries outperformed other countries in sub-Saharan Africa on four out of five criteria (World Bank Africa's Pulse, 2013 ⁴): counter-

corruption efforts, government efficiency, political stability, and the quality of the regulatory framework. (See chart1⁵ showing the of GDP in 3 Sub-Saharan countries)

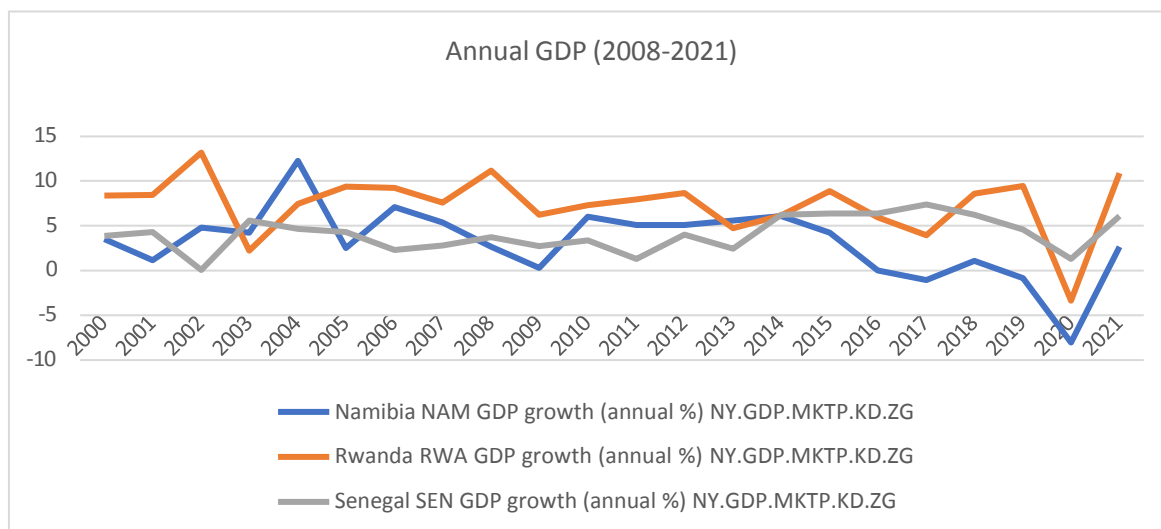


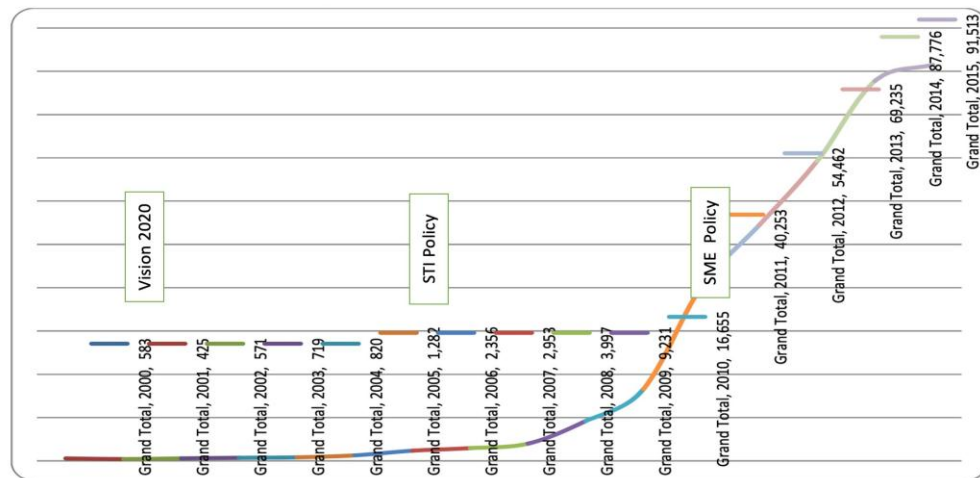
Chart1

The government aims to realize this ambition through a set of policies such as National Strategies for Transformation 1 (NST-1); Rwanda Small and Medium Enterprises (SME) Development Policy (2010); and the National Science and Innovation Policy consisting of a group of strategic policies (EDP, 2020; Investment Law, n.d.; NST1, 2017; SME policy, 2010; STI policy, 2006). These policies recognize the importance of innovation as a vital component for national progress and place emphasis on promoting inclusive economic growth, generating employment opportunities, and supporting private sector-led development in various growth sectors such as diversified tourism, local manufacturing, productive agriculture and agro-processing, and knowledge-based services and information and communications technology (ICT).

Moreover, these programs give priority to research, science, technology, and innovation, and job creation in the adoption of the STIP policy in 2010 (Gatete, 2016; Yongabo, 2021). For instance, one of the objectives of National Strategy for Transformation (NST1) adopted by Rwanda in 2017 is to promote and support of startups, toward the creation of 1,500,000 jobs by 2024.

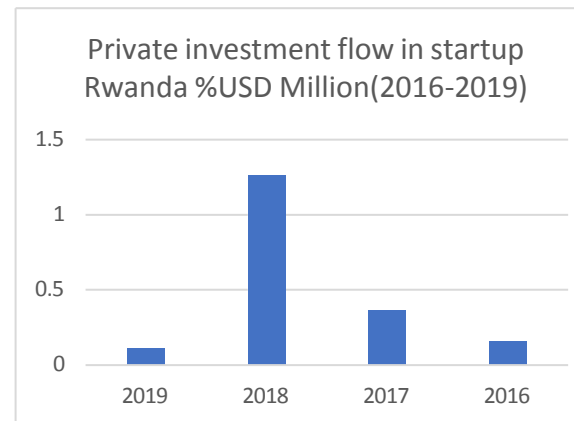
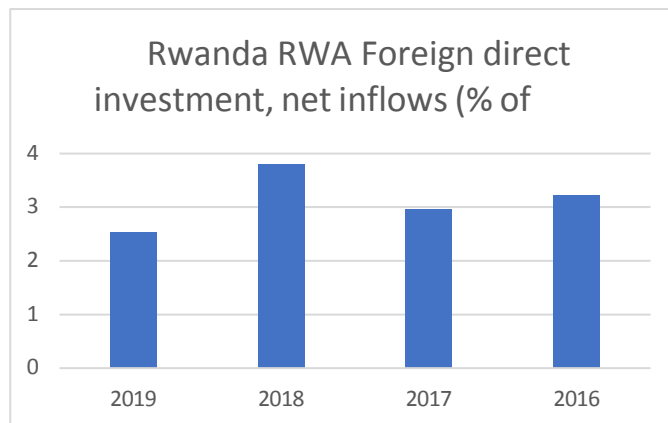
Additionally, the number of the creation of private companies rose from 583 to 91513 (Ndagijimana et al., 2016), when the policies reform was introduced. This rise can also be observed in the inflow of foreign direct investment as well in the private investment in startups between 2016-2019 (See Chart 2).

Figure 1. New businesses registration trend: 2000-2015 in Rwanda



Source: Calculations based on the Office of the Registrar General's (ORG's) data.

Chart 2⁶: FDI Flow Vs Chart 3⁷

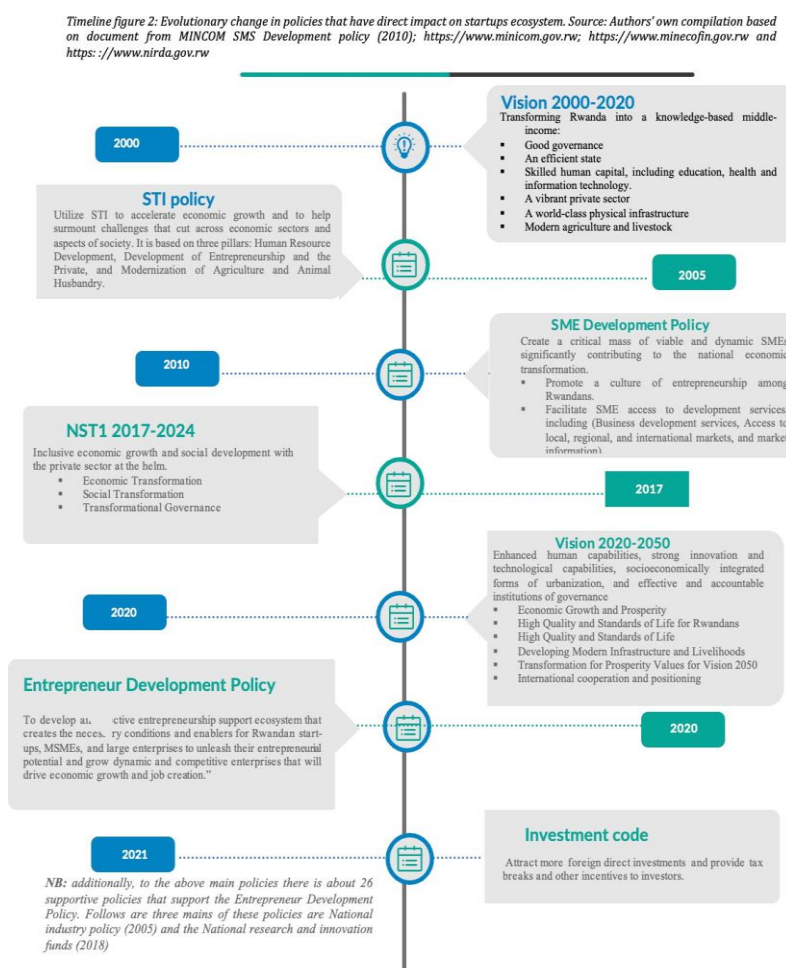


4.2. Chronology of policies affecting startups in Rwanda

The evolutionary change in the policies implemented by Rwanda can be the factor influenced how foreign investment has been attracted to the local economy. Below is Rwanda's timeline of the non-exhaustive list of selective policies related to Startups. They have been selected because of their direct impact on the startups. For example, in 2000, the government of Rwanda initiated Vision 2020; that policy consists in offering incentives to decrease operating costs, attract talent and promote innovation and diversification in firms investing in the country. In years 2005, the government, to create knowledge and promote partnerships, and support SMEs and startup growth, introduced the STI policy. In 2010, the SME policy 2010

was promulgated, focusing mainly on human resources and entrepreneurship. However, to promote comprehensive economic and social growth with the private sector at the center, the government introduced the National Strategy Transformation 1, which focuses on utilizing STI to accelerate economic growth and to help surmount challenges that cut across economic sectors and aspects of society. Furthermore, the investment law initiated in 2015 and updated in 2021 aims to attract foreign direct investments and provide investors with tax breaks and other incentives. While in 2020, the government adopted Vision 2050, aiming at enhancing human and technological capabilities, innovation, effective and responsible organizations of governance, international cooperation, and positioning. Additionally, in 2020, the government adopted the entrepreneurship development policy, which englobes SMEs and startups. This policy promotes entrepreneurship by facilitating access to funding for business development.

Figure 82



4.3. Overview of the Rwanda startup ecosystem

According to Sissel Hansen, “Rwanda is a small country, but by thinking bigger than its borders, it’s quickly becoming an important African tech hub,” (Kigali startup guide, 2020). Rwanda has about 13.58 million inhabitants (World Bank), of which 60% are youth. Global Gender Gap Report (2020) reported 43.2% of entrepreneurs in Kigali are women. The country has been consistently classified as one of the top countries in Africa for tech startups, for the following reasons: government support; infrastructure development; talent pool; access to capital; and favorable business environment (World Bank). Even though the Rwanda startup ecosystem is still young and growing, it is exploding with innovation and success. According to the Swisscontact (CSSC) Initiative (Report, 2019), over the last few years Rwanda had 403 startups. Today it has one of the highest ratios of new entrepreneurial support organizations (ESOs) per inhabitant worldwide.

Over the last decade, the Rwanda startup ecosystem has grown rapidly, and some support from government and international bilateral agencies and ventures is becoming available gradually in all the sector of activities. For example, the government’s HANGA Hubs Project initiative is supported young entrepreneurs. The program involves transferring job-readiness skills and accelerator programs to new incubation hubs, and providing space and assistance for young workers and startups to embrace breakthrough technologies that boost productivity, competitiveness, and economic growth. More than 1,000 young entrepreneurs have been trained in Rubavu, Rusizi, Muhanga and Nyagatare (Friedrich Ebert Stufun, case study 2022).

According to the Global Startup Ecosystem Index 2022(see *Table 2*) of StartupBlink, Rwanda is ranked the tenth best startup ecosystem in Africa and 84 globally (StartupBlink report, 2022). Rwanda's fast-growing startup ecosystem also attracts investments from bilateral organizations and private foreign firms from developed countries (see chart 3). In addition, Norrsken East Africa, the region's largest hub for entrepreneurship and innovation, opened its premises in Kigali Central Business District (CBD) in 2019. Norrsken also launched a HealthTech accelerator in partnership with Novartis Foundation. Furthermore, to support the startup ecosystem, the government of Rwanda launched a USD15 million commitment to promote innovation.

Table

⁹: Show the performance of Rwanda's startups ecosystem.

	Sector of activities of startup	Startup index	System rank in Africa	Ecosystem global rank
Rwanda	*Fintech; *Transport; *E-health;	1.235	10	84
Senegal	*Logistics;	0.753	11	92
Namibia	*E-commerce & retail-tech; *Ed-tech; *Energy; *Agri-tech; *Restaurant tech, e.g...	0.374	12	91

Given the potential and growth of the startup sector, this paper examines the case of the startup ecosystem, to examine how Rwandan national policy prompts international cooperation, and how that international cooperation helps startups to develop their innovation capability in Rwanda. This assumption builds on the fact that the development of private institutions, such as startups and international partnerships, is prioritized in the Rwandan Vision 2050 as one of its five key pillars. In addition, the national STI policy and the EDP policy are key elements that can increase and attract investment in R&D and innovation, and create jobs. The government intends to use these policies as drivers of knowledge production, transfer, and use; employment generation; and the provision of public services to the citizenry.

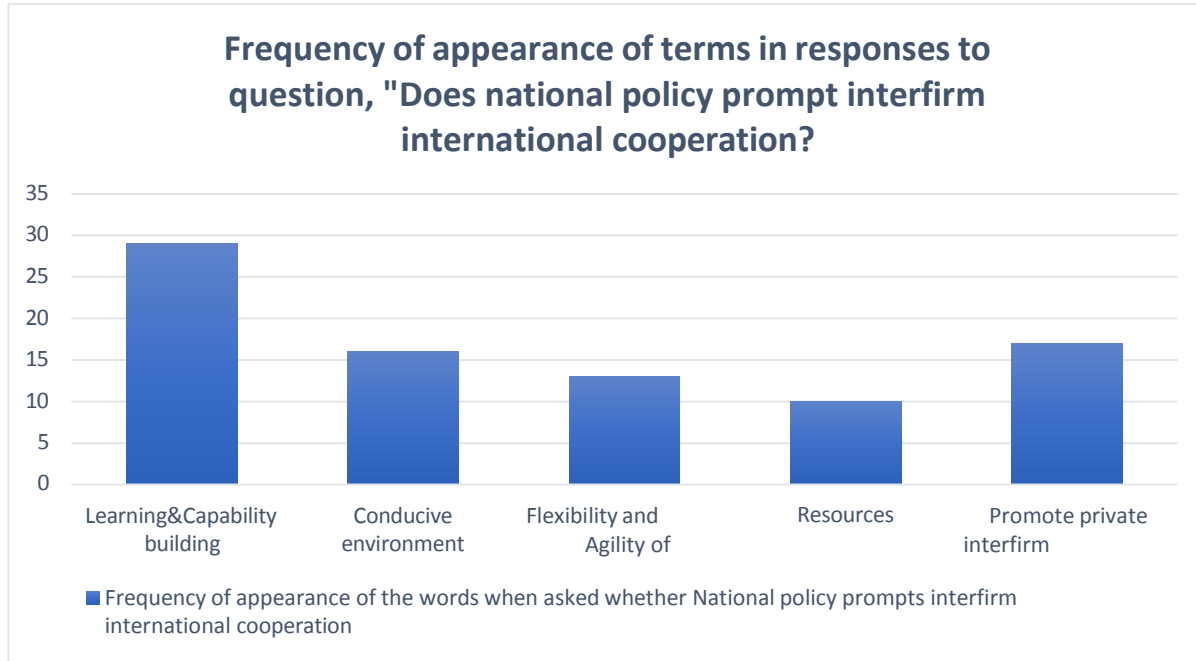
5. Results/Discussion

5.1. Results

After analyzing the transcripts, we identified key concepts that were present in the data. These themes are important for confirming the participants' understanding and determining their perceptions. These concepts have been assigned the terms: learning & capability building; conducive legal framework environment; flexibility and agility of the policy; infrastructure; and promotion of interfirm international cooperation (See Chart 4).

To strengthen our analysis, we identified themes that appear ten times or more in our analysis regarding Ahearn (2014), who utilized Word Clouds to explore thematic output in an academic journal. In her approach, Ahearn recognized the demand to separate phrases into main terms representing the keywords. At the end, she discovered that keywords were recurrent and helped to understand and interpret the participants' perceptions.

Chart 4



See Chart 3: Frequency of appearance of the terms when asked how Rwandan national policy prompts interfirm international cooperation (by the author using Nvivo).

Promotion of international interfirm cooperation

Almost all participants supported the statement that the innovation policies implemented in Rwanda prompted interfirm international cooperation and promote private foreign investment. They recognized that the policies do not create barriers to the flow of foreign private investment to local startups (*See table 3*). Nevertheless, some participants mentioned that the national policy partly promotes inter-firm international cooperation through public institutions, which are vital for coordination and matching startups with foreign firms.

However, some interviewees agreed moderately that in terms of private investment, the national policy was one factor, but that private investment depends mainly on the nature of the ecosystem and its maturity.

Flexibility and agility of the policy

Regarding factors of the innovation policies that trigger international interfirm cooperation, most participants stressed the importance of flexibility and agility of the policies in promoting the introduction of new technology in Rwanda. In addition, they found that the policy's openness, flexibility, and agility are key factors in attracting private foreign companies to invest in Rwanda, especially since many African countries have rigid policies. These findings are summarized in *Table 3*.

Conducive legal framework environment

Most interviewees underlined how essential the conducive legal framework environment in Rwanda was, how it played a key role in prompting interfirm international cooperation, and how it has contributed to attracting private investment. However, other interviewees highlighted that the driving forces behind the conducive environment are political will and the importance of the security of people and business.

Infrastructure

During the interviews, it was noted that the national political infrastructure of the country had contributed significantly to shaping its investment climate, resulting in favorable conditions for economic growth. This information can be found in *Table 3*.

Learning & capability building

According to most participants, the policy is crucial for the growth of startups. Startups in developing countries often face challenges in obtaining funding or lacking the necessary skills to be successful in the market. The policy environment has been instrumental in facilitating international cooperation and collaboration, improving startups' capability. Additionally, most interviewees pointed out that policies have positively impacted startups and incubation centers by providing funding and training programs to enhance their capability (*See table 3*).

Table 3: Shows the most frequent answer from the interviewees.

1	Theme	Frequency of appearance of the theme	Interviewees answers when asked whether How does National policy prompts interfirm international cooperation?
2	Learning& Capability building	29	•Most startups struggle to get funds, and incubators face the issue of funds, so the policy aims to support startups to get some funds. In addition, the policies aim to build the startup's capability and provide some funds. •The policies aim to support startups in ICT by providing funds and developing their capacity through training. •The role of the government is to support the capability building of the startup, capacity building of the people working in the startup, mostly through coordination, with a focus on how to increase the number of startups and Jobs. Moreover, one interviewee underlined the role of national policy in supporting soft skills and innovation. •So, the nature of the business is soft skills. The private foreign companies are helping us with soft skills, and the Ministry of Tourism and Culture is giving us some small funds for equipment or keeping some Incubation Centers, which helps those innovators improve their ideas, and maybe develop prototypes for a viable product.
3	Conducive environment	16	•Yes, if you look at the different reports on the facilities doing business, you will see that Rwanda is actually one of the countries that is excelling in terms of facilitating this foreign investment. Rwanda is among the countries with a good policy that may protect against and protect the investment of a contract that you enter. •First of all, for a conducive environment, in terms of political will, first there must be a political will to collaborate. Then, there must be security so that people can relocate from their country to come here to Rwanda, and then the country must be in an excellent economic condition; the country should have some opportunity for them to explore.
4	Flexibility and Agility of Policy	13	•I think Rwanda has already been a success in that regard. For example, the zipline case, the way it was introduced, is an example of an agile policy in which different companies are just coming to try things and mostly on emerging technology. So, I would say that our policy is in favor of enabling innovation and the introduction of new technology. •It is mainly related to the policies, openness of the policy, if, like, the environment is open, or the present moment is very open, and if it encourages competitiveness. •It is just because people are open. What happened during Covid is a real example of what makes the regulation more agile to enable new things. We could see more development, and we could see more innovation flourishing.
5	Infrastructure	10	•One of the key aspects is infrastructure. The policy in place enables suitable infrastructure implementation. So, infrastructure is one of the requirements, as well as security. •One thing I should mention is that the infrastructure also helped attract foreign investment. One primary condition that private foreign investors consider before coming to a country for investment is the availability of infrastructure (roads, electricity, and internet). For example, in the case of our business (outsourcing), high-speed internet infrastructure is essential for communicating with our partners outside Rwanda.
6	Promote private interfirm cooperation	17	Yes, the policy promotes interfirm international partnership, attracts investment, and promotes the creation of companies; we are number 3 in ease of doing business in Rwanda. And it is easy for a foreign citizen to open a company in Rwanda. So yes, that could be most on the investment side. So, there is an investment code and different instruments under the RDB. So, I could say they are some frameworks that do not create any barrier. •Yes, all this when it comes to investment, I think it goes more to the nature of the ecosystem. •Yes, it does; of course, Noesken (Norrskan is a non-profit impact ecosystem connecting founders with the capital, knowledge, and networking they need to make saving the world their business) is a perfect example. Noesken is present in Rwanda because the policy framework is attractive to investors. However, the framework is not a single policy, but a set of policies.

5.2. Discussion

Our results show that within the cohort sampled, 23% of respondents believed that national policy could only trigger inter-firm international cooperation if the startup ecosystem is mature, which means some critical resources (human resource capability or infrastructure) are available and the market is attractive. The Rwanda Vision 2020 and other supportive policies emphasize human resource capability, infrastructure, and innovation. This fits well with the argument of Mathews and Cho (2000), that government can use national policy to facilitate the acquisition of human capabilities and technologies and support acquisition to access economic growth.

However, it does not reflect Conconi and Perroni, who argued that a lack of policy dedication could make a country more inclined to step into international agreements because a nation facing a domestic commitment issue has comparatively more to benefit from securing well-organized policies (Conconi & Perroni, 2009). The chronological policy evolution, and the establishment of some government agencies, such as the Rwanda Development Board (RDB), may present a policy commitment of the government of Rwanda; despite the absence of an efficient coordination mechanism amongst government institutions (Hanlin et al., 2020).

Despite the variation in views, perceptions of the results of the national policy were highly similar: all interviewees acknowledged that national policy triggered inter-firm international cooperation. This echoes (Joseph et al., 2019) statement that the government used industrial policy to attract foreign direct investment by multinational companies, thinking that they would generate employment.

Regarding our question about the factors of the national policy that enable the international interfirm cooperation between a private foreign firm and local startup, several participants mentioned the policy's openness, flexibility, and agility as one of the main factors attracting private foreign firms. Indeed, most foreign tech companies are usually looking for a location for prototype testing. With its strategies of exporting knowledge, Rwanda, through its Vision 2050, intends to place itself as a knowledge center leveraging startups ecosystems and technology. Through its proof-of-concept policy for digital innovation, Rwanda offers foreign private firms a ground where they can "test-and-learn" and launch their innovations (Vision2050, 2020). This reflects Featherston et al. (2016) who underlined that developing countries eager to achieve economic growth may consider promoting agile and flexible policies and regulatory institutions to attract new knowledge and emerging technology to help them overcome local obstacles.

A conducive legal framework environment is also essential for facilitating the integration of private foreign firms. Most participants mentioned the political will, security, and tax policy that make it easy for private foreign firms to integrate. For example, in 2015, Rwanda adopted an investment code, and in 2020, the government updated that policy. This policy aims to attract more foreign direct investments and provide investors with tax breaks and other incentives. This aligns with observations by some scholars that institutional factors (e.g., intellectual property rights, taxation, labor market legislation, and removal of financial and legal obstacles to business creation) could shape economic activity across economic sectors (Coad, 2014; Davidsson & Henrekson, 2002).

6. Conclusion

The case of Rwanda's national policy demonstrates that developing countries can prompt private partnerships between foreign firms and domestic startups through national innovation policy by adopting flexible and agile policy essential to create new markets and attract foreign knowledge into startups and address grand challenges such as attracting investment from private and public actors, creating jobs, and solving modern care problems (Kattel & Mazzucato, 2018). This case illustrates the need for flexible, agile policies for knowledge transfer in private partnerships between foreign firms and domestic startups. Furthermore, it concludes that institutional factors such as the flexibility and agility of a policy could shape economic activity across economic sectors and attract foreign knowledge in the private sector. However, prompting private partnerships between a foreign firm and domestic startups in developing countries requires prior conditions such as a conducive environment, flexible and agile, and adaptable policy for introducing emerging technology. Additionally, it requires the availability of infrastructure (roads, electricity, banks, and internet connectivity) and the maturity of the startup's ecosystem. Moreover, government vision, political will, and good institutional coordination are essential to the process and can be mainstreamed as a prerequisite of the policy configuration.

By examining Rwanda's national policy, this paper clarifies that a country's dedication to policy can significantly increase its willingness to engage in international agreements. Rwanda's commitment to policies promoting economic growth and development has led them to actively participate in several international agreements and partnerships. Moreover, the success of Rwanda's policies can serve as an example to other countries of how policy dedication can lead to greater international cooperation and success.

The author is aware of the limitations intrinsic in illustrating a common understanding from a single case based on one country because there are some limitations related to data availability and resources. Therefore, further exploration of similar studies (two countries and how the emerging service produced by the partnership contributes to socio-economic development) is required to verify the observations presented here.

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Notes

¹ https://www.icr-facility.eu/fileadmin/files/downloads/icreports/20211026_csi_2_fr.pdf

² MINICT: Ministry of ICT and Innovation. RDB: Rwanda Development Board.

NCST: National Commission for Science and Technology

SEAD: Strengthen Education for Agricultural Development (SEAD) in the Western Province. IPAR: Institute for Policy Analysis and Research.

UR: University of Rwanda. RP: Rwanda Polytechnic.

JICA: Japanese International Cooperation Agency.

GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit. Expertise France

³ <https://www.imf.org/en/Publications/REO>

⁴ https://www.worldbank.org/content/dam/Worldbank/document/Africa/Report/Africas-Pulse-brochure_Vol7.pdf 5 Data source: World Bank (treated in excel by the author): Chart 1 Above presents the trend of GDP of Rwanda of Rwanda compared to Senegal and Namibia. The figure shows that Rwanda s country has experienced a steady and impressive increase in GDP growth in the last decade.

⁵ Data source: World Bank (treated in excel by the author): Chart 1 Above presents the trend of GDP of Rwanda of Rwanda compared to Senegal and Namibia. The figure shows that Rwanda s country has experienced a steady and impressive increase in GDP growth in the last decade.

⁶ In addition, Chart 2 shows the trend of the flow of Foreign Direct Investment between the years 2016 to 2019. As per the chart 3, it is evident that there was a significant increase in the flow of private invest into Rwanda after the introduction of the NST1 policy in 2017.

.Chart: 2 Source: Authors' own compilation based on FDI data from World Bank:

<https://data.worldbank.org/indicator/BX.KLT.DINV.WD.GD.ZS?contextual=default&locations=RW>

⁷ Chart 3 Source: Authors compilation based on private investment in startup between 2016-2019 from Africa Tech Venture Capital Report (partechpartners.com)

⁸ Figure 8 represent the 7 majors policies influencing the startups, they have been selected because of their direct impact on the startups

⁹ Source: (Disrupt Africa report 2022, The state of startup in Africa Q2 2022 report, StartupBlink report 2022: Compiled by the author)

Chinese Infrastructure Lending in Africa and Participation in Global Value Chains

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Abstract

We explore the extent to which Chinese lending to Africa can promote the participation in Global Value Chains (GVC). Using loan-level data on Chinese and World Bank lending to 37 African countries from 2000 to 2018 we find that, differently from World Bank lending, Chinese lending is associated with an increase in GVC participation. This association is driven by infrastructure lending, which is likely to contribute to a reduction of trade costs and therefore could make it easier to participate in GVCs. The increase in GVC participation, being persistent over time and concentrated on the downstream sectors, could contribute to export and productivity growth.

JEL Classification: F15; F34; O14; O55

Keywords: Chinese lending; Global value chains; Infrastructure; Africa

1. Introduction

At a global scale, with some ups and downs and a peak in 2016, Chinese overseas lending has continuously increased until 2018, reaching about 1.5 percent of world GDP (Horn et al. 2021). Notwithstanding the recent contraction, with net transfers from Chinese bilateral creditors to developing country public sector recipients turning negative from 2019 due to internal as well as external turmoil¹ (Horn et al. 2022), in the last decade China has become one of the most important lenders worldwide, especially to Africa.

Measuring the size, terms and destinations of Chinese official international lending is not an easy task because data are scarce, and the process of lending is not fully transparent. Using loan-level lending data, Horn et al. (2021) show that more than two dozen countries owe more than 10 percent of GDP to Chinese state-owned creditors, and among them at least 10 are from Africa. Moreover, after the Far East and Central Asia, Sub-Saharan Africa (SSA) is the most indebted region to China.

The Chinese aid to Africa has been widely criticised since the popular article by Naim (2009), which is based on anecdotal evidence and defines the financial flows coming from China as *rogue aid*, mainly guided by selfish interest. Since then, several studies have tested the rogue aid hypothesis, finding that this definition seems unjustified (Dreher and Fuchs 2015; Broich 2017; Dreher et al. 2021). What remains not fully understood are the channels through which Chinese lending could promote growth in Africa.

In this paper we look at the participation in Global Value Chains (GVC) as one channel through which countries, becoming more integrated in international markets, could accelerate the industrialization process and promote development (Taglioni and Winkler 2016). Moving from the observation that Chinese lending is particularly concentrated in infrastructure financing, which could reduce trade costs (de Soyres et al. 2019), we analyse if the acceleration of Chinese lending has been associated with an increase in GVC participation.

To understand the main characteristics of Chinese lending activities, the World Bank can be adopted as a useful benchmark because of the overall scale and consequences of the two lenders and because the World Bank, as the largest multilateral lender, promotes a common set of behavioural norms which other official lenders are encouraged to comply with (Denizer et al. 2013; Morris et al. 2020). The World Bank has an institutional mandate for openly pursuing the reduction of extreme poverty and the expansion of prosperity through its lending activities (Morris et al. 2020; Ruta et al. 2019). This translates into lending at concessional terms with loans mainly directed at budget support and social spending, at the expense of infrastructure financing (Dollar 2018;

Humphrey and Michaelova 2019; Morris et al. 2020; Zeitz 2021). With a focus on Africa and based on an index to measure how financing is subject to below-market rates, Morris et al. (2020) find that 60 percent of World Bank's loans to Sub-Saharan Africa are subject to concessionality, which characterizes only 22 percent of Chinese loans to the region.

Quite differently from the World Bank lending, China's official overseas loans resemble commercial international lending transactions with most loans denominated in US dollars and with interest rates which, as we have just seen, tend to be non-concessional (Horn et al. 2021). Chinese development financial institutions, such as the China Development Bank and China Export-Import Bank (Exim Bank)—which are the two main official Chinese lenders—differently from their Western counterparts tend to support large projects in transport and energy infrastructures, following a “big push” industrialization approach (Chin and Gallagher 2019). In a recent paper, Lee and Gonzales (2022) estimate that over the period 2007-2020 Chinese development banks provided 2.5 times more finance for public-private infrastructure projects in SSA than the US, Germany, France, and Japan's development finance institutions combined, also dwarfing multilateral developments banks in this field of intervention. As a matter of facts, between 2000 and 2019 according to Acker and Brautigam(2021) at least 80 percent of Chinese lending to Africa has funded economic and social infrastructural projects—mostly in sectors such as transport, power, telecoms, and water. The concentration of loans into these sectors reflects different factors. On the demand side, the strong African appetite for infrastructure development. On the supply side, Chinese sectoral specialization in low-cost and rapid infrastructure development, as well as Chinese policy banks' active support for their companies operating in these projects abroad (Hwang et al. 2022).

The nature and motivation of Chinese lending in African infrastructures is very controversial as attested by several discussed cases, such as the Standard Gauge Railway project in Kenya, linking Nairobi to Mombasa and mainly funded with loans from Exim Bank. This project generated a lot of speculation due to the rumour that Kenya used the Mombasa port as collateral behind the loan. Nevertheless, based on a very detailed analysis of the complex contracts between China and Kenya Brautigam et al. (2022) conclude that there was not such a collateral obligation but rather the railway project was creatively designed to reduce the risks of a sovereign default, involving high costs but also significant long-term benefits for Kenya. In general, what appears from the evidence available is that Chinese investments in infrastructures are very diversified and not necessarily should be considered as intrinsically predatory or inevitably problematic. For example, Vines et al. (2022) illustrate how a more recent Chinese loan to Kenya for building the expressway in Nairobi has a more familiar format to public-private partnerships elsewhere in the world, and it is at a much more manageable scale. They also illustrate the case of Chinese

lending in Côte d'Ivoire as a demonstration that in relatively well-run states Chinese loans can drive growth.

Considering the strong concentration of Chinese lending on infrastructure projects, it is relevant to explore their impact on the recipient countries. With data on 81 countries, Donaubauer et al. (2016) show that when aid is targeted at improving the countries' endowment with infrastructures in transportation, communication, energy, and finance, there is a positive impact on FDI attractiveness.

Participation in Global Value Chains (GVC) – through imports and exports of intermediate goods and services – is another way in which African countries can get involved in international markets by specializing and exploiting comparative advantages in some stages of production. Improvements of connecting infrastructures influence predictability, reliability, and timelines within GVCs given that trade in parts and components is even more sensitive to logistics performance than trade in final goods (World Bank 2019). Hummels and Shaur (2013) show how important efficient transport infrastructure is for accessing GVCs. They estimate that each day in transit equals to an *ad-valorem* tariff between 0.6 and 2.3 percent and empirically confirm that trade in parts and components can be much more affected by time delays than trade in final goods. In the specific context of Chinese infrastructure financing, de Soyres et al. (2019) show that the average reduction in shipment time from the Belt and Road Initiative ranges between 1.2 and 2.5 percent, leading to reduction of aggregate trade costs between 1.1 and 2.2 percent. Thus, improving transport and communication efficiency increases the speed and reduces the uncertainty of deliveries, therefore decreasing the costs of intermediates used in international production networks. Examples of GVCs that are particularly sensitive to delivery time are those specialized in electronics and fruits and vegetables, being the latter of particular importance in African countries (Arvis et al. 2010; Christ and Ferrantino 2011).

Building new infrastructures and improving the existing ones thanks to aid support can address the diffused infrastructural gaps in African countries with a positive impact on costs and times in trading intermediate inputs within GVCs (OECD and AfDB 2014; IMF 2015). As also pointed out by the OECD and WTO (2013), developing communication and transport infrastructures is crucial to manage and coordinate production activities that are geographically dispersed and to increase chances to access GVCs. The increased participation in GVCs is particularly relevant for African economies, which can exploit their comparative advantages without having to develop all the capabilities needed along the entire value chain, becoming part of the global market (IMF 2015; Amendolagine et al. 2019), with a positive impact on income and employment and, a reduction in poverty (Taglioni and Winkler 2016; Kummritz et al. 2017; World Bank 2019).

Against this backdrop, this paper investigates whether Chinese lending could facilitate the participation in GVCs in Africa. We combine loan-level data on Chinese lending to 37 African countries between 2000 and 2018—collected by the China-Africa Research Initiative (CARI)—with the UNCTAD-Eora Global Value Chain database, which provides country-level measures of GVC participation over the same time span. To account for the specificity of Chinese lending, the empirical analysis is extended to World Bank loans to Africa as a benchmark. The availability of loan-level data allows us to go beyond aggregate flows investigating the heterogeneity across loans to different sectors, with a focus on infrastructure financing.

In the next section, we explore data on Chinese lending to Africa. The comparison with World Bank loans highlights differences not only in the allocation across countries, but also across sectors, with Chinese loans being much more concentrated to infrastructure sectors. In the same section we also document that, even if GVC participation did not show any visible pattern across African countries, looking separately at upstream and downstream linkages shows that most countries experienced an increase in the *downstream* component of GVC participation, which denotes a specialization in phases close to final demand. This is an interesting piece of evidence because, as African countries' participation in GVCs is mostly at the upstream level, through natural resources exports, strengthening participation in downstream stages of GVCs could allow countries to take full advantage of global integration.

The empirical analysis, discussed in Section 3, shows that indeed the increase in Chinese lending to Africa, and especially infrastructure financing, is associated with an increase in GVC participation. This association is driven by loans to transport and communication sectors, which are likely to contribute to a reduction of trade costs and therefore could make it easier to participate in GVCs. In addition, the increase in GVC participation, which is economically sizable and persistent over time, is concentrated on the downstream component. These results are robust to the use of an instrumental variable approach and to a large set of additional exercises.

These findings are not mirrored when looking at World Bank lending, pointing to a specific role played by Chinese lending in easing GVC participation in Africa. A specialization in infrastructure lending could help recipient countries to join global value chains, especially in downstream industries. As downstream GVC participation, particularly in developing countries, is associated with export upgrading and productivity growth (Costantinescu et al. 2019; Ndubuisi and Owusu 2021; Veeramani and Dhir 2022), our findings provide an original contribution pointing to a significant positive effect of Chinese lending on recipient countries' output growth (Dreher et al. 2021).

2. Data and stylized facts

2.1 Chinese and World Bank lending

The empirical analysis is carried out on a database at country-year level covering 37 African countries observed for almost two decades (from 2000 to 2018).² Data on loans are from the database on Chinese Loans to Africa (CLA) which is an interactive project tracking loan commitments from Chinese policy and commercial banks, government entities, companies and other financial institutions to African governments and state-owned enterprises, managed by the China-Africa Research Initiative (CARI).³ The data sources include official government documents, contractor websites, fieldwork interviews, and media sources and being loan commitments, they are reported as public debt only when they are disbursed because the projects are implemented (Acker and Brautigam, 2021).

The database includes 1,141 loans to African governments and their state-owned enterprises worth more than USD 100 billion. For each loan, there is information about the year, the sector, the value, and the type of lender. For benchmarking purpose, similar information is also available on World Bank loans available in the World Bank Projects and Operations database.⁴ In the same period (and for the same sample of countries) the total number of World Bank loans is 2,231 for a total value of more than USD 200 billion. Considering the value of loans, on average Chinese loans are larger than World Bank ones, USD 133 million compared to USD 95 million.

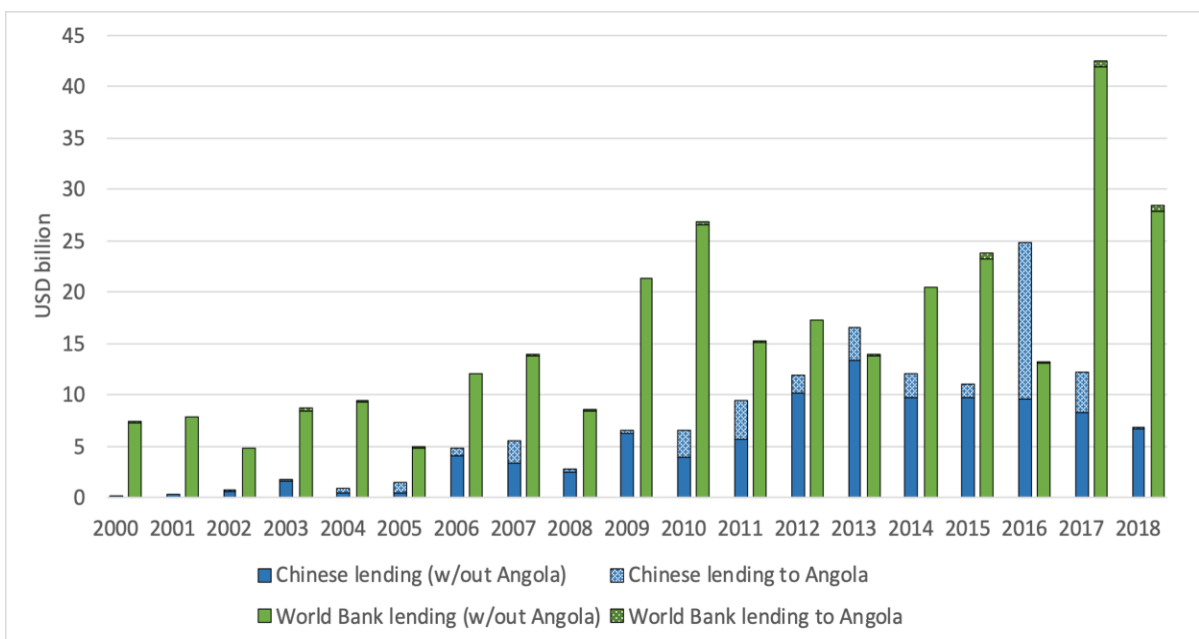
To provide a more complete picture of Chinese and World Bank lending, Figure 1 shows total flows to 50 African countries from 2000 to 2018. For Chinese loans we provide the aggregate value of loans going to African countries as well as the value of lending excluding Angola, which is an important outlier (especially in 2016).⁵ Excluding Angola, Chinese lending to Africa saw a peak in 2013, the year the Belt and Road initiative was launched, followed by a decline in comparison to the World Bank, which is consistent with pullbacks in other parts of the world. The decline reflects China's concerns about debt sustainability as well as some structural transformations in Chinese outward expansion, envisaging a trend towards smaller and more targeted projects in less risky countries, away from large loans to the oil sector such as in the case of Angola (Ray, 2023).

Figure 2 identifies the top 10 recipient countries of Chinese and World Bank loans, which are very different for the two lenders. As already seen, the top recipient of Chinese lending is Angola, due to large oil-related loan facilities from China Development Bank and Exim Bank, while the country ranking first among World Bank top recipients is Egypt, followed by Nigeria.

Figure 3 emphasizes another important difference between Chinese and World Bank lending in terms of sectors receiving the loans.⁶ About two thirds of Chinese loans go to infrastructure, which are concentrated in transport and communication infrastructures (36 percent), followed by energy and water infrastructures, to which the World Bank is also allocating a large share of its loan portfolio.

By contrast, the main area of lending for the World Bank is social projects in education, health, housing, food security, which represents instead a minimal share of total Chinese lending.

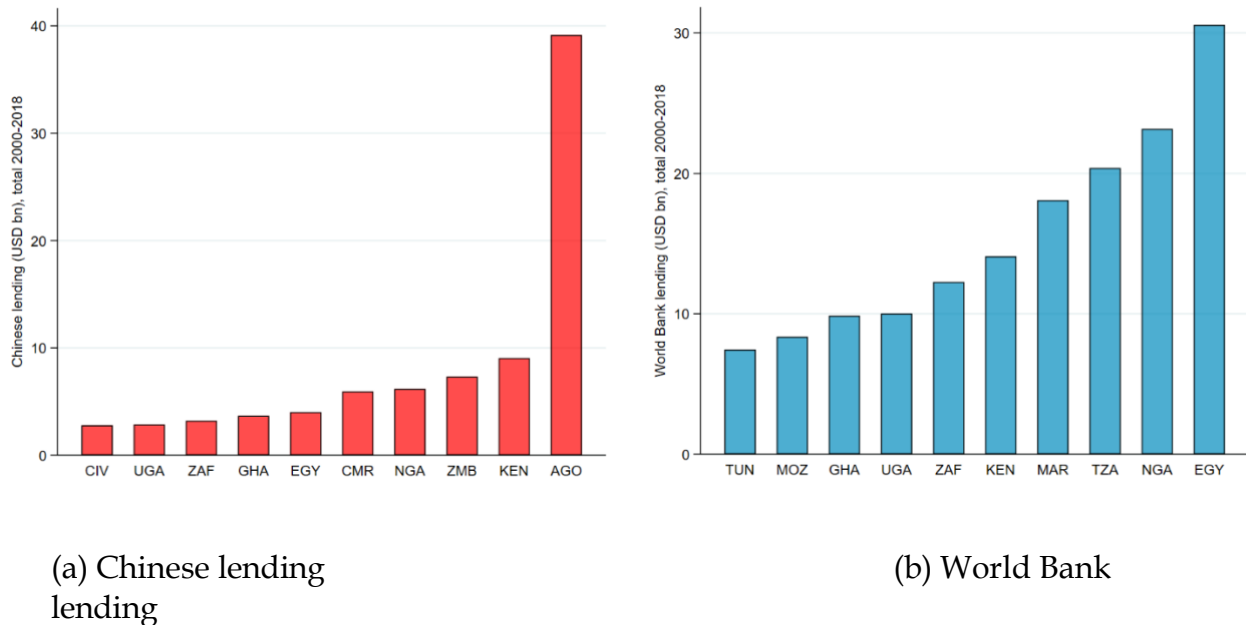
Figure 1 Chinese and World Bank lending to Africa (2000-2018)



Notes: the chart plots the total amount of lending by China and the World Bank to 50 African countries, from 2000 to 2018. Values are in billion current USD. For both China and the World Bank, lending is shown isolating flows to Angola (dotted bars), which is the largest recipient of Chinese lending.

Source: CLA and World Bank Projects and Operations database

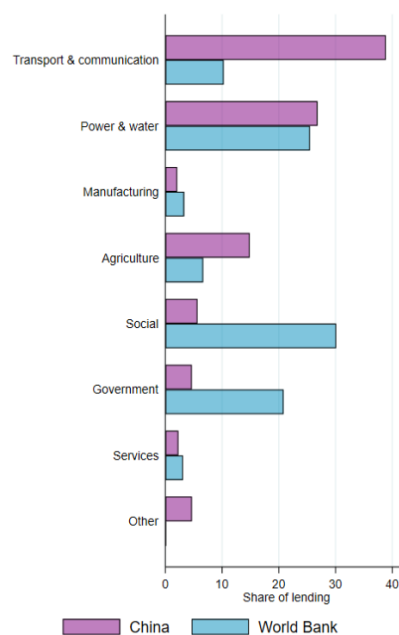
Figure 2 – Chinese and World Bank loans to Africa (2000-2018): Top 10 recipient countries



Notes: the charts plot the total amount of lending by China (panel A) and the World Bank (panel B) to the top 10 African recipients. Values are in billion current USD, cumulated over the period 2000 to 2018.

Source: CLA and World Bank Projects and Operations database

Figure 3: Chinese and World Bank lending to Africa: Sectoral allocation



Notes: the chart plots the sectoral allocation of lending by China and the World Bank to 50 African countries, from 2000 to 2018.

Source: CLA and World Bank Projects and Operations database

Table A.2 and A.3 in the Appendix provide detailed information about the sectoral distribution of Chinese and World Bank loans in African countries. In the Chinese top recipient countries, except for Angola and Egypt, the two most important sectors receiving loans are Transport and Communication and Power and Water. In countries such as the Côte d'Ivoire and Uganda almost the totality of loans is concentrated in infrastructures. Côte d'Ivoire where the two largest loans were used for upgrading the power grid and for expanding the Abidjan port represents a successful example of Chinese lending in infrastructures (Vines et al. 2022). While the Chinese loan to Uganda for the expansion to the Entebbe airport was in the news as a bad example because of some clauses included in the deal and the rumour that the airport itself could be seized in the event of default.⁷ Nevertheless, after Ugandan authorities protested, China Exim Bank agreed to renegotiate the agreement at less intrusive conditions and at the same time it was revealed that the airport itself was never been considered as a source of collateral (Parks et al. 2022).

2.2. GVC participation

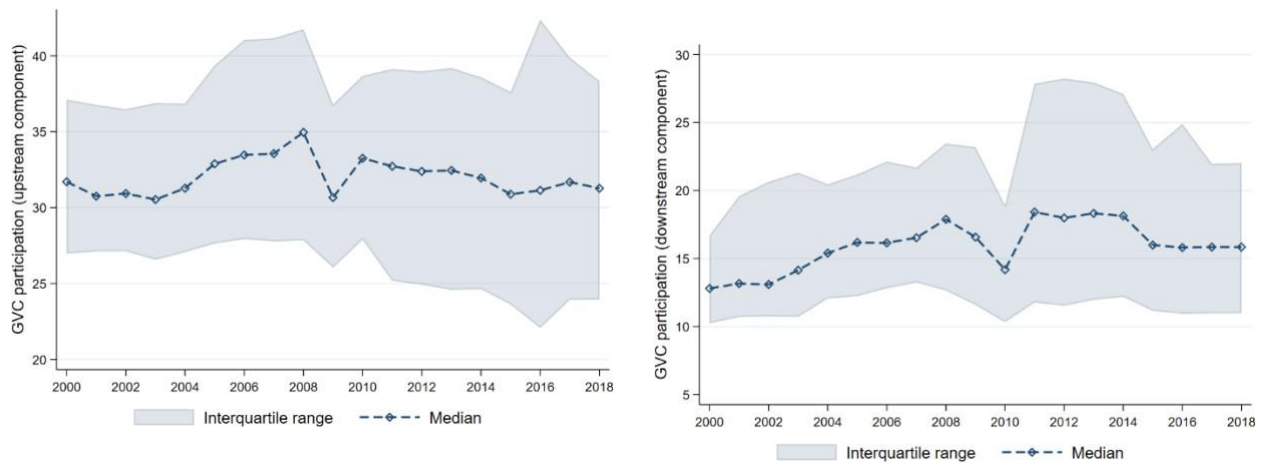
The extent to which African countries participate in GVCs is measured by the following indicator, constructed following Koopman et al. (2014) and Borin and Mancini (2019):

$$GVC\ PARTICIPATION_{it} = FVA_{it} + IVA_{it}$$

which is computed adding two components of the cross-border trade of intermediates for country i in year t . The two components are defined as follows. The *foreign value-added content of exports (FVA)* corresponds to the ratio between the value added of inputs that are imported to produce intermediate or final goods/services to be exported, and gross exports. It corresponds to the *downstream* component of GVC participation, which denotes a specialization in phases close to final demand (e.g., use of intermediates to produce final goods for exports). This is the *buyer* (or demand side) perspective in GVCs, where an economy imports intermediates to produce its exports. The *indirect domestic value added (IVA)* is the ratio between the value added embodied in intermediates exported to countries that re-exports them to a third economy as embodied in other products, and gross exports. This corresponds to the *upstream* component of GVC participation, which measures a specialization in the GVC phases of the production process which are remote from final demand (e.g., production of intermediates products used by other countries in their exports). This is the *seller* (or supply side) perspective in GVC participation.

Intuitively, a country which specializes more in downstream industries/productions would allow natural resources-rich/technology-scarce countries to produce more complex products and would capture a larger share of their value added. This component tends to be more strongly associated with the benefits from GVC participation in terms of export upgrading (Ndubuisi and Owusu 2021), as well as exports, output and productivity growth (Costantinescu et al. 2019; Veeramani and Dhir 2022). This is particularly relevant for developing countries, which need to import more advanced technology and higher quality intermediate inputs to upgrade the quality of their production and their position in the GVCs. However, African countries' participation in GVCs is mostly at the upstream level – see Figure 4 – through the exports of primary inputs and is unlikely to drive upgrading in production sophistication (Foster-McGregor et al. 2015; AUC and OECD 2022). Strengthening participation in downstream stages of GVCs would then allow countries to take full advantage of global integration.⁸

Figure 4. GVC participation in Africa, upstream and downstream component.



(a) Upstream component

(b) Downstream

Notes: panel A plot the median and the interquartile range of the ratio between the value added of inputs that are imported to produce intermediate or final goods to be exported, and gross exports. Panel B plots the median and the interquartile range of the ratio between the value added embodied in intermediates exported to third countries that re-exports them to a third economy as embodied in other products, and gross exports.

Source: UNCTAD-EORA database.

The GVC indicators are based on the UNCTAD-Eora database⁹, which provides information on international value-added trade for 189 countries observed from 1990 to 2018. Given the insufficient quality of value-added trade data for some countries, our sample includes 37 African countries for which the UNCTAD-Eora database provided GVC indicators, recipients of Chinese and World Bank loans.¹⁰

Figure 4 plots the upstream (panel A) and downstream (panel B) components of GVC participation across the sample of 37 African countries. While there is no discernible increase in upstream GVC participation (and even a decline in the bottom part of the distribution), the downstream component increased in 21 countries. In particular, for the median country the foreign value-added content of exports moved from 12.8 to 15.8 percent of gross exports. This increase is more visible at the top of the distribution, with the country at the third quartile moving from 16.7 percent in 2000 to 28.2 percent in 2002, before declining to 22 percent in 2018.

3. Empirical analysis

To investigate the association between Chinese lending and the degree to which recipient African countries participate in GVCs, we estimate the following model:

$$\Delta Y_{i,t+n} = \alpha \text{Chinese Lending}_{i,t} + X' \beta + \gamma_i + \delta_t + \varepsilon_{it}, \quad \text{with } n=1, \dots, 5 \dots (1)$$

where $\Delta Y_{i,t+n}$ is the change in GVC participation by country i between year t and $t+n$ (with the horizon n going from 1 to 5 years forward). The key explanatory variable (*Chinese Lending_{it}*) measures the amount of lending by China to country i in year t . Lending is in USD and the variable is transformed using the inverse hyperbolic sine (IHS), to take care of the zero lending flows in our panel.¹¹

In the baseline model, the vector X' includes: i) the IHS transformation of the amount (in USD) of World Bank lending, to compare the effect of Chinese lending with the main multilateral donor, ii) real GDP growth, to capture cyclical conditions which could be associated with overseas lending by bilateral lenders (Avellano et al. 2022) as well as with GVC participation and iii) the Rule of Law index from the World Bank World Governance Indicators, which could also be associated with GVC participation and overseas lending. Common shocks are absorbed by the year fixed effects δ_t , while country fixed effects (γ_i) control for unobserved heterogeneity across countries in the level of GVC participation.

Equation 1 is estimated over the sample of 37 African countries from 2000 to 2018. Given the relative short time period and the fact that we exploit the within-

it

country variation, the set of controls X' does not include other *structural* drivers of GVC participation, such as the stock of FDI, the resource endowment, and the level of human capital (Fernandes et al. 2022). A set of robustness exercises expands the set of controls. Finally, the model is estimated with OLS and the standard errors are clustered at the country level to allow for serial correlation within countries.¹²

Baseline results

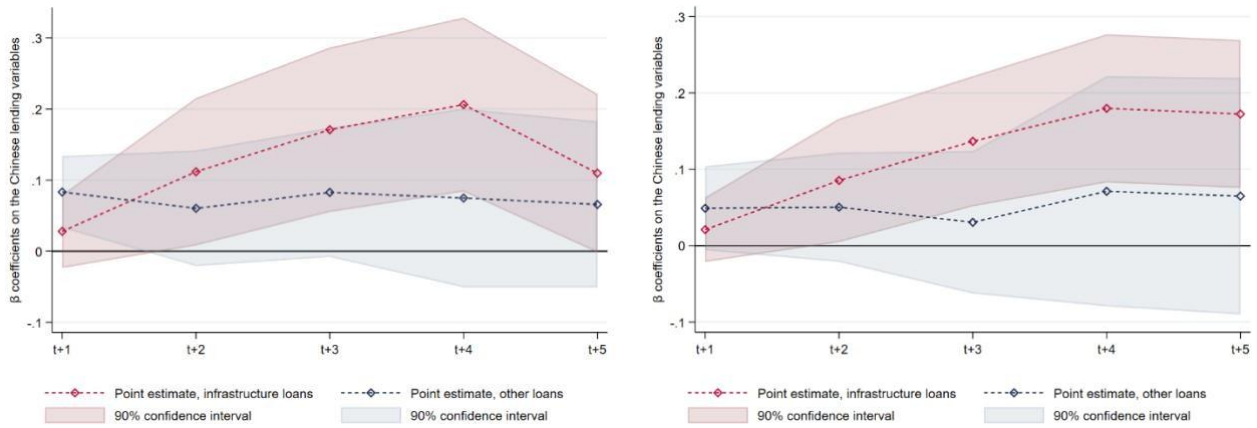
Table 1 shows the baseline results over a five-year horizon. The association between Chinese lending and the change in GVC participation is visible already the first year after lending and it increases in size over time, up to the fourth year. In economic terms, one standard deviation increase in Chinese lending is associated with 0.13 standard deviation increase in GVC participation after four years. Then it declines five years ahead, but it remains statistically significant. By contrast, the coefficient of the World Bank lending variable is negative, close to zero and never statistically significant. GDP growth and institutional quality are also not associated with GVC participation.¹³

As a key element that differentiates Chinese lending from that of traditional multilateral (and bilateral) donors is the dominance of infrastructure lending in the loan portfolio (Figure 2). Therefore, we next take advantage of the possibility to use the information at the loan level to split lending (by China and by the World Bank) to infrastructure sectors (transport, energy, water and communication) from that directed at other sectors. Given that infrastructure projects directed at improving communication and transportation networks could be more conducive to trade and facilitate GVC participation through a reduction in trade costs (Hummels and Schaur 2013; de Soyres et al. 2019), we further separate loans to transport and communication sectors from loans for energy and water projects. Results are reported in Tables 2 and 3, which shows that indeed a persistent increase in GVC participation is associated with infrastructure lending rather than with lending to other sectors. The coefficient is statistically significant only in years 2, 3 and 4, even though the coefficients in year 1 and 5 are very close to the 90 percent confidence level, as shown in Figure 5 (panel A). By contrast, the coefficients of loans to other sectors are never significant except from the first year. Within infrastructure lending, the results in Table 3 would suggest that transport and communication could be more relevant, as the effect is visible already in the second year and by year 4 is slightly larger than that of loans to energy and water. One standard deviation increase in Chinese lending in transport and communication (energy and water) is associated with 0.074 (0.066) standard deviation increase in GVC participation after four years.

Participation along the value chain

Participation in GVCs can happen in different phases of the value chains. Specifically, the value added included in intermediate goods that are exported to other countries is a measure of upstream participation in GVCs, since it relates to the first stages of value chains which are far from the final demand. Instead, the value added included in intermediate goods that are imported from other countries and then used to produce export goods is a measure of downstream participation in GVCs, since it relates to the final stages of value chains which are closer to the final demand. In Table 4 we show the results of the estimation of equation (1) in which the dependent variable is, alternatively, the downstream and upstream components of GVC participation. In Table 5 we decompose Chinese and World Bank lending into loans to infrastructure and to other sectors. The findings clearly indicate that positive association between Chinese lending and GVC participation is driven by the increase in the downstream component (panel A), while there is no statistical relationship between the upstream component, neither with Chinese lending, nor with World Bank lending (panel B). The relationship between Chinese lending and the downstream linkages shown in Table 4 is driven by loans directed at financing infrastructure, and it is already significant two years after loan origination, with increases over time remaining significant even after 5 years (Table 5, panel A, and Figure 5, panel B).

Figure 5. Chinese infrastructure lending and GVC participation



(a) GVC participation

(b) Downstream GVC participation

Notes: the chart plots the coefficients of Chinese lending to infrastructure and to other sectors—and the associated 90 percent confidence bands—as reported in Table X (panel A), and Table X (panel B).

Endogeneity

Our main findings show a robust association between Chinese lending and subsequent changes in GVC participation. However, this association could be biased by reverse causality—as countries which are becoming more integrated could attract more external financing—or by an omitted variable bias, as both GVC participation and Chinese lending could be driven by common factors. While we control for GDP growth, other (unobservable) factors—such as growth prospects—could still be at play. To tackle the endogeneity of Chinese lending, we employ an instrumental variable (IV) strategy. We follow a shift-share approach, as in Dreher et al. (2021) and Zeitz (2021) to construct two instruments for Chinese lending which are then used in the first-stage regression, as follows:

$$\text{Chinese Lending}_{it} = \theta_1 \text{Steel}_{t-3} * p_{chn,i} + \theta_2 \text{Reserves}_{t-3} * p_{chn,i} + \gamma_i + \delta_t + \dots (2)$$

First, we consider the three-year lagged Chinese production of steel (Steel_{t-3}), and we multiply it with the (country-specific) probability of receiving Chinese lending in infrastructure, calculated as the share of years (in the 2000-2018 period) in which a country received Chinese loans to infrastructure sectors ($p_{chn,i}$). Second, we consider the three-year lagged value China's net foreign exchange reserves (Reserves_{t-3}), multiplied—as in the previous case—by the probability of receiving Chinese lending. The first-stage regression, which includes country and year fixed effects) shows that the instruments are valid, as the Kleibergen-Paap first stage F-test for weak identification takes values larger than 20. Furthermore, the Hansen J statistic reveals that overidentification restriction is satisfied, meaning that the instruments are uncorrelated with the error term. Moving to the findings, the IV estimates are consistent with the OLS ones and suggest that an exogenous increase in Chinese infrastructure lending leads to a significant and persistent increase in GVC participation already after two years (Table 6, panel A). As in our main results, this effect is driven by the downstream components, which increase already one year after Chinese infrastructure lending (panel B).

Robustness checks

We test our results to changes in the sample, in the definition of the main variables, and in the set of controls variables. In the first exercise we address the possibility that results might be driven by Angola, which is by far the largest recipient of Chinese lending. Its exclusion, however, does not affect the results and the point estimates are, if anything, larger than in the baseline (Table 7).

A somewhat related concern has to do with the definition of lending flows. Our baseline analysis considers the volumes in USD as we are interested in capture the absolute size of Chinese and World Bank lending given that, especially

when considering the large costs of infrastructure financing, this is the relevant dimension. However, it could still be true that some relatively small flows could be relevant for countries which are relatively small (also because the costs of some infrastructures could also be smaller—think about road networks across countries very different in size). To deal with this concern, we scale lending flows by recipient countries GDP. Results are reported in Table 8 and are in line with the baseline ones.

A third concern is that part of the correlation between Chinese lending and GVC participation could be attributed to trade with China. If that were the case, countries would not really become more integrated in global value chains, but they would only strengthen their trade ties with China. In other words, Chinese lending would mostly benefit China itself, which would import from Africa intermediates which it finances through its overseas lending. To test this hypothesis, we calculate the measure of GVC participation considering only the value added in trade with all countries except China. Table 9 shows that our main results are not driven by specific trade linkages with China as Chinese lending is positively associated with the alternative measure of GVC participation which excludes China.

The final set of robustness tests considers the set of control variables included in the vector X' . First, we control for the value of GVC participation in year t . While the coefficient of this variable is negative and statistically significant and absorb a non-trivial part of the variation of the dependent variable (as shown by the increase in the R-squared), the coefficient of *Chinese Lending_{it}* is mostly unaffected, even if the standard errors tend to be slightly larger (Table 10). Second, we expand the set of controls to include variables which have been often shown to drive GVC participation. In

particular, we add: i) the stock of FDI over GDP (in percent); (ii) the share of mineral rents in GDP (in percent), which is a measure of the relevance of natural resources in the borrowing country; (iii) the human capital index, from the Penn World Tables (version 10.0), which is based on years and returns to education; and (iv) a dummy variable equal to one if country i has a bilateral agreements with China in year t .¹⁴ While these variables are generally not significantly associated with GVC participation (as probably most of their variation is absorbed by the country fixed effects), their inclusion does not alter our baseline results (Table 11).

4. Conclusions

The growing role of China in Africa has raised several questions about what drives its lending policies, and which the effects on growth in recipient countries could be. A large literature looks at these questions, but less is known about the channels through which Chinese lending could promote

development. In this paper we explore one potential channel, which is participation in global value chains, facilitated by the reduction in trade costs, thanks to large infrastructure investments. As one of the key features of Chinese lending, compared to traditional bilateral and multilateral lenders, is the concentration in infrastructure sectors—particularly transport and communications—we investigate whether Chinese loans are associated with an increase in GVC participation in African countries.

Our results, based on loan level data on Chinese and World Bank lending in 37 African countries between 2000 and 2018, provide several original contribution to the existing evidence. First, we show that Chinese lending—and especially infrastructure lending—is followed by a significant and persistent increase in GVC participation. This result is specific to Chinese lending and is not visible looking at similar data on World Bank loans. Second, we disentangle between the downstream and the upstream components and we find that the positive association between Chinese lending and GVC participation is driven by the increase in the downstream component, which denotes a specialization

in phases closer to final demand (e.g., use of imported intermediates to produce final goods for exports) and could contribute to export and productivity growth. Third, we exclude that the increase in GVC participation would only strengthen trade ties with China, showing that Chinese lending is positively associated with GVC participation also when excluding China.

Our empirical analysis contributes to an increasingly large stream of literature aimed at investigating the role of Chinese lending in large infrastructural projects in Africa, going beyond the diffused scepticism and the common misconceptions and contributing by adding evidence about the role that China could play in African development. African countries have a massive need for new infrastructures therefore showing that Chinese loans could facilitate involvement in GVCs and through that industrialization and job creation is a significant contribution to the complex and evolving presence of China in Africa.

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Table 1. Chinese lending and GVC participation, baseline results

	(1)	(2)	(3)	(4)	(5)
Dep. Var.: Δ GVC participation between t and	t+1	t+2	t+3	t+4	t+5
Chinese lending	0.0473* (0.026)	0.1021** (0.047)	0.1752*** (0.059)	0.2313*** (0.073)	0.1547** (0.069)
World Bank lending	-0.0111 (0.034)	-0.0176 (0.051)	-0.0032 (0.067)	-0.0151 (0.079)	0.0039 (0.089)
GDP growth (%)	0.0078 (0.024)	-0.0149 (0.040)	-0.0293 (0.039)	-0.0177 (0.043)	-0.0495 (0.049)
Institutional quality	-0.2831 (0.471)	-0.9549 (0.804)	-1.3271 (1.243)	-1.6657 (1.544)	-1.7995 (1.831)
Observations	651	614	577	539	503
R-squared	0.469	0.541	0.573	0.630	0.641
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS) to country i in year t . Both variables are transformed using the inverse hyperbolic sine. GDP growth is the annual percent change in real GDP in country i in year t . Institutional quality measures the quality of contract enforcement, property rights and the likelihood of crime and violence (the Rule of Law index from the World Bank World Governance Indicators). Each specification includes country and year fixed effects. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 2. Chinese infrastructure lending and GVC participation

	(1)	(2)	(3)	(4)	(5)
Dep. Var.: Δ GVC participation between t and	t+1	t+2	t+3	t+4	t+5
Chinese infrastructure lending	0.0279 (0.031)	0.1118* (0.063)	0.1709** (0.070)	0.2063*** (0.074)	0.1098 (0.068)
Chinese lending, other	0.0833** (0.031)	0.0603 (0.049)	0.0828 (0.055)	0.0748 (0.076)	0.0658 (0.071)
World Bank infrastructure lending	-0.0117 (0.031)	-0.0432 (0.044)	-0.0203 (0.049)	-0.0230 (0.042)	0.0145 (0.058)
World Bank lending, other	-0.0033 (0.034)	0.0196 (0.045)	-0.0283 (0.059)	-0.0346 (0.066)	-0.0406 (0.082)
Observations	651	614	577	539	503
R-squared	0.472	0.544	0.574	0.628	0.640
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS), to infrastructure (transport, energy, water and communication) or to other sectors, to country i in year t . These four variables are transformed using the inverse hyperbolic sine. Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality, as in Table 1. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3. Chinese lending to transport and communication infrastructures and GVC participation

Dep. Var.: Δ GVC participation between t and	(1) t+1	(2) t+2	(3) t+3	(4) t+4	(5) t+5
Chinese lending to transport and communication sectors	0.0240 (0.029)	0.1084* (0.057)	0.1171** (0.057)	0.1704** (0.071)	0.0808 (0.074)
Chinese lending to water and energy sectors	0.0127 (0.048)	0.0613 (0.064)	0.1586* (0.089)	0.1736* (0.097)	0.1223 (0.099)
Chinese lending, other sectors	0.0825** (0.031)	0.0577 (0.051)	0.0913 (0.057)	0.0812 (0.076)	0.0714 (0.073)
World Bank lending to transport and communication sectors	-0.0309 (0.030)	-0.0756 (0.050)	-0.0853 (0.061)	-0.0691 (0.067)	-0.0953 (0.075)
World Bank lending to water and energy sectors	-0.0036 (0.031)	-0.0191 (0.044)	0.0216 (0.045)	-0.0145 (0.045)	0.0562 (0.052)
World Bank lending, other sectors	-0.0016 (0.035)	0.0240 (0.044)	-0.0256 (0.057)	-0.0296 (0.064)	-0.0345 (0.079)
Observations	651	614	577	539	503
R-squared	0.473	0.546	0.577	0.630	0.642
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS), to infrastructure (transport and communication, and energy and water) or to other sectors, to country i in year t . These four variables are transformed using the inverse hyperbolic sine. Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality, as in Table 1. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4. Chinese lending and GVC participation: downstream and upstream components

Dep.Var : Δ GVC participation between t and	(1)	(2)	(3)	(4)	(5)
	t +1	t+2	t+3	t+4	t+5
Panel A. Downstream component					
Chinese lending	0.0410 (0.028)	0.0924** (0.041)	0.1179** (0.044)	0.1918*** (0.068)	0.1583** (0.064)
World Bank lending	-0.0497 (0.035)	-0.0542 (0.044)	-0.0583 (0.068)	-0.0921 (0.076)	-0.0607 (0.083)
R-squared	0.366	0.143	0.472	0.523	0.567
Panel B. Upstream component					
Chinese lending	0.0062 (0.030)	0.0097 (0.042)	0.0573 (0.050)	0.0395 (0.063)	-0.0036 (0.078)
World Bank lending	0.0385 (0.026)	0.0366 (0.040)	0.0550 (0.051)	0.0770 (0.056)	0.0646 (0.067)
R-squared	0.366	0.409	0.520	0.593	0.662
Observations	651	614	577	539	503
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in the downstream (Panel A) or upstream (Panel B) component of GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS) to country i in year t . Both variables are transformed using the inverse hyperbolic sine. Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality, as in Table 1. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5. Chinese infrastructure lending and GVC participation: downstream and upstream components

Dep.Var : Δ GVC participation between t and	(1)	(2)	(3)	(4)	(5)
	t +1	t+2	t+3	t+4	t+5
Panel A. Downstream component					
Chinese infrastructure lending	0.0210 (0.026)	0.0854* (0.049)	0.1367** (0.052)	0.1798*** (0.059)	0.1724*** (0.059)
Chinese lending other	0.0490 (0.033)	0.0504 (0.044)	0.0306 (0.057)	0.0712 (0.092)	0.0649 (0.094)
World Bank infrastructure lending	-0.0123 (0.023)	-0.0341 (0.040)	-0.0441 (0.046)	-0.0674 (0.052)	-0.0560 (0.064)
World Bank lending other	-0.0507* (0.028)	-0.0421 (0.034)	-0.0687 (0.053)	-0.0914 (0.060)	-0.1059 (0.064)
R-squared	0.367	0.414	0.475	0.524	0.570
Panel B. Upstream component					
Chinese infrastructure lending	0.0070 (0.030)	0.0264 (0.048)	0.0342 (0.044)	0.0265 (0.050)	-0.0627 (0.061)
Chinese lending, other	0.0343 (0.039)	0.0099 (0.052)	0.0522 (0.064)	0.0036 (0.087)	0.0009 (0.081)
World Bank infrastructure lending	0.0006 (0.029)	-0.0091 (0.042)	0.0238 (0.045)	0.0445 (0.041)	0.0705 (0.048)
World Bank lending, other	0.0474* (0.028)	0.0617* (0.036)	0.0405 (0.041)	0.0568 (0.055)	0.0653 (0.056)
R-squared	0.368	0.411	0.520	0.593	0.664
Observations	651	614	577	539	503
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in the downstream (Panel A) or upstream (Panel B) component of GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS) to country i in year t . Both variables are transformed using the inverse hyperbolic sine. Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality, as

in Table 1. Standard errors, clustered at the country level, are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6. Chinese infrastructure lending and GVC participation: IV estimates

Dep.Var : Δ GVC participation between t and	(1)	(2)	(3)	(4)	(5)
	t +1	t+2	t+3	t+4	t+5
Panel A. GVC Participation					
Chinese infrastructure lending	0.1105 (0.092)	0.2783* (0.146)	0.4328* (0.222)	0.5583* (0.275)	0.6241* (0.321)
Panel B. GVC participation, downstream component					
Chinese infrastructure lending	0.1991** (0.092)	0.4160** (0.187)	0.5562* (0.298)	0.7270* (0.425)	0.8101 (0.492)
1st stage F-statistic	23.5317	23.4737	23.6649	31.7760	33.3382
Overidentification test (p-value)	0.2111	0.5857	0.8118	0.8160	0.8297
Observations	651	614	577	539	503
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents instrumental variable estimates of equation 1, where Chinese lending is instrumented as in equation 2. Please see text (Section 3) for additional details. The dependent variable is the forward change in GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese infrastructure lending variable is measured by the amount of lending (in UDS) to infrastructure (transport, energy, water and communication) to country i in year t . The variable is transformed using the inverse hyperbolic sine. Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality. The F-statistics refers to the Kleibergen-Paap first stage F-test for weak identification, while the overidentification tests reports the p-value of the Hansen J statistic. Standard errors, clustered at the country level, are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7. Chinese lending and GVC participation: excluding Angola

Dep.Var : Δ GVC participation between t and	(1)	(2)	(3)	(4)	(5)
	t +1	t+2	t+3	t+4	t+5
Panel A. Total Tending					
Chinese lending	0.0422	0.1004**	0.1809***	0.2334***	0.1546**
	(0.026)	(0.048)	(0.060)	(0.074)	(0.070)
World Bank lending	0.0039	-0.0027	0.0028	-0.0020	0.0123
	(0.032)	(0.052)	(0.072)	(0.082)	(0.095)
R-squared	0.469	0.539	0.570	0.627	0.637
Panel B. Infrastructure lending vs to other sectors					
Chinese infrastructure lending	0.0339	0.1124*	0.1766**	0.2138**	0.1205*
	(0.032)	(0.066)	(0.074)	(0.079)	(0.071)
Chinese lending, other	0.0616**	0.0546	0.0967	0.0722	0.0519
	(0.027)	(0.055)	(0.059)	(0.082)	(0.074)
World Bank infrastructure lending	-0.0144	-0.0429	-0.0241	-0.0168	0.0194
	(0.032)	(0.045)	(0.051)	(0.044)	(0.061)
World Bank lending, other	0.0123	0.0306	-0.0223	-0.0286	-0.0415
	(0.033)	(0.046)	(0.062)	(0.069)	(0.085)
R-squared	0.471	0.542	0.571	0.625	0.636
Observations	633	597	561	524	489
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The sample exclude Angola, which is the largest recipient of Chinese lending. The dependent variable is the forward change in GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS), to all sectors (Panel A) or to infrastructure (transport, energy, water and communication) and other sectors (Panel B), to country i in year t . These variables are transformed using the inverse hyperbolic sine. Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality, as in Table 1. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 8. Chinese lending and GVC participation: flows scaled by GDP

Dep.Var : Δ GVC participation between t and	(1)	(2)	(3)	(4)	(5)
	t +1	t+2	t+3	t+4	t+5
Panel A. Total Tending					
Chinese lending (% GDP)	0.0518* (0.026)	0.1348*** (0.045)	0.2614** (0.124)	0.4226** (0.167)	0.2623 (0.173)
World Bank lending (% GDP)	0.0031 (0.022)	-0.0276 (0.028)	-0.0452 (0.053)	-0.0647 (0.045)	-0.0700 (0.048)
R-squared					
Panel B. Infrastructure lending vs to other sectors					
Chinese infrastructure lending (% GDP)	0.0117 (0.051)	0.1262 (0.097)	0.2785* (0.152)	0.4721** (0.178)	0.2456 (0.189)
Chinese lending, other (% GDP)	0.1057*** (0.039)	0.1479** (0.068)	0.0845 (0.293)	0.1995 (0.341)	0.3353 (0.330)
World Bank infrastructure lending (% GDP)	0.0178 (0.038)	-0.0330 (0.051)	-0.0279 (0.078)	-0.0949 (0.084)	-0.0626 (0.070)
World Bank lending, other (% GDP)	-0.0041 (0.023)	-0.0242 (0.028)	-0.0557 (0.049)	-0.0489 (0.041)	-0.0736 (0.048)
R-squared	0.469	0.541	0.569	0.627	0.641
Observations	633	597	561	524	489
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (scaled by GDP), to all sectors (Panel A) or to infrastructure (transport, energy, water and communication) and other sectors (Panel B), to country i in year t . These variables are transformed using the inverse hyperbolic sine. Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality, as in Table 1. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 9. Chinese lending and GVC participation: excluding linkages with China

Dep. Var.: Δ GVC participation between t and	(1) t+1	(2) t+2	(3) t+3	(4) t+4	(5) t+5
Chinese lending	0.0501* (0.026)	0.1059** (0.046)	0.1795*** (0.059)	0.2401*** (0.078)	0.1772** (0.078)
World Bank lending	-0.0107 (0.032)	-0.0203 (0.049)	-0.0135 (0.070)	-0.0316 (0.084)	-0.0071 (0.090)
Observations	651	614	577	539	503
R-squared	0.427	0.500	0.536	0.592	0.603
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in GVC participation for country i , calculated excluding linkages with China and as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS) to country i in year t . Both variables are transformed using the inverse hyperbolic sine. Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality, as in Table 1. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 10. Chinese lending and GVC participation: controlling for the initial values

	(1)	(2)	(3)	(4)	(5)
Dep. Var.: Δ GVC participation between t and	t+1	t+2	t+3	t+4	t+5
Chinese lending	0.0413 (0.025)	0.0842* (0.048)	0.1546** (0.057)	0.1893*** (0.068)	0.1234* (0.065)
World Bank lending	-0.0192 (0.033)	-0.0305 (0.050)	-0.0337 (0.058)	-0.0384 (0.064)	-0.0206 (0.066)
GVC participation	-0.1421*** (0.038)	-0.2513*** (0.054)	-0.3574*** (0.065)	-0.4562*** (0.079)	-0.5647*** (0.089)
R-squared	0.514	0.607	0.657	0.722	0.750
Chinese infrastructure lending	0.0135 (0.029)	0.0719 (0.059)	0.1310** (0.063)	0.1631** (0.068)	0.0833 (0.060)
Chinese lending, other	0.0871*** (0.030)	0.0726 (0.047)	0.0898* (0.051)	0.0567 (0.066)	0.0467 (0.046)
World Bank infrastructure lending	-0.0099 (0.028)	-0.0418 (0.040)	-0.0164 (0.045)	-0.0114 (0.035)	0.0075 (0.049)
World Bank lending, other	-0.0070 (0.032)	0.0158 (0.042)	-0.0436 (0.050)	-0.0402 (0.053)	-0.0381 (0.064)
GVC participation	-0.1422*** (0.038)	-0.2496*** (0.055)	-0.3560*** (0.065)	-0.4566*** (0.079)	-0.5654*** (0.089)
R-squared	0.517	0.608	0.657	0.721	0.749
Observations	651	614	577	539	503
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS), to all sectors (Panel A) or to infrastructure (transport, energy, water and communication) and other sectors (Panel B), to country i in year t . These variables are transformed using the inverse hyperbolic sine. GVC participation is the initial value in year t . Each specification includes country and year fixed effects, the annual percent change in real GDP, and the measure of institutional quality, as in Table 1. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 11. Chinese lending and GVC participation: additional controls

Chinese lending	0.0341	0.1079**	0.1988***	0.2582***	0.1806**
	(0.023)	(0.048)	(0.058)	(0.065)	(0.070)
World Bank lending	0.0086	-0.0181	-0.0063	-0.0146	0.0198
	(0.029)	(0.045)	(0.064)	(0.079)	(0.089)
GDP growth (%)	0.0087	-0.0225	-0.0096	-0.0023	-0.0367
	(0.023)	(0.043)	(0.050)	(0.049)	(0.051)
Rule of law	-0.5295	-1.1856	-1.8032	-2.4352	-2.7796
	(0.478)	(0.815)	(1.258)	(1.502)	(1.756)
FDI stock (% GDP)	-0.0012	-0.0041*	-0.0037	-0.0075*	-0.0097
	(0.002)	(0.002)	(0.003)	(0.004)	(0.007)
Bilateral trade agreements with China (0/1)	-0.1954	-0.3946	-0.8639	-0.7180	-0.3248
	(0.302)	(0.667)	(1.043)	(1.178)	(1.321)
Human capital index	1.1167	2.3717	4.7848	7.3769	8.8448
	(0.811)	(2.066)	(3.593)	(5.514)	(8.272)
Mineral rents (% of GDP)	-0.0197	-0.0419	-0.0570	-0.0745	-0.0504
	(0.013)	(0.025)	(0.050)	(0.076)	(0.090)
R-squared	0.517	0.563	0.584	0.647	0.661
Chinese infrastructure lending	0.0203	0.1153*	0.1719**	0.2122***	0.1044
	(0.032)	(0.064)	(0.071)	(0.073)	(0.068)
Chinese lending, other sectors	0.0757**	0.0637	0.1205**	0.1055	0.0989
	(0.030)	(0.044)	(0.055)	(0.077)	(0.077)
World Bank infrastructure lending	-0.0154	-0.0459	-0.0441	-0.0366	0.0094
	(0.034)	(0.048)	(0.056)	(0.047)	(0.062)
World Bank lending, other sectors	0.0243	0.0260	-0.0196	-0.0153	0.0019
	(0.029)	(0.037)	(0.059)	(0.070)	(0.084)
GDP growth (%)	0.0084	-0.0245	-0.0085	-0.0025	-0.0363
	(0.023)	(0.044)	(0.050)	(0.049)	(0.052)
Rule of law	-0.5230	-1.1859	-1.7453	-2.3054	-2.7394
	(0.483)	(0.825)	(1.265)	(1.527)	(1.796)
FDI stock (% GDP)	-0.0010	-0.0037	-0.0033	-0.0072*	-0.0097
	(0.002)	(0.002)	(0.003)	(0.004)	(0.007)
Bilateral trade agreements with China (0/1)	-0.2183	-0.4117	-0.8872	-0.7111	-0.2734
	(0.310)	(0.666)	(1.064)	(1.222)	(1.355)

Human capital index	1.2172 (0.803)	2.3933 (2.053)	4.8004 (3.630)	6.9083 (5.715)	8.4719 (8.532)
Mineral rents (% of GDP)	-0.0186 (0.012)	-0.0412 (0.025)	-0.0546 (0.051)	-0.0723 (0.078)	-0.0476 (0.093)
R-squared	0.522	0.567	0.585	0.644	0.658
Observations	593	560	527	494	461
Country FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y

Notes: The table presents OLS estimates of equation 1. The dependent variable is the forward change in GVC participation for country i , calculated as difference between year t and year $t+n$, where n is indicated in the column header. The Chinese and World Bank lending variables are measured as the amount of lending (in UDS), to all sectors (Panel A) or to infrastructure (transport, energy, water and communication) and other sectors (Panel B), to country i in year t . These variables are transformed using the inverse hyperbolic sine. GDP growth is the annual percent change in real GDP in country i in year t . Institutional quality measures the quality of contract enforcement, property rights and the likelihood of crime and violence in country i in year t (the Rule of Law index from the World Bank World Governance Indicators). FDI stock is the stock of inward FDI country i in year t , as a share of GDP. Rule of law is a measure of the extent to which agents have confidence in and abide by the rules of society, from the World Governance Indicators. The bilateral trade agreements with China is a dummy variable equal to 1 if a trade agreement between country i and China is in place in year t , and zero otherwise. Each specification includes country and year fixed effects. Standard errors, clustered at the country level, are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Appendix

Table A.1. Sector classification

CLA Database	World Bank Database	Our aggregation
Agriculture	Agriculture; Fishing and Forestry	Agriculture and Mining
Banking	Financial Sector	Services
Communication	Information and Communications Technologies	Transport and Communication
Education	Education	Social
Environment	Environment	Other
Government	Public Administration	Government
Health	Health	Social
Industry	Industry	Manufacturing
Mining	Mining; Oil and Gas	Agriculture and Mining
Multisector	Multisector; Private Sector Development	Other
Other social	Social Protection	Social
Power	Energy and Extractives	Power and Water
Trade	Trade and Services	Services
Transport	Transportation	Transport and Communication
Unallocated	Economic Policy	Other
Water	Water	Power and Water

Source: CLA and World Bank Projects and Operations database

Table A.2. Chinese Loans by Sector (2000-2018)

Country			Distribution of value by sector (%)							
	# Loans	Value US\$ millions	Transport & Communication	Power & water	Manufacturing	Agriculture & Mining	Social	Government	Services	Other
Algeria	2	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Angola	255	39146	19.3	11.9	0.0	48.2	10.2	1.4	0.3	8.5
Botswana	13	931	4.6	88.6	0.0	0.0	6.0	0.0	0.0	0.8
Burundi	2	45	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cameroon	44	5933	49.0	37.2	0.2	0.0	5.2	7.3	0.0	1.1
Cape Verde	5	49	0.0	0.0	0.0	0.0	6.1	61.2	26.5	6.1
CAR	6	35	0.0	51.4	0.0	0.0	0.0	11.4	17.1	20.0
Chad	3	247	10.1	52.6	37.2	0.0	0.0	0.0	0.0	0.0
Cote d'Ivoire	20	2791	39.9	52.4	0.0	0.0	3.6	2.9	0.0	1.1
Djibouti	8	1298	73.0	26.3	0.0	0.0	0.0	0.0	0.0	0.6
Egypt	13	4021	0.0	17.2	0.4	0.0	1.5	24.9	42.3	13.8
Gabon	24	1344	37.1	33.7	0.0	0.0	21.1	0.5	0.0	7.5
Ghana	37	3671	15.1	73.1	0.0	0.0	4.3	5.8	0.9	0.8
Kenya	40	9048	64.7	21.7	0.0	0.8	2.4	1.9	1.6	7.0
Lesotho	2	106	92.5	0.0	0.0	0.0	0.0	0.0	0.0	7.5
Liberia	2	55	90.9	0.0	0.0	0.0	0.0	0.0	0.0	9.1
Madagascar	6	456	45.0	43.2	0.0	0.0	11.0	0.0	0.0	0.9
Malawi	4	262	8.8	0.0	0.0	0.0	91.2	0.0	0.0	0.0
Mali	10	964	65.7	25.7	1.9	0.0	0.0	0.0	0.0	6.7
Mauritania	6	431	88.4	0.0	0.0	0.0	0.0	0.0	0.0	11.6
Mauritius	21	489	58.3	28.8	0.0	0.0	4.5	0.0	1.2	7.2
Morocco	9	1182	15.6	39.0	0.0	0.1	1.1	0.0	0.0	44.2
Mozambique	19	2269	73.8	0.0	2.6	7.5	4.2	11.4	0.0	0.5
Namibia	12	546	30.4	0.0	0.0	42.7	4.8	2.4	18.3	1.5
Niger	6	351	34.8	35.9	0.0	29.3	0.0	0.0	0.0	0.0
Nigeria	16	6176	62.3	26.0	0.0	0.0	0.0	11.8	0.0	0.0
Rwanda	13	415	83.4	0.0	0.0	0.0	0.0	0.5	0.0	16.1
Senegal	16	1886	72.0	19.7	1.2	0.0	0.0	6.9	0.0	0.2
Seychelles	6	35	31.4	2.9	0.0	0.0	65.7	0.0	0.0	0.0
Sierra Leone	7	230	91.7	1.3	0.0	0.0	0.0	7.0	0.0	0.0
South Africa	17	3220	49.4	43.5	0.0	0.0	0.0	7.1	0.0	0.0
Tanzania	12	2043	17.1	57.2	0.0	0.0	0.7	23.7	0.0	1.2
The Gambia	1	25	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Togo	14	634	80.1	12.9	0.0	0.0	0.0	3.9	0.0	3.0
Tunisia	7	131	97.7	0.0	0.0	0.0	0.0	0.0	0.0	2.3
Uganda	14	2863	27.0	70.3	0.0	0.0	1.4	0.0	0.0	1.3
Zambia	62	7318	49.6	19.0	2.3	0.2	7.3	20.6	1.0	0.0
Total	754	100655	35.9	24.5	0.4	19.3	6.2	5.9	2.2	5.6

Notes: In bold the ten largest recipient countries Source: CLA database

Table A.3. World Bank Loan by Sector (2000-2018)

Country	# Loans	Value US \$ millions	Distribution of value by sector (%)							
			Transport & Communication	Power & Water	Manufacturing	Agriculture & Mining	Social	Government	Services	Other
Algeria	11	480	35.9	0.0	23.5	0.1	26.1	12.7	1.7	0.0
Angola	24	3093	4.3	33.0	0.0	12.1	21.7	28.9	0.0	0.0
Botswana	7	2521	15.3	81.9	0.0	0.8	2.0	0.0	0.0	0.0
Burundi	56	1795	7.7	21.8	0.0	11.3	32.6	21.3	5.3	0.0
Cameroon	58	5545	10.2	53.8	2.0	10.1	14.4	9.5	0.0	0.0
Cape Verde	31	404	24.7	14.7	5.0	0.0	8.4	46.1	1.1	0.0
CAR	43	700	8.4	8.9	3.4	1.2	41.8	34.9	1.4	0.0
Chad	41	1548	10.8	11.1	0.0	18.1	30.5	29.4	0.0	0.1
Cote d'Ivoire	55	4329	19.4	22.9	16.2	5.4	15.1	20.7	0.4	0.0
Djibouti	45	408	10.3	33.8	4.2	4.0	36.4	10.1	1.2	0.0
Egypt	65	30576	6.0	41.9	3.9	3.4	26.3	8.2	10.3	0.0
Gabon	15	825	23.2	7.3	2.2	8.5	12.1	46.7	0.0	0.0
Ghana	114	9863	19.6	18.1	1.2	6.9	20.7	31.1	2.3	0.0
Kenya	102	14088	13.2	34.9	0.5	7.0	31.2	11.9	1.1	0.1
Lesotho	34	582	12.3	13.1	4.9	7.4	37.5	24.9	0.0	0.0
Liberia	88	2278	45.9	12.6	0.0	3.2	7.1	29.1	2.2	0.0
Madagascar	82	4450	30.8	5.2	10.9	11.3	15.9	23.9	2.1	0.0
Malawi	71	4450	4.4	16.2	2.6	21.3	36.1	16.1	3.4	0.0
Mali	77	3640	9.2	13.7	7.9	20.6	29.4	17.2	1.7	0.1
Mauritania	46	1299	19.6	14.6	3.7	6.2	36.8	19.1	0.0	0.0
Mauritius	17	444	18.3	5.8	17.6	0.0	9.0	47.9	1.4	0.0
Morocco	87	18089	8.7	51.0	8.1	5.0	15.9	4.9	6.5	0.0
Mozambique	118	8365	26.9	23.6	1.5	5.5	23.1	18.0	1.4	0.0
Namibia	9	192	0.0	0.2	0.0	19.1	63.2	17.3	0.0	0.3
Niger	72	3298	8.2	24.5	2.1	15.6	26.9	21.2	1.5	0.0
Nigeria	129	23164	6.8	21.3	2.4	9.7	38.0	17.6	4.2	0.0
Rwanda	85	4248	5.7	17.4	7.9	17.2	24.0	22.7	5.0	0.0
Senegal	90	6589	24.1	21.2	3.7	4.1	31.4	13.0	0.0	2.5
Seychelles	13	58	3.7	12.9	12.1	7.2	20.8	27.7	15.6	0.0
Sierra Leone	86	1420	9.5	21.5	5.8	4.2	19.5	34.2	5.3	0.0
South Africa	17	12265	0.0	98.2	0.0	0.9	0.0	0.2	0.8	0.0

Tanzania	121	20376	12.0	19.0	1.2	6.1	45.8	13.6	1.5	0.7
The	33	554	5.0	25.3	2.2	9.1	40.6	16.9	0.9	0.0
Gambia										
Togo	46	855	0.2	24.1	3.9	9.8	22.2	38.4	1.4	0.0
Tunisia	63	7456	10.5	7.1	18.8	9.8	13.0	30.1	10.7	0.0
Uganda	109	10019	14.1	28.8	1.0	13.4	13.4	28.1	1.1	0.0
Zambia	71	3047	24.0	20.8	4.0	11.8	25.1	12.8	1.5	0.0
Total	2231	21331	11.6	32.4	3.9	7.5	25.1	15.6	3.8	0.2
		2								

Notes: In bold the ten largest recipient countries Source: World Bank Projects and Operations database

Notes

¹ The COVID19 pandemic impacted both developing countries' ability to borrow and China's willingness to lend. Moreover, the conflict in Ukraine is affecting Chinese overseas lending given that China's state-owned banks have traditionally invested in and lent heavily to Russia, Ukraine, and Belarus (Horn et al. 2022).

² The sample includes Algeria, Angola, Botswana, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Cote d'Ivoire, Djibouti, Egypt, Gabon, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, South Africa, Tanzania, The Gambia, Togo, Tunisia, Uganda, and Zambia. The main constraint in defining the sample is the availability of UNCTAD-Eora data on GVC participation, which are not available for some African countries (e.g., Ethiopia).

³ The China Africa Research Initiative is based at Johns Hopkins University's School of Advanced International Studies (SAIS-CARI). As of March 2021, the CLA Database is managed by the Boston University Global Development Policy (GDP) Center. Data are now available at [bu.edu](https://datacatalog.worldbank.org) and were accessed in November 2020.

⁴ Data are available at <https://datacatalog.worldbank.org>, accessed in November 2020

⁵ Angola accounts for approximately 30 percent of all Chinese loan commitments to the region over the past decade, with a peak in 2016. The volume and modalities of Chinese lending to Angola differ from China's lending to other African countries in some important ways. Most Chinese lending to Angola is secured by oil exports, while aside from Angola, only 8 percent of Chinese lending in Africa is secured by future flows of natural resources (Acker and Brautigam 2021). After a peak in 2016, Angola has registered a sharp decline in Chinese loans in recent years, due to the effort of trying to diversify its external partnership away from an over dependence on China (Vines et al. 2022).

⁶ Table A.1 shows how the original sector classifications in the two databases are aggregated in our analysis.

⁷ See the Financial Times article: China applies brakes to African lending published in January 11, 2022

⁸ For example, in a key sector for African economy, such as agri-food, downstream activities (processing, marketing and retail) are expected to generate eight times higher productivity than farming (Tschirley et al. 2015).

⁹ The database is available at <https://worldmrrio.com>

¹⁰ Overall, the Chinese loans to the countries included in our sample amount to 100.6 US\$ billion, that is around two thirds of the entire value directed to the African continent, equal to 153 US\$ billion.

¹¹ The inverse hyperbolic sine of a variable x is equal to $\ln(x + \sqrt{x^2 + 1})$. The IHS transformation behaves like a logarithm transformation, but it allows retaining zero-valued observations (Bellemare and Wichman 2020). Results are robust to scaling lending flows over GDP.

¹² Clustered standard errors deliver conservative estimates. Using robust standard errors deliver more precise estimates.

¹³ Results are robust to excluding all controls and focusing only on Chinese and World Bank lending

¹⁴ Data on bilateral trade agreements are sourced from UNCTAD, at: <https://investmentpolicy.unctad.org/international-investment-agreements>

Economic and social upgrading in Costa Rica from policies to reach export diversification

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Abstract

There have been a continuous effort in Costa Rica in the last decades to promote a structural change through the economic diversification of exports aimed to reach economic and social upgrading in the country. In this paper we examine the strategy of economic diversification and capabilities building in the country, considering the rationality of the main policies along the time that permitted to Costa Rica to successfully integrate with the global economy and to build new sources of competitive advantage. We include in the analysis the changes in the policy framework, specially those taking advantage of new windows of technological, learning, or sectoral opportunities, in order to break the middle technology and income trap. The theoretical framework considers the global value chain and the system of innovation approaches but also the middle income trap approach to make the analysis of economic and social upgrading of the Costa Rican Economy.

Key Words: Theme of the conference: Economic and social upgrading for sustainable Catch-up: trade policies, FDI, value chains and innovation networks in a knowledge-driven economy

Introduction

In this document we make a historical analysis of the changes that Costa Rica has been promoting to improve their living conditions, going from a model of import substitution, which once it was considered exhausted, was moving to a model of opening up the economy. and promotion of exports, combined with the attraction of foreign investment, applying a series of policies in successive phases.

In this directions, There have been a continuous effort in Costa Rica in the last decades to promote a structural change trough the economic diversification of exports aimed to reach economic and social upgrading. In this paper we examines the strategy of economic diversification and capabilities building in the country, considering the rationality of the main policies along the time that permitted to Costa Rica to successfully integrate with the global economy and to build new sources of competitive advantage. We include in the analysis the changes in the policy framework, especially those taking advantage of new windows of technological, learning, or sectoral opportunities, in order to break the middle technology and income trap. The theoretical framework consider the global value chain and the system of innovation approaches but also the middle income trap approach to make the analysis of economic and social upgrading of the Costa Rican Economy.

In the following section we introduce a theoretical framework. In section 2 we explain the crisis of the import substitution model and structural adjustment programs. In section 3 we discuss the policies in the first phase of export promotion and diversification programs. In section 4 we include the analysis of the policies to attract foreign direct investment, mainly in high technologies. In section 5 we develop the analysis of the main institutional changes in the new phase of the model. In section 6 we include some indicator of the programs. And finally, in sections 7, we introduce some conclusions.

1. Theoretical and methodological framework: rationality of export promotion policies from innovation system, global value change and middle income trap approaches

a. Theoretical framework

There is a wide literature considering the phenomena known as the “middle income trap” (MIT) and the possible strategies to move towards high income possibilities (Gill and Kharas, 2007). It is convenient to considering this literature for the analysis of the possibilities of economic and social upgrading in a country.

The main argument is that when a country cannot grow fast, it is difficult to reach economic and social upgrading. Because of that, it is necessary to promote changes in the model of development. There are different options to promote the necessary changes. We consider in here the options of programs from the rationality of global value change or the option of policies from system of innovation approaches. There is also the possibility to combine both approaches. As suggested by Perez-Sebastian, 2007; Agenor and Canuto, 2012; Agenor et al (2012), when some countries reach the middle-income level, the pool of unemployed and underemployed rural workers drain out, wages start to rise, but an significant problem is that benefits from imitation and importing foreign mature technologies decrease in importance. The result is then that the capital accumulation starts to show decreasing returns and difficulties to grasp further scale economies.

The empirical literature on the MIT suggests the relevant roles of capabilities, structural change and technological progress as the key factors able to better positioning a middle income country moving to better conditions (Vivarelli, 2014). A key point in the literature is that changing the structure of the economy (diversification from low productivity sectors into high- productivity ones) and on the types of product exported are the most important drivers in the strategies to overcome MIT (Gill and Bhattasali, 2007). Hidalgo and Hausmann (2009) understand economic development as a process based on building capabilities and learning capacities as the center of the strategy to produce and export more complex and sophisticated goods throughout a continuous process of diversification, product differentiation and product up-grading.

It is important to consider that capability building and catch-up by domestic firms depend greatly upon the nature and features of innovation systems and it is necessary to consider the heterogeneous nature of the knowledge base, the specificity of the national, sectoral, and regional contexts, and the role of institutions in which innovative activities occur (Malerba and Lee, 2021). Strong efforts to promote innovation and structural change in the export sector, are then necessary and it is then necessary to strengthen the system of innovation.

In the innovation system approach, the set of interrelated components is understood as a system working towards a common objective (Carlsson et al, 2002). Therefore, the set of parts and aspects of the economic structure and institutional set-up that affect learning and research are understood as the Innovation System (Lundvall, 1992). Innovation policy is then understood as an element of strategic coordination between the pressure of transformation, the ability to innovate and adapt to change, and the cost-benefits of that change with its respective social and spatial distribution (Lundvall, 2002). The comprehensive analysis of a national innovation system transcends the economic or financial

sphere and reaches other institutional frameworks. The rationality of innovation policies refers to the background that is in this process and responds to why, when, and how to intervene in innovation processes (Lundvall, Chaminade and Haneef, 2018).

Chaminade and Edquist (2010) understand innovation policies as those public actions that drive innovation processes, both for development and dissemination processes. They can be oriented to both economic and non-economic objectives. Edquist (2014, p. 191) and Borrás and Edquist (2018) suggest ten basic objectives that an innovation system should fulfil. The rationality of innovation policies is based on trying to solve system problems. There are some failures in the system that hinders the possibility to reach these objectives. System problems to meet those objectives can usually be understood as problems of: infrastructure provision and investment problems; of transition; of "lock-in"; institutional; network problems; skills and learning; exploration-exploitation imbalance; complementarity problems (Chaminade and Edquist, 2010). Borrás and Edquist (2013), suggest a possible way to group policies and instruments to foster innovation, considering: regulations (intellectual property, regulations), economic transfers (competitive funds, exemptions), soft instruments (alliances, agreements). Orozco (2017) argues that to increase the efficiency of such policies and instruments, it is important to consider the geographical, sectoral or firm size specificities (there is a deeper analysis in Orozco, 2017 and in Orozco and Guillén, 2020).

Considering the analysis by Porter (1985), value chains have become a reference for the analysis of trade and industrial organisation. One of the main characteristics is a global strategy to organise the full range of activities that firms and workers perform to bring a product or service from its conception to end-use and beyond. The whole range of activities (design, production, marketing, distribution, and support to the final consumer) can be contained within a single firm or divided among different firms. There is now a highly flexible and dynamic context. The location of different activities is a key issue. The location of the activities is based on decisions about choices related to country differences in the cost of input factors, competitiveness drivers, social and environmental conditions, but also geographic and cultural proximity to the final consumer (Cattaneo et al., 2013).

One lesson in the global value chain (GVC) approach is the necessary paradigm shift from public to private impetus. In the new paradigm, trade and development policies should be increasingly designed and implemented in consultation and – where possible – in association with the private sector, moving from supply-side to demand-driven trade strategies. Three major intermediate objectives should be added to the trade competitiveness and development strategies: joining,

maintaining participation, and moving up value chains (Cattaneo et al., 2013). The challenge is hard, because of the heterogeneity of sectors, since the organisation of GVCs tends to be sector-specific (and sometimes even firm-specific), and there are no one-size-fits-all policies (Sturgeon and Memedovic, 2011).

The rationality of policies in GVC approaches is aimed mainly to facilitate trade. According to OECD (2012) and Cattaneo et al (2013), in the approach of GVC there are two main objectives for policies: suppressing/reducing obstacles to trade at the border, including trade facilitation (suppression of quotas and other quantitative restrictions on imports and exports; reduction of tariffs, suppression of tariff peaks, tariff escalation or simplification of tariff schedules; customs modernization and reform, harmonisation of procedures and cooperation across borders; simplification of customs procedures, including SPS, TBT, and other certifications, rules of origin, valuation, etc. to conform with relevant agreements or international best practices; implementation of WTO or regional/bilateral commitments), and increasing the accessibility and connectivity of the domestic market, and the security, predictability, reliability and efficiency of transports/logistics, telecommunications and ICT (reforms of the telecommunications sector, including infrastructure, regulation, competition, and access for all segments to include fixed lines and mobiles; development of the ICT sector and the Internet -infrastructure, regulation, competition, access-; reforms of the transport, logistics and ancillary services, including infrastructure, regulation, competition for land -road and rail, maritime/water and air; regional infrastructure for trade corridors, and other forms of regulatory harmonisation and cooperation).

More specific to innovation and building capacity, the approach recognizes that GVCs facilitate capacity constraints, since a country does not need to develop a fully integrated industry to participate in international trade. But capacities and productivity remain key factors for foreign investors and lead firms. In the new trade paradigm, adaptability to the lead firms' requests, responsiveness, and capability to innovate are also key factors (World Bank, 2010).

The potential of a country for GVC participation is determined by different aspects including capacity for scale production; availability of services necessary to support production and market integration; education and skills of the workforce matching the needs of global producers and buyers; and capacity for innovation in its multiple dimensions, including environment sustainability (Cattaneo, et al, 2013). In the new context, lead firms have to define strategies where innovation centres are decentralised. Lead firms need to innovate in developing countries, and solve their specific needs and eventually, they can bring the results back home, thereby contributing to boosting the developing countries' exports (Govindarajan and Trimble, 2012). This requires the host developing country to develop

innovation capacities, based on education and skills.

There is a strong connection between the policy approaches of innovation systems and GVC. It is clearer for the approach of sectoral systems of innovation. But it is also clear that for more geographical approaches of innovation systems, it is also necessary to consider both the challenges and the opportunities from the conditions of international trade. Most of the challenges for economic and social upgrading in GVC require strong innovation systems. The main differences could be in the objectives to promote in both approaches, but the kind of policy instruments seems to be similar in the national dimension. However, it is necessary to consider the strong focus of GVC on international trade and on the role of the private sector and the multinational firms.

b. Methodology:

For the analysis of the Costa Rican case, we use a historical approach, considering the set of policies in different phases. We started with a review of the literature and include some data to show the main changes in the economy, as a result of the change in the developing model.

2. The crisis of the import substitution model and structural adjustment programs

For several decades, starting in the 1950s, Costa Rica developed a state apparatus focused on improving the living conditions of the population, attending at different times to the social demands of the population and leading to the development policy becoming a key component to promote a virtuous circle of economic growth with social equity. This style of development was inspired by Keynesian approaches and the ideas of the Welfare State, which were reflected in expansive monetary and fiscal policies aimed at developing the industrial sector through public investments in infrastructure, tariff protection policies and various incentives for industrial production, with clear features of an import substitution industrialization model (for a detailed analysis, see Arias and Muñoz, 2007).

This industrialisation model achieved significant improvements in the living conditions of the population. However, the model began presenting several contradictions and eventually emerged a strong crisis that affected economic growth, political stability, and the possibility of continuing to improve the population's welfare in a sustained manner. As stated by Furst (1986) and Sojo (1984), the problems in the development style were connected to several factors such as: the impact of higher oil prices after the creation of OPEC, the external debt crisis, adverse conditions in the international economy, a growing fiscal crisis and the inconsistency and lack of consensus in the management of economic policy,

especially in the period 1978-1982. This set of internal and external situations led to a deep crisis in the years 1979 to 1982, with a clear economic recession and increases in unemployment and poverty levels which, together with the problems of a high external debt, the deterioration of the terms of trade and the high deficit in the balance of payments, imposed the urgency of a change in policies to promote the country's development (Arias, 1992).

As a result of the bilateral negotiation processes with the International Monetary Fund (IMF) and the World Bank (WB) during the 1982-1986 period, the objective was to obtain financial resources to promote the stabilisation and reactivation of the country's economy. A slow recovery of the main macroeconomic indicators was achieved (Herrero and Rodríguez, 1987) and a new development model was introduced, focused on promoting exports of non- traditional products to third markets (Arias and Muñoz, 2007).

In 1982, with the signing of the first agreement with the IMF, the country began a process of economic reforms structured based on a sequence of IMF and WB cross conditionality, expressed in their stabilisation and structural adjustment programs, respectively.

The collective application of these programs is what has been called structural adjustment. In 1985, with the signing of the first Structural Adjustment Program (SAP), together with the agreements with the IMF and the World Bank, the path of the country's economic reform was defined by a structural adjustment and opening to the international market, through the promotion of export. In addition to the objectives of addressing the compliance of depth payments by increasing exports and reducing public expenditure, restructuring the state apparatus, generating foreign exchange to meet the country's commitments, and restructuring the production to promote the exportable production of non-traditional products to third markets through monetary and fiscal incentives (Arias and Muñoz, 2007).

The implementation of the new strategies gradually yielded results, achieving a growing GDP trend, controlling inflation, controlling the exchange rate, and reducing the fiscal deficit. Unemployment was also reduced, and exports began to grow, as will be seen below. Subsequently, deeper reforms were required to consolidate the progress made since 1984.

3. First phase of export promotion and diversification programs

For many years, Costa Rica had been using tariff protection as part of the import substitution model. But it must be kept in mind that this type of protection also affects the export sector, since in practice it becomes a kind of two-way tax, raising

the price of the intermediate goods that are protected and therefore increasing the price of exports that use those intermediate goods, and causing an overvaluation of the exchange rate, which in turn reduces the purchasing power of the local currency that exporters receive for each dollar exported (Willmore, 1997). Part of the changes towards an export stimulus model was the gradual reduction of tariff protection. In the meantime, free-trade zones were created in which part of the incentive was the reduction of taxes on intermediate goods, as well as lower taxes on profits.

Temporary admission regimes were also promoted, which allowed production plants located anywhere in the country to carry out assembly or maquila work using imported inputs, with the purpose of exporting them free of customs duties (Willmore, 1997).

In Costa Rica, direct subsidies were also provided to promote exports. The figure used was the tax credit certificate (CAT) for exporters. This instrument required a minimum value added (around 35%) of national origin in their products. As Willmore (1997) argues, by 1992 a large part of Costa Rica's non-traditional exports obtained these subsidies, but they were later eliminated in the early 2000s. Several authors analysed the incentive scheme and concluded that it had different types of problems. For example, Alonso and Alonso (1990) argued about the high fiscal impact of CATs. Furst (1992) and Corrales and Monge (1990) argued that the instruments applied did not guarantee an authentic productive transformation capable of achieving a solid insertion of the Costa Rican economy in international markets.

Corrales and Monge (1990) carried out a study in which they obtained important data. They showed that exonerations for raw materials and inputs were a factor of great relevance for 97% of exporting companies, 87% gave great importance to the CAT and 61% said that exoneration from national taxes was of great relevance.

Based on a more in-depth study of several companies in different branches of industrial activity, Orozco (1996) pointed out several risks of the CAT, since they were being applied without solving more general problems, such as lack of export infrastructure, complexity of export and import procedures, the protectionism of some target markets and the complexity of the international legal system. In addition, Orozco concluded that many of the companies were not making significant transformations that would lead them to generate sustained competitiveness, and the CAT came to mean more than 100% of their profits, so there was an imminent risk that when the incentive disappeared, the companies would not be able to survive.

Costa Rica's non-traditional exports to third markets (outside Central America) responded to the set of incentives and changes in trade policy. As will be seen later in the paper, even though the model had some problems such as those noted above.

One of the most relevant aspects of the economic reform process in Costa Rica was the gradual application of productive transformation measures. The Costa Rican State managed to maintain the characteristics of the welfare state, the institutional framework and the network of public organisations aimed at addressing the social problems of a small economy in the process of development. Thus, the transition from an import substitution model to a more export-oriented model of insertion in the international market was carried out through a set of policies in which the State was setting the tone and generating greater participation spaces for the private productive sectors. Thus, a process dominated by productive diversification aimed at exports, both of agricultural products and others manufactured by a growing industry, found in trade liberalisation and direct interaction with other foreign actors an increasingly attractive space for economic growth and learning.

4. Attraction of foreign direct investment focused on high technologies

As mentioned above, in the 1980s Costa Rica began to open its economy and create a series of institutions and policies to promote international trade and attract investment. Gradually, a more outward-oriented growth development model was adopted. The effort was accompanied by investment promotion efforts aimed at guiding companies to reduce costs and improve efficiency (Dunning, 1993).

The 1981-1982 crisis generated many reactions and measures for change not only in the productive structure but also in a process of opening and export promotion, which marked the changes in the period between 1983 and 1999. A set of policies framed within the framework of the Structural Adjustment Programs of the World Bank and the Monetary Stabilisation Programs of the International Monetary Fund, marked the route in terms of the creation of new production activities and taking advantage of competitive advantages that were being created. It was these policies, in an environment of gradualism and the discovery of external markets, which, together with the enhancement of people's capabilities and the country's natural capital, explain the economic transformation and the favourable insertion of the Costa Rican economy (Salazar, 2022).

In the early stages, much of the FDI attracted to the country was focused on the textile and apparel industries and some agro-industrial activities. A major change

occurred in 1997 with the arrival of Intel. This company paved the way for other multinational high-tech companies. A solid reputation of Costa Rica as an investment destination was generated. This was opening space to attract investments in other sectors such as business services and manufacturing, such as medical devices, aeronautics, and automotive parts (Gómez et al., 2018).

As Monge and Zolezzi (2012) argued, the arrival of Intel in Costa Rica can be considered as the turning point of the country's insertion into global production sharing schemes and as the beginning of a sector oriented to the production and export of sophisticated, high-tech manufacturing and value-added services. The arrival of Intel helped attract emblematic multinationals in other sectors, especially in business services, which contributed to the country's participation in global value chains. Much greater dynamism in FDI inflows occurred from the mid-1990s onwards. Thus, starting in 1997 Costa Rica saw a pronounced increase in the number of firms operating in knowledge-intensive sectors such as, for example, IT and IT-enabled Services, Advanced Manufacturing, and Medical Devices (Gómez et al., 2018).

CAFTA-DR brought significant changes. This trade agreement led to the greatest growth in FDI flows to the medical device industry, especially from U.S. companies. The trade agreement provided for the reduction or elimination of tariffs and included investment protection mechanisms with a secure and predictable framework. In addition, CAFTA-DR introduced liberalisation of the telecommunications sector, which was gradually opened up. It was also increasing investment and reinvestment of foreign companies in the business services sector, many with U.S. capital (Gómez et al., 2018).

Many other internationally well-known companies opened operations in Costa Rica over time, such as Fiserv, which installed a captive centre dedicated to application development, quality assurance, technology documentation writing and information security; P&G installed in the country the Financial Services Centre for the Americas, from peer-to-peer to a financial operation that provides complex and value-added services and then continued to expand its operations in Costa Rica. In 2009 Hewlett Packard also invested in Costa Rica and established the first R&D Centre outside the United States. Other companies such as Baxter Healthcare, Hospira, Allergan and Bridgestone also made important investments in Costa Rica, generally using Free-Trade Zone schemes. The number of companies has then continued to grow (a detailed analysis can be found in Gómez et al. (2018)).

As will be seen below, the country's efforts to attract foreign direct investment have been successful and exports in modern services and high-tech manufacturing

have been growing steadily. The origins of this policy date back to the second half of the 19th century when education was declared free and compulsory, and using the resources that were previously used by the army. Subsequently, as summarised by Gómez et al. (2018), the country invested in other organisations focused on education and training for the industrial sector.

In that sense, a series of policies have been implemented to promote exports by modern service sectors. The most relevant groups of policies have been focused on competence and capability building. Among some of them, we can highlight the efforts made by CINDE to identify the competence and skills requirements of FDI firms established in the country and those that have shown interest in investing in Costa Rica (Ruiz, 2020; p 25). This initiative has made possible to coordinate with vocational training organizations to introduce changes aimed to satisfy the demand for these skills. Another one is the creation of new careers at the vocational secondary schools, an example is the Cedes don Bosco where the technical offer includes vocational training on Graphic Design, Electronics, Electromechanics, Network Computing, Computer Science in Software Development and Precision Mechanics. The Instituto Nacional de Aprendizaje (INA, for its Spanish acronym) is one of the state organizations with the greatest scope of action in professional training, through face-to-face and virtual courses as well as dual training. This organization has 54 training centres around the country and an important part of its training courses are related to the demands of the export services sectors. Projects have also been achieved with local universities in areas of computer engineering, mechatronics, electronics, project management, among others (Gómez, et al., 2018). It is clear that capabilities, competences and skills of the labour force have been a central element of Costa Rica's relative success in attracting foreign direct investment (Salazar, 2022).

Another group of policies have focused on tax incentives, which are found in Law No. 7210 of the Free Zone Regime, and its reforms. The main benefits of the regime contemplate, the internment of raw materials, processed or semi-processed products, and machinery and equipment without taxation, which also includes work vehicles; exemption for a period of ten years from the payment of capital tax and real estate transfer tax; exemption from sales and consumption tax on purchases of goods and services; exemption from taxes on fuels and oils; exemption from all taxes on profits, with differentiated percentages depending on the location of the company inside or outside the Greater Metropolitan Area (GAM); exemption for ten years of all taxes and municipal patents; exemption of all taxes on remittances abroad.

It can be considered that the main FDI attraction policy is centred on all the incentives contemplated in the Free Trade Zone Regime Law, but other policies

have also been generated, among which the negotiation of bilateral investment agreements (BIT's) that in general have included investment chapters (there are more than twenty bilateral investment agreements and 15 are in force).

Costa Rica joined the Central American Common Market (CACM) in the early 1970s. This was the country's first regional trade agreement. In the mid-1980s. A unilateral reduction of tariffs and non-tariff barriers was applied and as mentioned, the promotion of non-traditional exports was initiated. Entry into the General Agreement on Tariffs and Trade (GATT) and subsequent participation as a founding member of the World Trade Organisation (WTO) took place in 1995. The first bilateral trade agreement was signed with Mexico and entered into force in 1995. Bilateral agreements were also signed with the Dominican Republic, Chile, and Canada. These entered into force in 2002. In addition, a free trade agreement was negotiated with the Community of Caribbean States (CARICOM). This treaty entered into force on different dates: for Trinidad and Tobago (2005); for Guyana and Barbados (2006), for Belize (2011) and finally for Jamaica (2015). With Panama, a treaty was negotiated at different times and finally entered into force in 2008. One of the most important negotiation efforts was the Central America- Dominican Republic-United States Free Trade Agreement (CAFTA-DR), which was completed between 2003 and 2004. One of the most drastic changes brought about by this agreement was the opening of some service sector activities. The Association Agreement between Central America and the European Union was also negotiated between 2007 and 2010. This agreement entered into force in 2013. Subsequently, a trade agreement with China (2013), with Peru (2013) and with Colombia (2016) was put into force. A trade agreement with South Korea was negotiated in 2018. This high number of agreements have been favourable, particularly for the services sector, because of the clauses they contain regarding cross-border trade in services, financial services, telecommunications, and temporary entry of businesspersons. In addition, these agreements guarantee respect for the most favoured nation (MFN) and national treatment (NT) principles and include a series of preferential market access conditions (Gómez et al., 2018).

5. Main institutional changes

In order to promote a stable and reliable country image, making it attractive for attracting investment and to promote investment in general, several institutional changes have been generated. In 2011, the Law for the Protection of the Person against the Processing of Personal Data was created, which was later complemented with other regulations. The Agency for the Protection of Personal Data (PRODHAB) was also created with the function of overseeing compliance with the data protection rules established in the national legislation. Similarly, emphasis has been given to the Protection of Intellectual Property, based on

internal regulations and on what has been negotiated in most of the free trade agreements, as well as with the signing of multilateral agreements.

Among the fundamental actions has been, as explained by Gómez et al (2018), the pursuit of a strategy for the export of modern services, with concrete measures for the attraction of foreign direct investment focused on high value-added services, complemented by the negotiation of trade agreements and bilateral investment agreements. Likewise, actions have been proposed to take advantage of labour force capabilities and competences and the benefits granted by the free trade zone regime. Export goals for this type of services began to be set for the period 2006-2010. This type of goals made it possible to evaluate the results with respect to the goals set and to periodically review the strategies.

As part of the strategy, coordination processes were initiated between various public and private actors. The Ministry of Foreign Trade (COMEX, for its acronym in Spanish) stands out, and within it the General Directorate of Foreign Trade and the Directorate of Investment. Of great relevance has been the Foreign Trade Promoter (PROCOMER), which functions as an export promotion agency and as the executing arm of the policies defined by COMEX.

The Costa Rican Coalition of Development Initiatives (CINDE) has also been playing a fundamental role, responsible for attracting foreign direct investment and is also an executing arm of COMEX. The Ministry of Science, Technology and Telecommunications (MICITT) has also played a role, as it is responsible for dictating policy that promotes the use of knowledge and innovation as mechanisms to improve competitiveness and welfare. Other entities such as the Ministry of Labor and Social Security (MTSS), the Ministry of Public Education (MEP), the Central Bank of Costa Rica (BCCR), the National Learning Institute (INA), the Chamber of Information and Communication Technologies (CAMTIC), the Costa Rican Union of Chambers and Associations of the Private Business Sector (UCCAEP) and the Association of Free Zone Companies of Costa Rica (AZOFRAS), also participate as key players in the system, contributing from their specific fields of action. A strength of the strategy is that very effective coordination mechanisms have been achieved between the different public and private entities, including specific mechanisms such as the creation of working groups between exporting companies and government institutions (Gómez et al, 2018). It highlights that CINDE's Investment Climate Directorate, addresses aspects of relevance to meet the challenges in terms of investment climate.

6. Main results

There are several stages that have marked the evolution of Costa Rica's

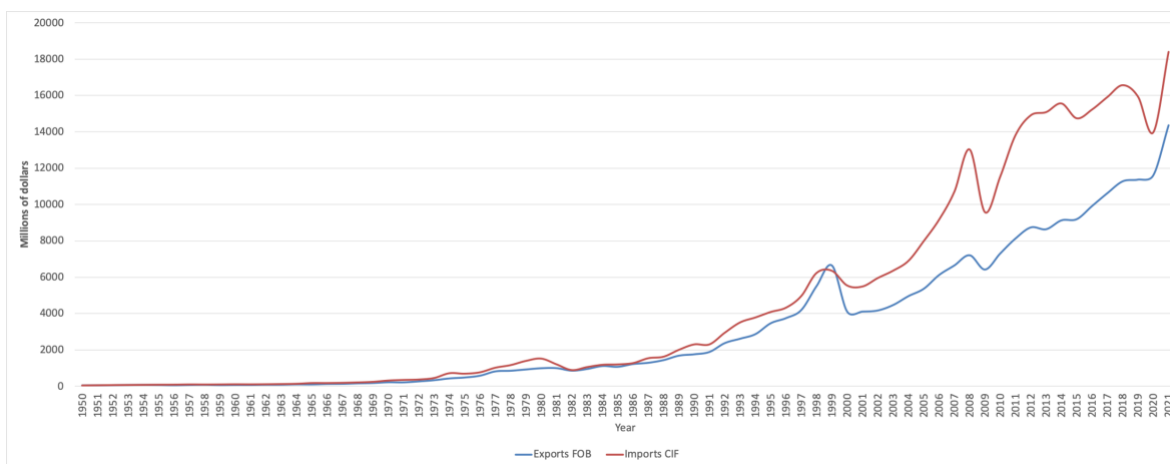
international trade over the last 71 years. A first stage is clearly identified until the 1970s by the export of traditional products, mainly dominated by coffee and banana exports. As mentioned in section 1, between 1980 and 1982 there was a turning point caused mainly by the severe crisis that led to a significant change in the growth model and greater interaction with the international market.

This was followed by a diversification of exports, always dominated by exports of agricultural products, although many of them were no longer traditional products. It is from the end of the 1980s and more markedly in the 1990s, when the attraction of foreign direct investment gave way to the development of free trade zones and the manufacturing industry, increasingly accompanied by services, began to play a more important role in the national export dynamics. However, during the last 20 years, from 2000 to 2021, the structure has remained relatively constant in terms of the participation of national production (traditional and non- traditional) and products originating under the free trade zone regime (see Figure 3).

The dynamics of imports have been closely aligned with the evolution of exports. Figure 1 shows that imports are higher than exports and that both share a growth trend (see Figure 2). Therefore, when appreciating the differential between exports and imports, there is a trade deficit from 1955 to 2021, except for 1999. This deficit has accelerated since 2000, when the trade balance has been negated by up to one third of total exports. In this sense, Ruiz (2012) points out that the trade deficit was financed by the growing income from Foreign Direct Investment (FDI), which represented 98% of the country's current account balance for that period.

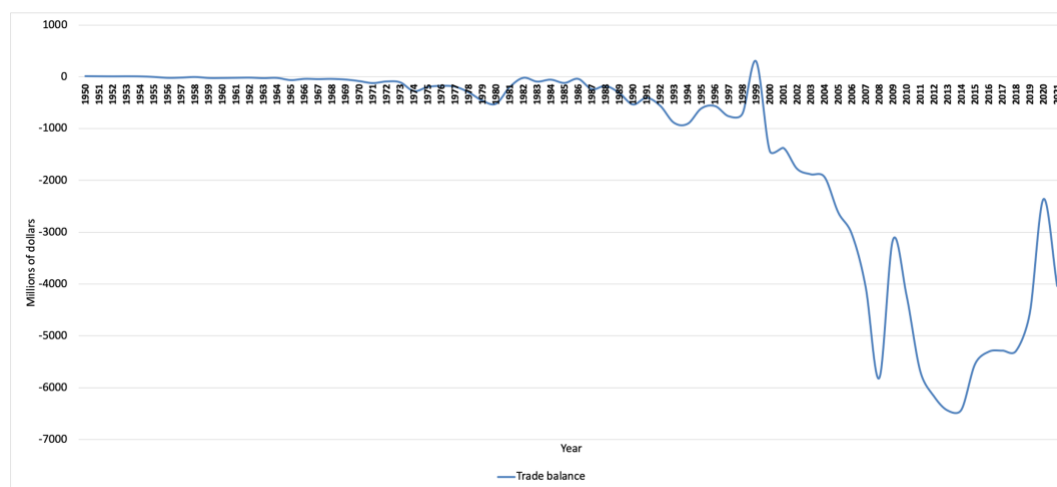
In addition, it is important to note that, when observing the evolution of exports and imports, different depressions can be seen in both series, most of which occurred during periods of world economic recessions, when there was a generalised decrease in economic activity, such as: the international oil price crisis (1973-1974), the Latin American debt crisis (1980), the world dollar crisis (1985), the Asian crisis (1996), the subprime mortgage crisis and commodity prices (2008) and the global crisis of the Covid-19 (2020).

Figure 1. Costa Rica: Evolution of Exports FOB and Imports CIF, 1950 - 2021
(millions of dollars)



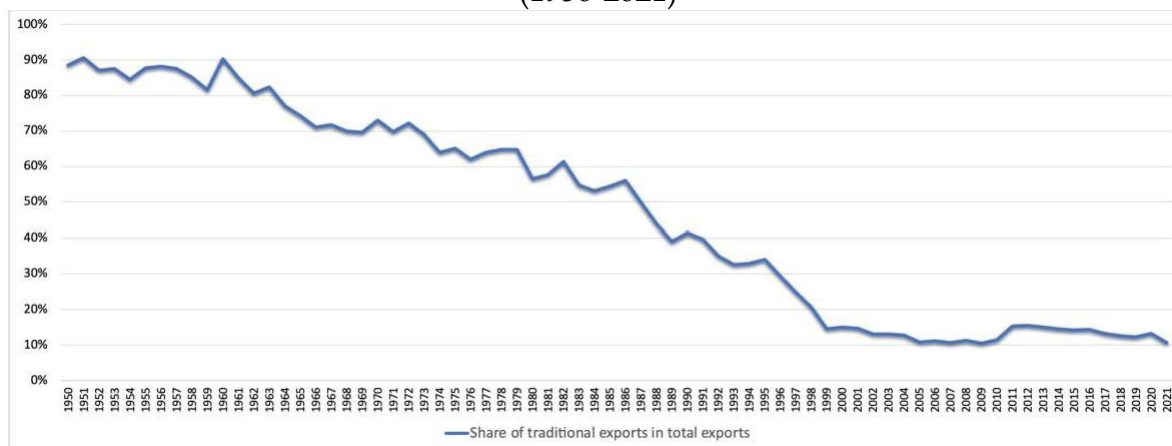
Source: Data compiled from the Central Bank of Costa Rica.

Figure 2. Costa Rica: Trade balance of Costa Rican Exports and Imports, 1950 - 2021



Source: Data compiled from the Central Bank of Costa Rica.

Figure 3
Costa Rica: Share of traditional exports in total exports
(1950-2021)



Source: Data compiled from the Central Bank of Costa Rica.

With the stabilisation policies and the change to the export promotion model, starting in 1992 there was a marked difference in the growth of exports and imports, boosted by the growth of certain agricultural products and the manufacturing industry.

The participation of the free-trade zones had a marked influence, which reached a key point in 1999 when, after many years and as an exceptional case in the balance of trade balance, exports exceed imports. However, this trend was cut short by the great contraction in 2000, when exports fell by 38% and imports by 13%, while imports fell by 1% in 2001. It is important to mention that, for this period prior to the year 2000; exports of services began to gain an important weight in Costa Rica's productive matrix, representing approximately 27% by the end of 2000. An important characteristic of Costa Rica's trade dynamics with respect to the evolution of traditional exports (coffee, bananas, meat, and sugar) in relation to exports of products identified as non-traditional is that the trend stabilises and the structure, with some ups and downs, is maintained throughout the last two decades.

The next drop in exports and imports occurred in 2008-2009, with the Subprime Mortgage Crisis and the prices of raw materials in the international market. At that time, the world and the country began a recession due to a collapse of the economic and financial system, which had not been seen since the Great

Depression of 1930. Costa Rica was also affected by this crisis, the best example being an 11% drop in exports in 2009, while imports registered a 26% drop in 2009.

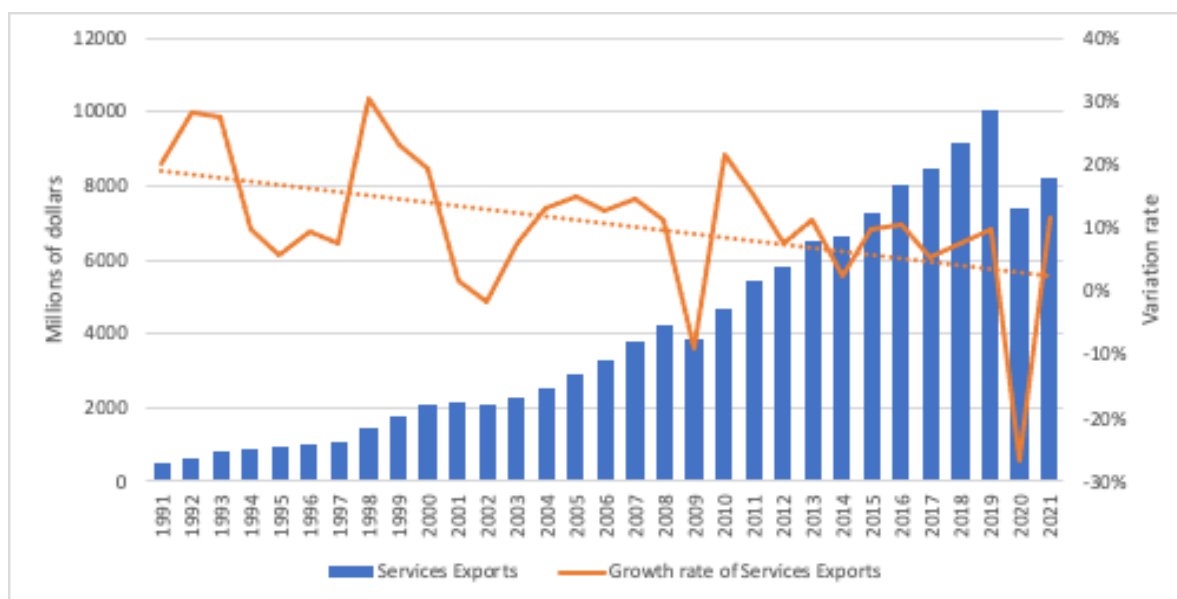
For its part, the State of the Nation Program Sustainable Human Development (2014), mentions the following about exports of goods and services: "Goods [exports] presented negative rates only in the years 2001 and 2009, while those of services in 2001, 2002 and 2009" (p. 12). This is due to the fluctuations of the world economy, especially with the economy of the United States, with which Costa Rica has an important commercial relationship.

Finally, there is a significant drop in imports of 4% in 2019 and 12% for 2020, this drop corresponds to the paralysis of world trade, due to the Covid-19 pandemic, where many economies of the world adopted confinement measures with their population to curb the contagions, therefore, trade was paralyzed. In addition, there is also a positive decrease in exports due to the collapse of tourism and transportation, but the most affected were imports, as they reached negative annual growth rates.

Costa Rica's economy experienced a significant transformation, with clear expansion, sophistication and diversification of its exportable supply, in which the growth of exports of modern services has played a role of relevance, which has become one of the most dynamic in our economy (Gómez, et al, 2018). There are some results in this regard in the following paragraphs.

Figure 4 shows how services exports have a marked growth, although with decreasing rates. But accumulating significant amounts of exports in the period. Two points with negative results were presented, the first during 2009 of approximately 1% and the second, being the lowest point of growth of the series, where it was reached during 2020 due to the Covid-19 pandemic with a negative growth of 27%.

Figure 4. Costa Rica: Evolution of services exports 1992 - 2021. (millions of dollars)

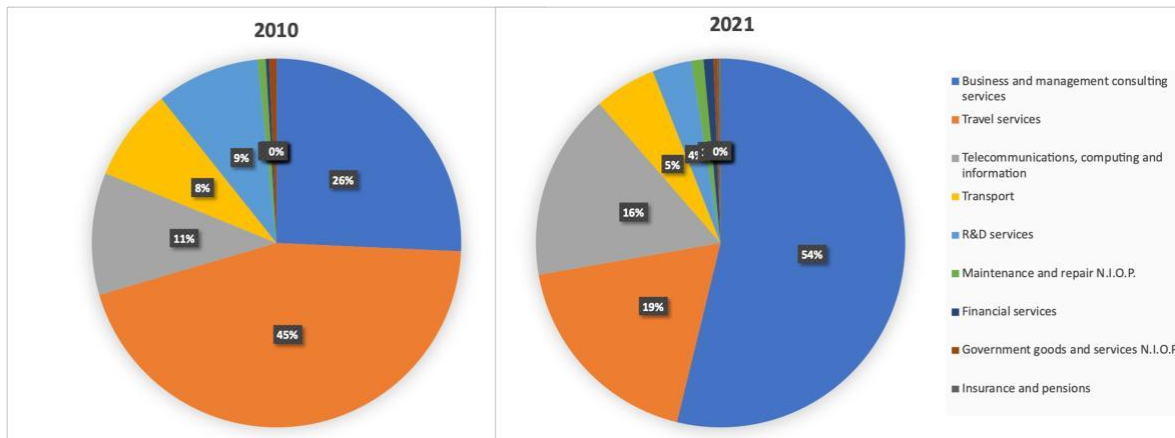


Source: elaborated with data of Banco Central de Costa Rica (2021).

Figure 5 shows the changes on the distribution of services exports by type between 2010 and 2021. The total amount of exports on services were 5 021 and 8 005 millions of dollars in 2010 and 2021 respectively, where business and management consulting (including public relations) shows the biggest change among those years, changing from 26% to 54%. Travel services lost participation in the structure of services exports from 45% in 2010 to 19% in 2021, ICT services increase from 11% to 16% during the decade. It is relevant to note that R&D services were important around 2010 years (9%) then reduce it participation in the structure of services exports and it is increasing again in 2021 but it is only 4% of total services exports.

The most important activities within service exports are those related to business and management consulting services. Other business services are also important such as travel (accommodation, food, transportation), as well as telecommunications, computing and information. Therefore, it can be affirmed that services exports in Costa Rica are quite diversified and that this has been an important result of the incentives and the new institutional framework in the country.

Figure 5. Costa Rica: distribution of services exports for 2021



Source: elaborated with data of Banco Central de Costa Rica (2010 - 2021).

7. Conclusions: Pending aspects in the development of the innovation system

There is a strong connection between the policy approaches of innovation systems and GVC. It is clearer for the approach of sectoral systems of innovation. But it is also clear that for more geographical approaches of innovation systems, it is also necessary to consider both the challenges and the opportunities from the conditions of international trade. Most of the challenges for economic and social upgrading in GVC require strong innovation systems. The main differences could be in the objectives to promote in both approaches, but the kind of policy instruments seems to be similar in the national dimension. However, it is necessary to consider the strong focus of GVC on international trade and on the role of the private sector and the multinational firms.

Considering the rationality of both approaches, it is clear that Costa Rica's export promotion and foreigner investment attraction policies have been mainly based on the GVC approach. Indeed, the strategy has focused on lowering barriers to international trade and consolidating an institutional framework to attract investment and promote new export products. From the point of view of the innovation system approach, there are still many gaps in the country's policies, as will be discussed in the following section. These gaps have contributed to the MIT.

There is an analysis of the functions of the system which are still weak (towards a comprehensive vision of policies; insufficiency of the financial system, coordination of the fundamental entities of development policies, role of universities, policies for stronger linkages between foreign and local firms; challenges in the development of new technological capabilities and innovation. Without strategies to solve these problems, it will be so difficult for the country to overcome the MIT.

Several studies have analysed the functioning of the innovation system in Costa Rica (OECD, 2017, Orozco and Guillén, 2020 and Orozco, 2021). The OECD concludes that the country's innovation system is very underdeveloped and highly fragmented, further stating that its actors have generally weak capacities to fulfil the functions that the system should address. The OECD study also states that funding schemes for technology and innovation have been weak and that public research has suffered from a lack of focus on national problems. It also states that there are weak institutions and governance mechanisms that do not contribute to an adequate articulation and implementation of effective policies. In this sense, it is reflected that the interactions required in modern national innovation systems are not achieved. The study also shows that there are great challenges to improve the quality of education. One of the aspects highlighted is the lack of coincidence between the demand and supply of labour force competences and the weakness of the system to promote the improvement of people's general capabilities to integrate into the labour market.

An additional aspect that stands out is the weakness in advancing in mission-oriented research to solve the needs of the different sectors. Completing the diagnosis, the conclusion is that the system has a series of characteristics that limit its capacity to promote innovation: (a) weak priority given to STI in national strategies and low budgets to STI; (b) institutional overlaps and legal/regulatory constraints hindering the effectiveness of STI policies, with high fragmentation; (c) ineffective governance practices, with weak coordination mechanisms and a legalistic approach; (d) inefficient procedures in the allocation of funds through STI programs; (e) weak accountability of institutions/programs in STI, with insufficient monitoring and evaluation; (g) underdeveloped statistical infrastructure for reporting STI and benchmarking policies, with imbalances in funding to different institutions with respect to universities; (h) absence of intermediary institutions for technology diffusion and business innovation; (i) weak absorptive capacity of domestic enterprise; low investments in R&D and technology adoption and weak industry-academia linkages; (j) increasing supply and demand mismatches of skilled personnel and weak vocational training; (k) weak enforcement of the legal framework for intellectual property rights (OECD, 2017 and Orozco, 2021).

There are also barriers in the functioning of the financial sector to promote innovation processes in the productive sectors, so most companies depend on their own funds to promote their innovations (Orozco and Guillén, 2020). In response to so many weaknesses in the innovation system, a law was passed in the country in 2021 creating the Innovation Agency. The entity began operating at the end of 2021 but is in a process of transition from its predecessor, CONICIT. There is still a long way to go to identify the real contribution it will have in strengthening the country's innovation system.

With what has been argued in the previous paragraphs, it is even more evident that the export promotion and FDI attraction strategy did not consider the innovation system as a whole, but was based on partial policies from GVC approaches. Many problems persist in the country, such as the lack of linkage of foreign companies with domestic suppliers, general unemployment, although there is a lack of personnel with qualifications in certain areas and other problems such as those pointed out to the innovation system, which prevents better results of the national economy as a whole.

Gomez et al (2018) argue that a pending challenge for the new development model to be sustainable is to achieve economic growth based on increasing productivity. In addition, these authors raise the need to increase the value of the domestic content of exports, for which it would be necessary to strengthen the linkages of exporting companies with the local production activities. We add that this type of linkages cannot be achieved without increasing the technological capabilities of national companies and competencies and capabilities of the labour force. Therefore, policies must be promoted from the logic of understanding the innovation system and supporting the existing linkages and promoting new interrelations among actors.

Arias and Munoz (2007) raised an issue that remains unresolved. They argue that there is an implicit contradiction in Costa Rica's export promotion model, since due to exonerations and subsidies to stimulate exports, it has contributed to a structural fiscal deficit but has not been complemented by a productive restructuring strategy in the other sectors of the economy. An associated issue that has been dragging on for a long time, given the weaknesses in fiscal matters, is the limited capacity to promote projects to improve infrastructure, professional training, and research and development, which would require an increase in the fiscal burden (Garnier, 2005).

Thus, although export activity in Costa Rica remains very dynamic, it has not been able to consolidate itself as the engine of the economy, mainly due to the weak productive and technological integration with the national economy (Mora, 2000). Mora's argument is still applicable today. He also made another argument that is

still valid, namely, that a regulatory framework should be formulated to improve the international transfer of productive knowledge, technology transfer and regional development.

A similar point has been made more recently. The argument is that, despite the great dynamism of the export sector and even considering the profound process of structural transformation, the economy's growth rates are still low and volatile. Problems such as informal employment and unemployment persist, largely due to the lack of linkages between the productive sectors and the rest of the economy. Important infrastructure problems, weaknesses in the educational system and personnel training, lack of an understanding and support to innovation system, are fundamental limitations (Salazar, 2020).

To grow at higher and sustained rates and reduce productive dualism, the country needs a new generation of productive development policies. It is necessary to include policies to achieve a more competitive environment, which implies internationally competitive electricity tariff prices, facilitation of procedures and commercial activities; in addition, productive development policies with a territorial approach with clear coordination between the public and private sectors; educational reforms and the vocational training system and strengthening of the national innovation system (Salazar, 2022). It is important that the new institutions generated with the creation of the Agency of Innovation can contribute significantly to promoting new initiatives, facilitating interrelationships among actors and supporting capability building in the innovation system and generating proactive policies to consolidate the development model, but advancing in environmental sustainability and closing the social gaps. As suggested by Monge (2020), the strategy to overcome the MIT must include the development of an efficient NIS, which implies the need to work in several areas: human resources (quality and quantity); financing (new instruments and hedging); governance of innovation policy (steering and execution of policies and programs); and create the necessary institutions for the correct attention of the typical market failures in terms of innovation.

Considering the experience of Costa Rica, we can enumerate some important policy lessons. First, as suggested by the literature of MIT, it is possible, and it was the case of Costa Rica, to move from low income to middle income applying correct policies for structural change of the export sector, but it is much more difficult to move towards high income levels. The policies to open the economy and to promote structural change in exports was a key strategy to move from low to middle income levels, but these were in some way partial policies which did not developed de system of innovation as a whole. The second lesson is that for overcoming the MIT it is necessary to promote new policies in order to strengthen

the system of innovation. it is necessary the diversification of exports but it is not enough. It is not possible to advance in the necessary capacity building for new sectors with high productivity, without a holistic strategy to strengthen the system of innovation. in this direction, another policy lesson is that in the case of Costa Rica, it is necessary to apply good strategies to solve the mentioned problems of the system of innovation. A good strategy is elaborated mix of policies, some of them aimed to a new stage of diversification in the export sector, but aimed to more productivity and value added, which mean more innovation and then better capabilities to do it.

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Trade, Labour Reallocation and Productivity Growth in the Indian Manufacturing Sector

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Abstract

This article examines the nexus between trade, structural change, and labour productivity growth in India's organized manufacturing sector. The study aims to investigate the impact of trade on labour productivity and labour reallocation that has contributed to aggregate productivity growth during the 1991-2018 period. The descriptive statistical analysis reveals that both exports and imports have increased significantly, and the composition of exported products has shifted towards medium-high-technology-intensive products. We find that the major growth in value added and wages has been observed in the medium-to-high-technology-intensive industries, whereas the low-technology segment continues to dominate employment generation. The panel econometric analysis suggests that productivity growth is primarily driven by technical change within industries, and trade mainly induces intra-sectoral productivity growth with limited impact on labour reallocation between sectors. The absence of structural change from trade openness can be attributed to the existence of market frictions and structural rigidities that prevent efficient resource allocation across the manufacturing sector in India.

Keywords: International Trade, Structural Change, Labour Productivity, Shift-Share Framework, Indian Manufacturing Sector, Panel Regression

JEL Classifications: L60, O47, F14

1 Introduction

In this paper, an attempt is made to study the relationship between international trade, structural change and productivity in the Indian manufacturing sector. The theoretical literature on trade, from the classical tradition of Ricardo to the “New” New Trade theory of Melitz, predicts that increasing trade openness has significant implications for the allocation of economic resources within and across the sectors of an economy. According to the classical theories of comparative advantage where countries' specialisation depends upon the relative difference in technology or factor endowments, changes in relative prices induce a shift in the allocation of productive resources across sectors (Thirlwall and Pacheco-López, 2017). In the endogenous growth models where trade facilitates the transmission of technology across countries, a reduction in trade barriers can have significant implications on the sectoral movement of labours if the transfer of technology impacts the modern and traditional sectors differently (see Grossman and Helpman, 1994; Konte, 2022).

With the recent advancement in trade theory that incorporates the existence of firm heterogeneity, product differentiation and increasing returns to scale, trade is often found to be concentrated in narrowly defined industries within sectors. As trade expands, workers reallocate towards more productive firms within the same industry (Melitz, 2003). In such cases, aggregate productivity improves from the reallocation of resources from less to more efficient manufacturing plants within an industrial sector¹. Hence, the theoretical proposition on trade suggests that the level of trade openness resulting from trade policy reforms will have significant implications on the allocation of scarce resources both within and across sectors.

The reallocation of productive resources across different sectors of the economy or structural change has been one of the prominent forces of economic growth and productivity (see Lewis 1954; Kaldor 1966; Syrquin 1988). Empirical studies, however, traditionally focused on the labour movement from agriculture to manufacturing, overlooking the structural dynamics within the manufacturing sector (Timmer and Szirmai, 2000). In general, as the economy develops, industries tend to evolve and factor inputs can shift from less productive segments to more productive branches. This process of structural transformation from low-productive to high-productive activities can be associated with substantial structural change bonuses in terms of higher aggregate productivity and income per capita (see Timmer and Szirmai, 2000;

Szirmai, 2012). However, it is worth noting that the rate of aggregate labour productivity growth is influenced by both intrasectoral effects and intersectoral effects (Peneder, 2003; Konte, 2022). The intrasectoral component or within effect is the share-weighted average productivity growth of the individual

industries while the intersectoral component or between effect reflects the growth rate of labour productivity resulting from the movement of workers across sectors². This indicates that the pace of aggregate labour productivity in manufacturing could be affected by trade exposure as the specialisation pattern shifts towards industries having comparative advantage (intersectoral effects) or as most efficient import-competing firms survive and expand due to new market opportunities from trade while forcing the less- efficient firms to exit (intrasectoral effects)³.

In this paper, an attempt is made to evaluate the impact of trade participation on aggregate labour productivity of the manufacturing sector in India, and to determine whether trade exposure has contributed to labour productivity growth by inducing reallocation of resources, either within or across manufacturing sectors or both. We know that since 1991 India has systematically moved from the shackles of an import-substitution regime to a more outward- orientated regime. The trade policy reforms have gradually reduced tariff and non-tariff barriers. The elimination of trade-distorting factors and anti-export bias is expected to induce the relocation of resources to productive manufacturing. Scholars have extensively studied the industrial response to liberalisation, examining various aspects of manufacturing performances such as output growth (Goldar, 2018; Nagaraj, 2017), productivity (Krishna *et al* 2022; Goldar *et al*, 2017; Das *et al* 2016; Goldar 2014; Balakrishnan and Pushpangadan, 1994; Ahluwalia, 1991), and structural change (Rijesh, 2023; Erumban *et al* 2019; Ahsan and Mitra, 2016). The impact of trade on productivity has been a topic of extensive research, with empirical findings being largely mixed. Studies that examined the initial reform period have not found a significant positive impact of trade on productivity (see Das, 1998; Goldar and Kumari 2003). More recent studies, however, suggest that trade has a positive impact, especially through the channels of imports (see Goldberg *et al*, 2010; Topalova and Khandelwal, 2011; Rijesh 2019).

In this context, the present study aims to examine the effect of trade on labour productivity using disaggregated industry-level data. The study seeks to determine whether trade has facilitated the allocation of resources either within or across different branches of the manufacturing sector. The theoretical literature on trade and growth suggests that as countries participate more in trade, resources will be allocated more efficiently within and across sectors, leading to significant improvements in overall labour productivity. Therefore, we hypothesise that as trade expands there will be marked improvement in resource reallocation, which will have a positive impact on the aggregate labour productivity growth in the manufacturing sector.

The remainder of the paper is structured as follows. Section 2 discusses the methodology and datasets. Section 3 provides a descriptive statistical account of trade and productivity in the Indian manufacturing sector. Section 4 reports

and discusses the estimation results. Section 5 presents concluding remarks.

2 Methodology and Data

The study uses the following methodology and data sources to examine the relationship between trade, structural change and productivity.

2.1 Accounting for Structural Change: Shift-Share Framework

As mentioned earlier, there are two ways in which labour productivity grow; either within sectors as a result of technological innovation, skill upgrading training programmes and capital accumulation or between sector either through more efficient allocation of resources across industries or through the movement of workers from less productive industries to more productive ones. To decompose labour productivity, we employ the Shift-Share decomposition framework, which has been extensively used in the empirical literature (see Fagerberg 2000; Timmer and Szirmai 2000; McMillan and Rodrik, 2011; Konte *et al* 2022; Rijesh 2023). In this framework, the aggregate labour productivity is given by

$$LP_t = \sum_{i=1}^n s_{i,t} lp_{i,t} \quad \text{--- (1)}$$

Where LP_t is aggregate labour productivity in the manufacturing sector in year t , $s_{i,t}$ represent the proportion of total workers employed in the industry i at time t , and $lp_{i,t}$ represent labour productivity in an industry i at time t . We use real-value added (volume) to measure output per worker. Then, the change in total labour productivity (ΔLP) between t and $t-k$ period can be written as

$$\Delta LP_t = \sum_{i=1}^n s_{i,-k} \Delta lp_{i,t} + \sum_{i=1}^n \Delta s_{i,t} lp_{i,t-k} + \sum_{i=1}^n \Delta s_{i,t} \Delta lp_{i,t} \quad \text{--- (2)}$$

Equation (2) shows that total productivity change can be decomposed into three effects, namely

(a) *Within-Shift Effect* (b) *between/static Shift Effect* and (c) *Dynamic-Shift Effect*. The within-effect, the first term on the right-hand side, is the changes in labour productivity weighted by the base period share of employment in the industry. This captures how much the overall productivity of labour growth can be attributed to changes within industries. The within- technical change results from an improvement in capital accumulation, learning by doing or technological advancement over time. The second term on the right-hand side indicates the between effects which is the sum of changes in labour allocation across industries weighed by the labour productivity in the base period. The

Static Effect will be positive/negative when industries with higher productivity attract more/fewer workers and thereby increase/decrease the share in total employment. The third term on the right-hand side is a covariance term that captures the impact on aggregate labour productivity of simultaneous changes in sectoral productivity and employment. The interaction effect reflects the scenario when increased labour reallocation is directed towards industries with higher growth in labour productivity. The last two terms reflect a structural change or intra-sectoral changes in total productivity due to the movement of workers across different industries of an economy (Rijesh, 2023).

2.2 *Econometric Methodology*

The study adopts a panel econometrics approach to analyse the impact of trade on labour productivity and whether trade participation affects labour productivity through a more efficient allocation of resources either within industries or across industries or both. The four main dependent variables in the study are the annual growth rate of labour productivity, within effect, and between effect and dynamic effect of labour productivity growth. We relate productivity change ΔLP_i in Indian manufacturing to the effect of trade participation and other control variables. The impact of trade is identified through three variables, namely export intensity (EXI), import penetration (IMP) and relative import price ($RIMP$). The control variables (X) are capital intensity (KI) and capacity utilisation (CU). The estimating equation is given as follows

$$\Delta LP_i = \alpha_0 + \alpha_1 \Delta EXI_{it} + \alpha_2 \Delta IMP_{it} + \alpha_3 \Delta RIMP_{it} + \alpha_4 \Delta X_{it} + \sigma_i + t + \varepsilon_i \quad (3)$$

Here the dependent variable is the relative changes in labour productivity growth in manufacturing sector i in period t . ΔEXI_{it} is the per cent change in export share in an industry i at time t , ΔIMP_{it} is the per cent change in import penetration in an industry i at time t , $\Delta RIMP_{it}$ is the per cent change in relative import price ratio in the industry i at time t . ΔX_{it} is the control variable including per cent change in KI and CU in the industry i at time t . The vector t includes period dummies.

To analyse the effect of trade on within and the structural change components of the growth rate of labour productivity we use the following equations to effectively regress the within, between, and dynamic components of structural change on trade performance.

$$Within_i = \gamma_0 + \gamma_1 \Delta EXI_{it} + \gamma_2 \Delta IMP_{it} + \gamma_3 \Delta RIMP_{it} + \gamma_4 \Delta X_{it} + \sigma_i + t + \varepsilon_i \quad (4)$$

$$Static Shift_i = \beta_0 + \beta_1 \Delta EXI_{it} + \beta_2 \Delta IMP_{it} + \beta_3 \Delta RIMP_{it} + \beta_4 \Delta X_{it} + \sigma_i + t + \varepsilon_i \quad (5)$$

$$Dynamic Shift_i = \varphi_0 + \varphi_1 \Delta EXI_{it} + \varphi_2 \Delta IMP_{it} + \varphi_3 \Delta RIMP_{it} + \varphi_4 \Delta X_{it} + \sigma_i + t + \varepsilon_i \quad (6)$$

The empirical analysis is based on 58 cross-section industries identified at the 3-digit level for the period 1991-92 to 2018-19. The panel is balanced and the

inferences are based on standard panel regression methodology.

2.3 *Data Sources and Variable Constructions*

The data on industrial production is obtained from the Annual Survey of Industries (ASI), which is published every year by the Central Statistical Office (CSO), the government of India. The ASI is the principal source of information on registered manufacturing factories under the census and sample frame units distributed across the Indian States. We collected the major characteristics of industries at the 3-digit level of the National Industrial Classification (NIC) scheme of 2008 from the annual report of ASI, Vol 1 and EPWRF India Time Series, which is an interactive online database covering major sectors of the Indian economy. The trade statistics on the Indian manufacturing sector are compiled by the Directorate General of Commercial Intelligence and Statistics (DGCI&S). We assessed the disaggregated trade statistics at the 6-digit level of Harmonized System (HS) from the UN Comtrade which collects and disseminates the official trade statistics of India and other countries. The Wholesale Price statistics at the disaggregated level were collected from the Office of the Economic Advisor, Ministry of Commerce & Industry, and Government of India. The Consumer Price Index (CPI) for Industrial Workers series was obtained from the Labour Bureau, Government of India. The rupee-dollar (average) exchange rates were collected from the Handbook of Statistics on the Indian Economy, Reserve Bank of India. All price series were based on 2011-12=100.

We prepared an industry correspondence to map the different NIC classifications following the official concordance of the Central Statistical Office (CSO), Government of India and EPWRF. To map trade products across different industries, we use the official correspondence series of International Standard Industrial Classification (ISIC) rev3, which correspond to the NIC-2004, and HS. The selected industries are further classified into three categories based on technology intensity (see OECD, 2011; Weiss 2015; Rijesh 2023). These are the Medium to High and High technology (MHT), Medium to Low Technology (MLT) and Low Technology (LT). Accordingly, the following industries fall under each of these categories (a) MHT: chemicals and chemical products, machinery and equipment n.e.c, Office, accounting, and computing machinery, electrical machinery and apparatus, radio, television, and communication equipment and apparatus, medical, precision, and optical instruments, motor vehicles, trailers & other transport equipments; (b) MLT: coke, refined petroleum products and nuclear fuel, rubber and plastics products, other non-metallic mineral products, basic metals, fabricated metal products; and (c) LT: food products and beverages, tobacco products, textiles, dressing and dyeing of fur, Tanning and dressing of leather, wood and wood products, paper and paper products, Publishing, printing, and reproduction of recorded media, furniture & recycling.

The variables in the study are constructed as follows. The *EXI* is the ratio of exports to total manufacturing output; The *IMP* is the ratio of total imports to domestic demand which is the difference between output and exports. The *RIMP* is the relative import price to domestic price which is constructed using the unit value of imports and the wholesale price index of manufacturing output, base 2011-12=100. The *KI* is the ratio of real fixed capital to the total person engaged in manufacturing and *CU* is based on the minimum capital-output ratio method used by Goldar and Kumari (2003) and Rijesh (2019).

3 Trends in Manufacturing Trade, Production, and Productivity: Descriptive Analysis

3.1 Trends in Manufacturing Trade

The Indian manufacturing trade performance during the reference period is presented in Table

1. We can observe that both the export and import of manufacturing goods have seen considerable expansion over time. In 1991, India's exports and imports of manufacturing were US\$12 billion and US\$11 billion, respectively. By 2018, these values had expanded to US\$265 billion and US\$358 billion, respectively. The growth rate of exports was 12 per cent per annum, while the growth rate of imports was 14 per cent per annum. In 1991, the majority of exported items were LT products whereas the imported items were predominately MHT products. However, by 2018, there had been a significant shift in the composition of exported products, with MHT products constituting 42 per cent and MLT products constituting 33 per cent of total exports. The share of LT products exported by India declined to 26 per cent. On the import side, high and medium-technology products continued to dominate throughout the period.

Table 1

India's Trade Performance: By Technology Classification (1991-2018)

Year	Export-Intensity				Import-Penetration			
	Manufacturing	MHT	MLT	LT	Manufacturing	MHT	MLT	LT
1991	11.5 (100.0)	8.0 (23.7)	4.9 (13.1)	20.5 (63.2)	10.3 (100.0)	15.6 (57.4)	10.8 (34.8)	2.7 (7.8)
1995	13.1 (100.0)	7.9 (22.3)	6.5 (15.3)	25.4 (62.4)	14.2 (100.0)	19.5 (56.9)	14.4 (33.8)	5.3 (9.2)
2000	15.6 (100.0)	10.9 (25.7)	10.1 (18.7)	25.3 (55.6)	14.0 (100.0)	18.5 (53.9)	15.5 (34.5)	5.9 (11.6)
2005	17.8 (100.0)	15.8 (31.3)	14.8 (33.1)	25.2 (35.7)	19.5 (100.0)	27.3 (55.7)	17.4 (35.7)	8.3 (8.6)
2010	17.3 (100.0)	18.4 (35.2)	17.0 (40.6)	16.5 (24.3)	19.8 (100.0)	29.1 (54.6)	18.1 (37.4)	7.1 (7.9)
2015	22.2 (100.0)	24.0 (38.5)	18.9 (31.6)	24.5 (29.9)	24.2 (100.0)	34.4 (57.2)	21.4 (33.2)	10.4 (9.6)

2018	21.5 (100.0)	25.0 (41.6)	18.2 (32.9)	21.5 (25.5)	27.0 (100.0)	39.6 (60.6)	21.8 (30.5)	11.4 (8.8)
Growth Rate of Exports (%)					Growth Rate of Imports (%)			
1991-2018	12.0	14.4	15.9	8.3	13.8	14.0	13.2	14.3
1991-2000	10.4	11.4	14.8	8.8	10.4	9.6	10.3	15.4
2001-2010	20.7	25.0	31.6	10.1	24.6	24.8	25.7	19.4
2011-2018	7.1	9.7	4.0	7.8	9.3	10.9	6.1	11.0

Note: The figure in parenthesis is export/import shares in per cent. The growth rates are based on CAGR (%);MHT=Medium-high to high technology, MLT=medium-low technology, LT=low technology

Source: Author's calculations based on UN Comtrade, accessed through the WITS database.

The decade-wise analysis reveals that both export and imports experienced considerable expansion during the 2001-2010 period. However, since 2010 there has been noticeable decline in both export-intensity and import-penetration, which can be attributed to the global demand slump following the 2007-08 global financial crisis. In terms of export intensity, India exported only 12 per cent of its manufacturing output in 1991, but this has increased consistently and reached 22 per cent in 2018. In the case of medium to high-technology-intensive industries, the export intensity has grown significantly over the years whereas it remained stagnant in the case of low-technology segments. Similarly, the import-to-domestic consumption ratio has seen a significant increase over time. For instance, the import-penetration ratio in the overall manufacturing sector has gone up from 10 per cent to 27 per cent between 1991-2018. The largest increase in import penetration is observed in the MHT industries, where it reached 40 per cent in 2018. This indicates the growing significance of imports in catering to domestic demand in the Indian economy. During all periods, the rate of growth in high-technology products was higher than that of low-technology products, as shown in Table 1.

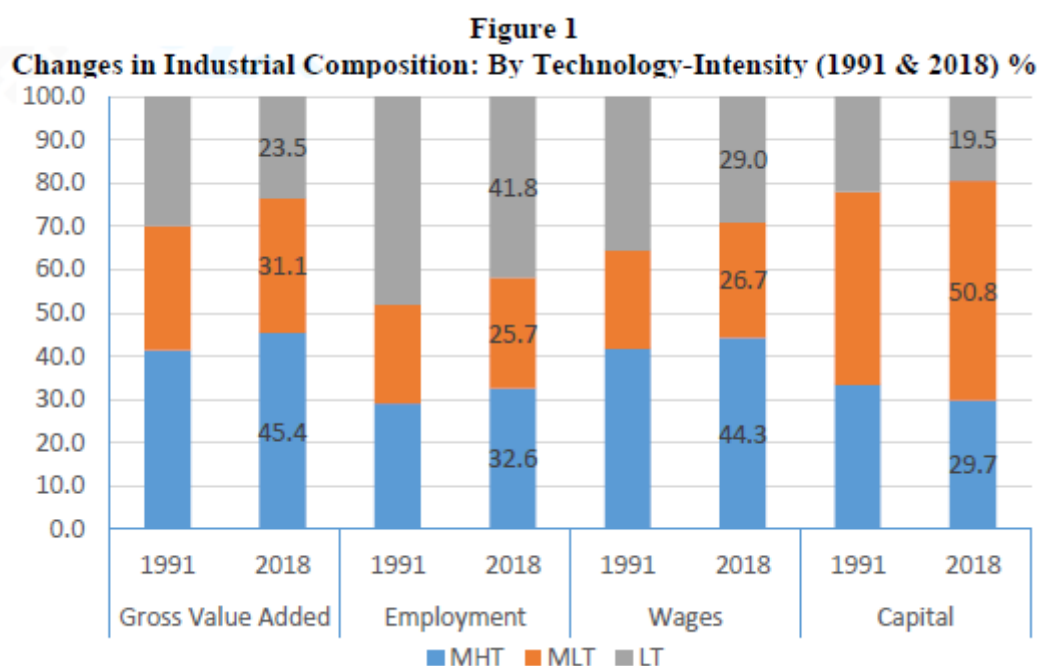
3.2 Trends in Manufacturing Production

At the aggregate manufacturing level, the composition changes of key performance indicators such as Gross Value Added (GVA), Wages, Employment, and Capital across different technology categories are illustrated in Figure 1. With regards to GVA, the largest contributor was found to be the Medium to High Technology (MHT) sector, followed by the Medium Low Technology (MLT) and Low Technology (LT) sectors. In terms of wages also the MHT sector had the highest contribution, followed by LT and MLT. In terms of employment, the LT sector employed most workers, while the MLT sector had the least. Finally, in terms of the proportion of capital in the total manufacturing sector, the MLT sector had the highest share, followed by MHT and LT (see Figure 1). Overall, it can be concluded that the MHT sector was the largest contributor in terms of GVA and wages among the three technology categories in the manufacturing sector. The LT sector had the highest employment, while

the MLT sector had the largest share of capital in the total manufacturing sector.

The detailed disaggregated analysis at the 3-digit level is given in Table A1 in the appendix. At the 3-digit level, we have compiled the time series data for key performance variables for 58 manufacturing industries based on the NIC-2008 nomenclature. These industries are also categorised by their technological intensity. In the recent period, the largest GVA contribution is from the manufacture of basic iron & steel (9 per cent), pharmaceuticals, chemicals and botanical products (8 per cent), basic chemicals (6 per cent), non-metallic mineral products (6 per cent) and refined petroleum products (5 per cent). Most of these industries are in the medium-low to high technology-intensive segments, a sharp contrast to the situation in 1991 when low-technology-intensive manufacturing, such as the spinning, weaving, and finishing of textiles, had a major share of 11 per cent. The characteristics of the Indian industries have shifted towards more technology-intensive manufacturing over time. For example, 15 out of 26 MHT industries have increased their share of GVA from 1991 to 2018.

Figure 1



Note: MHT=Medium to High Technology, MLT=Medium to Low Technology, LT=Low Technology

Source: Authors compilation from Annual Survey of Industries (CSO), various issues

However, the textile sector (including spinning, weaving, finishing, and wearing apparel), which is an LT segment, continues to dominate employment generation, holding a significant share of 14 per cent compared to medium-high and medium-low technology industries. Among the technology-intensive

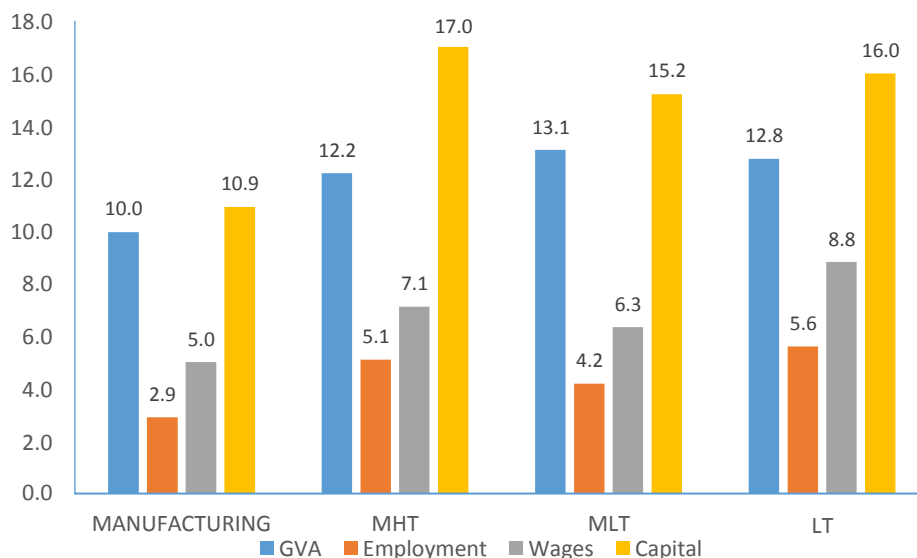
segments, the non-metallic minerals (6 per cent), motor vehicles (5 per cent), pharmaceuticals (5 per cent) and general-purpose machinery (5 per cent) have a major share of overall manufacturing employment. Apparently, in 2018 the technology-intensive industries such as pharmaceuticals, motor vehicles and machinery had a major share in the overall wages and capital inputs in manufacturing (see Table A1 in the appendix).

3.2.1 Growth Profile

The study of industrial growth performance, based on compound annual growth rates, revealed that the output of manufacturing grew at a rate of 10 per cent per annum from 1991 to 2018. The employment growth, however, was relatively modest, with a growth rate of only 3 per cent per annum, relative to the growth in wages (5 per cent) and fixed capital (12 per cent). The strikingly modest growth in employment relative to other factor inputs is also observed across technology-intensive industries, as illustrated in Figure 2. Among them, the labour-intensive industries of LT segments experienced the highest employment growth rate during the study period, with a rate of 6 per cent per annum. Strikingly, all manufacturing sectors have experienced significant growth in capital, indicating a shift towards more capital-intensive manufacturing production since the implementation of liberalization policies (Rijesh, 2023).

Figure 2

Industrial Growth Performance (1991-2018): By Technology-Intensity Classification (%)



Note: MHT=Medium to High Technology, MLT=Medium to Low Technology, LT=Low Technology

Source: Authors compilation from Annual Survey of Industries (CSO), various issues
The disaggregated analysis at the 3-digit level revealed that several technology-

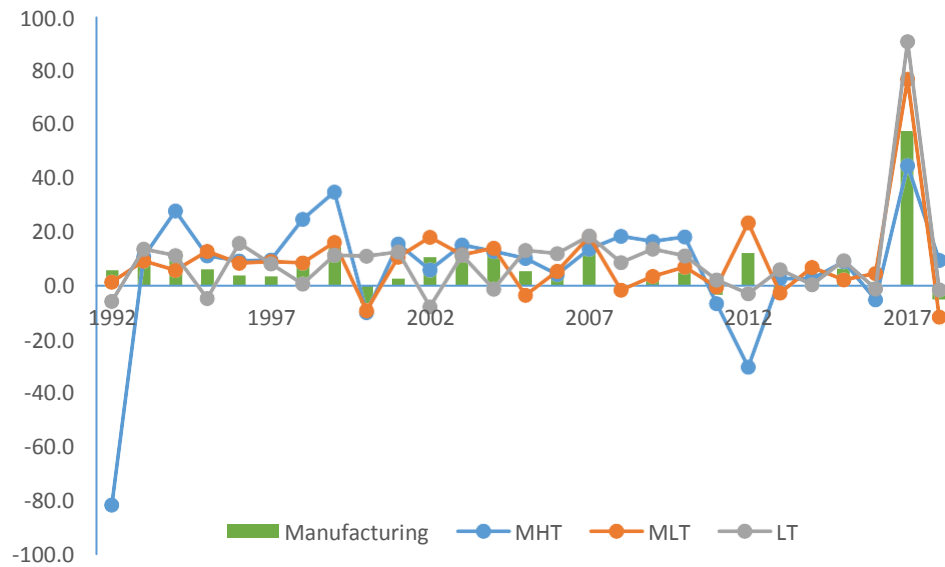
intensive industries recorded double-digit growth in GVA (see Table A1). Some of the noteworthy industries in this category include weapon, ammunition, and military fighting vehicles (22 per cent), parts of motor vehicles (15 per cent), motor bodies and trailers (15 per cent), transport equipment n.e.c (14 per cent), electronic components (14 per cent) and pharmaceuticals (13 per cent). Among these industries, notable employment gains were only seen in parts and accessories of motor vehicles (8 per cent) and weapon, ammunition, and military fighting vehicles (7 per cent). In general, the employment growth was largely confined to low-technology sectors such as knitted and crocheted apparel (10 per cent), textiles n.e.c (9 per cent), processing and preserving of meat (9 per cent), wearing apparel (7 per cent), animal feeds (7 per cent), processing and preserving fruits and vegetables (7 per cent) and processing and preserving of fish (7 per cent). It is worth mentioning that most of these notable industries in the MHT and LT categories recorded double-digit growth in wages and capital during the reference period.

3.3 *Structural Change and Labour Productivity*

In this sub-section, we report the nature of productivity and structural change dynamics. Figure 3 presents the productivity pattern in the aggregate manufacturing sector as well as technology-intensive industries. We can observe that the annual growth rate of productivity is largely cyclical. During 1991-2018, the average productivity growth rate in the overall manufacturing sector was 7 per cent. The sub-period analysis shows that productivity was comparatively higher during the 2001-2010 and 2011-2018 periods (see Figure 4). The examination of productivity growth across the technology-intensive category shows that the performance was relatively weak during the initial period of economic liberalisation (1991-2000). On the other hand, high-technology-intensive industries experienced higher productivity growth during the 2001-2010 period, while low-to-medium technology industries recorded increased productivity during the 2011-2018 period (see Figure 4).

Figure 3

Growth of Labour Productivity in Indian Manufacturing Sector: By Technology (1991-2018)%



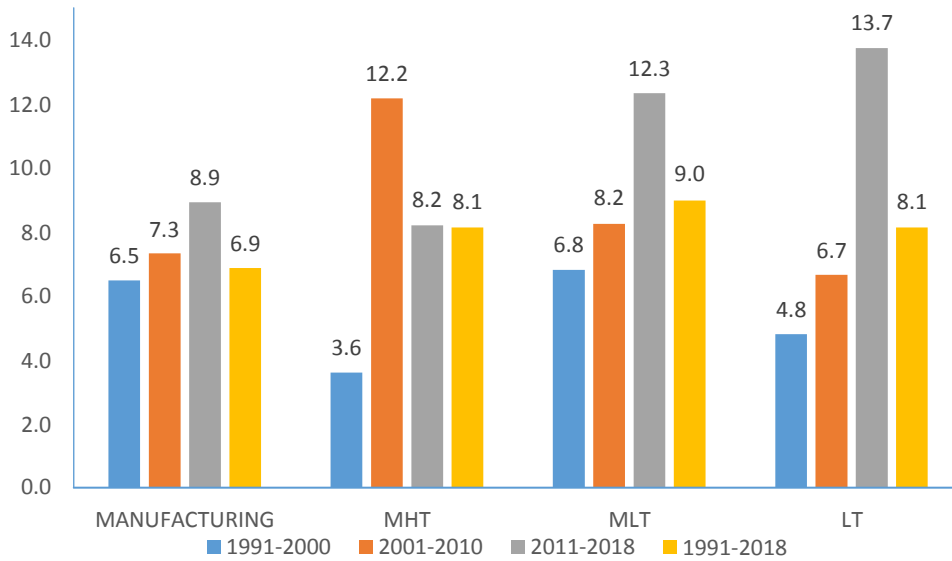
Note: MHT=Medium to High Technology, MLT=Medium to Low Technology, LT=Low Technology

Source: Authors compilation from Annual Survey of Industries (CSO), various issues

A comprehensive analysis at the 3-digit level analysis revealed that a significant portion of the technology-intensive industries such as weapon, ammunition and military fighting equipment, medical equipments, transport equipments including ships, railways and motor vehicles and electronic components exhibited superior productivity growth relative to the overall manufacturing during the entire study period (see Table A1 in the appendix). Furthermore, a sub-period analysis reveals that these industries maintained their high growth trajectory throughout each selected period. In contrast, low to medium-technology industries failed to maintain consistent productivity growth across the varying period. This could be attributed to the influence of certain sector-specific factors or policy effects. In the 1990s and 2000s, a considerable number of LT industries, such as wood, meat & fruit preservation, leather and apparel, recorded a decline in productivity growth. However, this trend revised during the 2011-2018 period, as most industries witnessed positive productivity growth. For MLT, a substantial upward trend in productivity was observed during the 2011-2018 period, particularly in basic iron & steel, metal fabrication and casting, and plastic products.

Figure 4

Labour Productivity Growth in the Manufacturing Sector: By Technology (1991-2018) %



Note: MHT=Medium to High Technology, MLT=Medium to Low Technology, LT=Low Technology

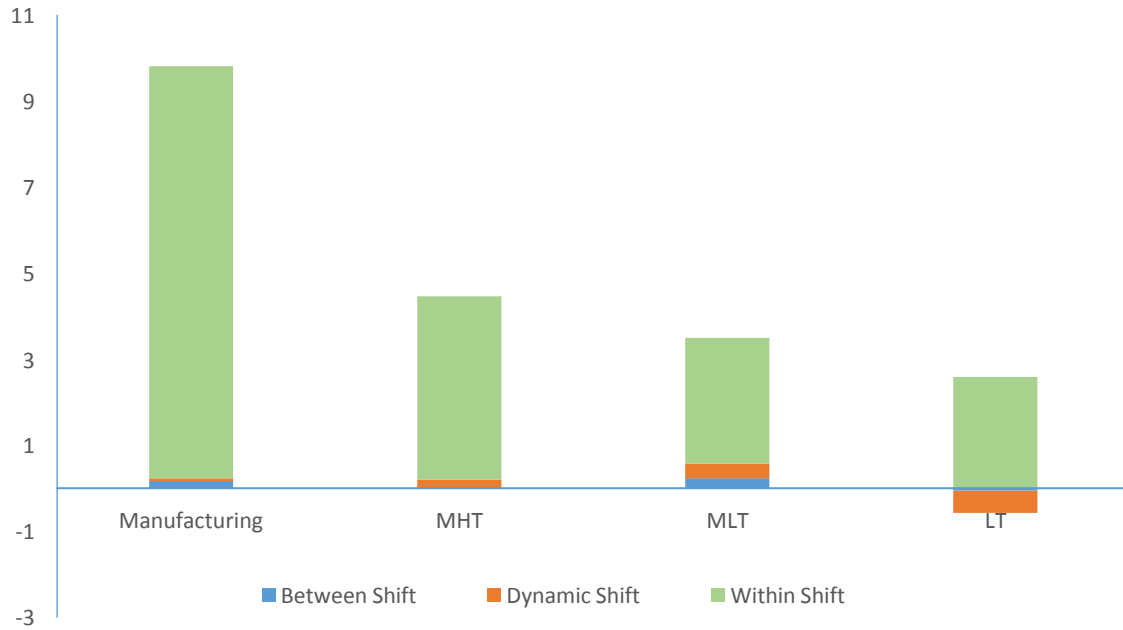
Source: Authors compilation from Annual Survey of Industries (CSO), various issues

3.3.1 Productivity Decomposition Analysis

We have observed that there have been significant changes in labour productivity across the manufacturing sector. As explained in the methodology, the aggregate productivity can be decomposed into three effects, namely, (a) the average growth rate of labour productivity within industries, (b) the effect of productivity resulting from workers' reallocation due to disparities in productivity levels between industries and (c) the effect of productivity from workers movement driven by divergent productivity growth rates between industries over selected period. These latter two components reflect the inter-industrial component where productivity growth stems from the movement of workers between sectors (i.e. structural change), while the first component represents pure technical change within industries over time. The intra-industry effects or within effect is positive when the weighted growth in labour productivity is positive over time. The static-shift component is positive when workers move from industries with less productivity to those with above-average productivity levels. Finally, the dynamic component of the intra-industrial component is positive when workers reallocate towards industries that experience improvement in productivity growth over time. The positive effects reflect that the fast-growing productive industries have been able to improve their share in total manufacturing employment.

Figure 5

Labour Productivity Decomposition in Indian Manufacturing Sector: 1991-2018



Note: MHT=Medium to High Technology, MLT=Medium to Low Technology, LT=Low Technology

Source: Authors compilation from Annual Survey of Industries (CSO), various issues

Figure 5 illustrates the decomposition of labour productivity changes in the manufacturing and technology-intensive industries across three effects. During 1991-2018, the overwhelming part of total productivity growth is accounted for by productivity growth within industries (intra- reallocation effect). This finding is consistent with earlier research conducted by Rijesh (2023), Krishna *et al* (2022), Erumban *et al* (2019) and Ahsan and Mitra (2016). The pattern of intra- industry reallocation is further observed across all technology-intensive industries. The inter- reallocation channel, however, was found to be positive only among the MHT and MLT industries. Conversely, the static and dynamic shifts were found to have negative signs in the LT sector which implies that these industries were unable to improve both productivity and employment opportunities over time. At the aggregate level, we can argue that the majority of industries have not experienced a major reallocation of workers across sectors that contributed to aggregate productivity. The dominant force of productivity gains results from within-sector technical change over time.

Table 2 provides the decomposition exercise across various sub-periods. For the manufacturing sector, the structural change components were found to be positive for all periods, except for the dynamic shift during the period of 2011-2018. Among technology groups, the static effect is found to have a positive impact on the overall productivity of MLT industries in all sub- periods, while

for the MHT industries, it was positive only during the periods of 2001-2010 and 2011-2018. In terms of dynamic effects, the MLT showed a positive change only during the 2001-2010 period, while for the MHT group, it was positive during the 1991-2000 and 2011-2018 periods. In the case of LT industries, most of the structural change effects had a negative impact on productivity growth. In all cases, the intra-sectoral relocation channel was found to have a positive effect throughout the selected periods. Thus we can infer that the within-reallocation channel had a positive effect on productivity across all categories of manufacturing while the static effect was relatively dominant across different industries.

Table 2
Decomposition of Labour Productivity: By Technology-intensive groups (1991-2018) %

Changes in Productivity	Period	Manufacturing Sector	MHT	MLT	LT
<i>Static Shifts</i>		0.161	-0.015	0.232	-0.062
<i>Dynamic Shifts</i>	1991-2018	0.069	0.199	0.338	-0.514
<i>Within Effects</i>		9.583	4.258	2.921	2.586
<i>Static Shifts</i>		0.055	-0.029	0.006	0.068
<i>Dynamic Shifts</i>	1991-2000	0.074	0.070	-0.001	-0.005
<i>Within Shifts</i>		1.130	0.586	0.432	0.149
<i>Static Shifts</i>		0.124	0.019	0.242	-0.136
<i>Dynamic Shifts</i>	2001-2010	0.020	-0.016	0.179	-0.141
<i>Within Shifts</i>		2.867	1.181	1.004	0.662
<i>Static Shifts</i>		0.321	0.223	0.148	-0.066
<i>Dynamic Shifts</i>	2011-2018	-0.059	0.158	-0.135	-0.074
<i>Within Shifts</i>		5.543	2.159	1.880	1.588

Note: LT= Low Technology, MLT: Medium to Low Technology, MHT: Medium to High Technology.

Source: Author calculation based on Annual Survey of Industries (Vol 1), various issues

4 Trade, Structural Change and Productivity: Estimation Results

In this section, we present the econometric results of the model outlined in the methodology. As mentioned previously, the objective of the empirical study was to investigate the impact of trade on labour productivity and determine whether participation in trade enhances labor productivity by facilitating a more efficient reallocation of resources within industries, across industries, or both. Our analysis employs a panel of 58 manufacturing industries identified at the 3-digit level of industrial classification. Further, we categorise the entire sample into threetypes of industrial sectors based on their technology intensity. We apply the standard panel regression method for 58 cross-section units observed over 28 years. Our preferred estimation method, based on the Hausman specification tests, is Random Effects (RE) model, which assumes that the unobserved individual-specific effects are uncorrelated with the observed explanatory variables, and randomly distributed across individuals in the panel. This implies that the individual-specific effects are uncorrelated with the error term in the regression model(see Wooldridge 2010). We use the Huber-

White standard errors to calculate the standard errors, as they are robust in the presence of panel-level heteroscedasticity and autocorrelation of the unknown form, which may be present in our data. To ensure the robustness of our results, we further estimated our model using the panel Feasible Generalized Least Squares (FGLS) estimator which accounts for unobserved heterogeneity across manufacturing units and periods as well as the possibility of serial correlation and heteroscedasticity in the data⁴. This approach estimates a variance-covariance matrix of the error term which takes into account the potential heteroscedasticity and serial correlation in the data.

4.1 Impact of Trade on Labour Productivity

The baseline specification result is reported in Table 3 where we regress the growth rate of labour productivity in overall manufacturing and three technology-intensive categories on various aspects of trade participation, such as changes in the export intensity, import penetration and relative import prices. We also use capital intensity and capacity utilisation as control variables across all specifications. In all regression results, the coefficient estimates on capital intensity and capacity utilisation are statistically significant and positive. This confirms the prevalence of capital deepening in Indian manufacturing and the pro-cyclical nature of productivity, which is consistent with the findings reported by Rijesh (2019).

The results of the panel estimation show that the impact of trade on labour productivity varies considerably depending on different trade aspects. For the manufacturing industry overall, the relative price of imports seems to have a significant negative impact on the growth of labour productivity. This suggests that competition from international products has been detrimental to productive efficiency. This finding is further supported by the negative and statistically significant coefficient on import penetration across both RE and FGLS estimates. Among all the trade variables, only the export coefficient is found to be positive and significant, although its magnitude varies across industry groups. In the case of technology-intensive industries, relative import price has a positive and statistically significant impact on labour productivity in the MLT and LT sectors. In the case of MHT industries, the coefficient is negative but not statistically significant. The technology segments exhibit a dominance of negative economies of scale effects over the productivity-enhancing effects, particularly in the medium technology industries. Conversely, the positive impact of export intensity is only evident in the medium-technology industries, whereas for other industries, we find a negative and statistically significant association between exporting activity and labour productivity.

4.2 Impact of Trade on Structural Change and Productivity

One of the important questions in this paper is whether trade has induced an efficient allocation of resources within sectors, across sectors or both. Using the baseline specification, we investigate the effect of trade participation on the three components of labour productivity growth⁵. The three main dependent variables are the within-effects, static-shift effects and Dynamic Shift effects of structural change. The results of the panel estimation based on REs are reported in Table 4.

In the manufacturing sector, both import penetration and export intensity have a positive effect on within-sector productivity, although the former is not statistically significant. This result is inconsistent with recent trade theories, which suggest that trade can generate gains result without necessitating changes in the specialisation pattern across industrial sectors. However, the positive and statistically significant coefficient on the relative import price variable suggests that competitive pressure from low-priced imports has adversely impacted the intrasectoral productivity of the import-competing industries. Conversely, the impact of trade on the structural change components (i.e., static and dynamic) is all found to be insignificant.

Table 3								
Panel Regression Results of Trade and Labour Productivity in the Manufacturing Sector								
Dependent Variable: Percent Change in Labour Productivity								
Explanatory Variables	Manufacturing		MHT		MLT		LT	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
	RE	FGLS	RE	FGLS	RE	FGLS	RE	FGLS
$\Delta RIMP$	0.0986** (0.049)	0.1239*** (0.019)	-0.0063 (0.027)	0.0097 (0.020)	0.3175*** (0.061)	0.3647*** (0.056)	0.4776*** (0.087)	0.5054*** (0.039)
ΔEXI	0.0014 (0.025)	0.0210* (0.011)	0.0036 (0.027)	-0.0151 (0.011)	0.8296** (0.417)	0.6738* (0.357)	-0.2448** (0.102)	-0.3338*** (0.070)
ΔIMP	-0.0002** (0.000)	-0.0001 (0.000)	-0.0005*** (0.000)	-0.0002 (0.000)	-0.5334 (0.447)	-0.7297* (0.400)	0.0010 (0.005)	0.0006 (0.004)
ΔKI	0.0114 (0.007)	0.0184*** (0.002)	0.0100 (0.024)	0.0343*** (0.003)	0.0075*** (0.002)	0.0087*** (0.002)	0.0373*** (0.013)	0.0652*** (0.008)
ΔCU	1.1883*** (0.121)	1.2122*** (0.041)	1.0275*** (0.208)	1.1972*** (0.059)	1.2253*** (0.117)	1.0834*** (0.077)	1.3022*** (0.300)	1.4288*** (0.075)
Constant	0.0899*** (0.012)	0.0761*** (0.005)	0.0906*** (0.027)	0.0724*** (0.008)	0.0796*** (0.008)	0.0744*** (0.011)	0.0884*** (0.011)	0.0612*** (0.008)
Observations	1,487	1,487	655	655	286	286	546	546
NIC08	58	58	26	26	11	11	21	21
Hausman	2.02		1.16		4.38		0.94	
Prob>chi2	(0.73)		(0.88)		(0.49)		(0.97)	
Chi2-Stat	397.7	104.2	366.2	431.7	290.9	327.1	47.99	728.2
Prob>chi2	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: (a) RE, Random Effects; FGLS, Feasible Generalized Least Squares Estimator, (b) The Huber-White robust standard errors are given in parentheses under estimated coefficients, (c) p-values are given in parentheses under chi² – statistics for Wald test statistic, (d) Hausman statistic is asymptotically χ^2 distributed with p-values in brackets, (e) RIMP, relative import price, EXI, export-intensity, IMP, import penetration, KI, capital intensity, and CU, capacity utilization, (f) MHT, Medium High to High Technology, MLT=Medium Low Technology, LT, Low Technology, *** p<0.01, ** p<0.05, * p<0.1

Table 4

Panel Regression Results: Trade and Labour Reallocation Component of Productivity

Dependent Variable: Within/Static/Dynamic Component

xplanatory Variables	Manufacturing			MHT			MLT			LT		
	Within	Static	Dynamic	Within	Static	Dynamic	Within	Static	Dynamic	Within	Static	Dynamic
$\Delta RIMP$	0.0196** (0.008)	-0.0009 (0.001)	-0.0007 (0.001)	0.0053** (0.002)	-0.0006 (0.001)	0.0002 (0.000)	0.1081* (0.055)	-0.0036 (0.004)	-0.0103 (0.009)	0.0469*** (0.013)	-0.0008 (0.001)	-0.0005 (0.001)
ΔEXI	0.0003 (0.001)	-0.0005 (0.000)	-0.0001 (0.000)	0.0001 (0.000)	0.0003** (0.000)	-0.0001 (0.000)	0.2471** (0.125)	-0.2142 (0.164)	-0.0197 (0.018)	-0.0085 (0.007)	-0.0061* (0.004)	0.0002 (0.001)
ΔIMP	0.0003** (0.000)	-0.0001*** (0.000)	-0.0000 (0.000)	0.0006* (0.000)	-0.0000*** (0.000)	-0.0000 (0.000)	-0.0871 (0.175)	-0.0669 (0.066)	0.0041 (0.020)	-0.0001 (0.000)	0.0001 (0.000)	-0.0001 (0.000)
ΔKI	0.0023*** (0.001)	-0.0003*** (0.000)	-0.0000 (0.000)	0.0013* (0.001)	-0.0004** (0.000)	0.0000 (0.000)	0.0035*** (0.001)	-0.0004*** (0.000)	-0.0000 (0.000)	0.0008* (0.000)	-0.0001 (0.000)	-0.0000 (0.000)
ΔCU	0.1067*** (0.031)	-0.0026 (0.002)	0.0001 (0.002)	0.0613*** (0.021)	-0.0026 (0.004)	0.0001 (0.003)	0.2851** (0.121)	-0.0095 (0.011)	0.0034 (0.007)	0.0374** (0.015)	-0.0023 (0.001)	0.0001 (0.000)
Constant	0.0040*** (0.001)	0.0011** (0.001)	-0.0006*** (0.000)	0.0050*** (0.001)	0.0013** (0.001)	-0.0010** (0.000)	0.0022 (0.007)	0.0044 (0.003)	-0.0005 (0.000)	0.0033*** (0.001)	-0.0003 (0.001)	-0.0002 (0.000)
Observations	1,487	1,487	1,487	655	655	655	286	286	286	546	546	546
NIC08	58	58	58	26		26	11		11	21		21
Chi2-Stat	41.09	49.43	2.527	674.3	170.2	3.124	92.75	18.85	47.99	23.14	9.005	17.07
Prob>chi2	(9.02e-08)	(1.81e-09)	(0.7720)	(0.000)	(0.000)	(0.681)	(0.000)	(0.000)	(3.57e-09)	(0.000)	(0.109)	(0.0043)

Note: (a) Estimation results are based on the Random Effects model (b) The Huber-White robust standard errors are given in parentheses under estimated coefficients, (c) p- values are given in parentheses under chi² – statistics for Wald test statistic, (d) Hausman statistic is asymptotically χ^2 distributed with p-values in brackets, (e) RIMP, relative import price, EXI, export-intensity, IMP, import penetration, KI, capital intensity, and CU, capacity utilization, (f) MHT, Medium High to High Technology, MLT=Medium Low Technology, LT, Low Technology, *** p<0.01, ** p<0.05, * p<0.1

The technology categorisation of industries revealed that trade affects growth by inducing intra-sectoral productivity and not structural change. The impact is mediated by import penetration in MHT and export intensity in MLT. In the LT sector, trade has limited effect as most of the components of productivity growth lack statistical significance. Additionally, the positive coefficient on import prices suggests that higher international competition has a negative impact on domestic production, consistent with previous findings. These results suggest that the impact of trade on aggregate productivity is not substantial and primarily confined to reallocation within industries. The absence of intersectoral changes from trade participation can be attributed to market frictions and rigidities, such as entry barriers, labour market distortions and institutional bottlenecks.

5 Concluding Remarks

In this article, we examined the nexus between international trade, structural change and labour productivity growth in the organised manufacturing sector in India. It is often argued that participating in the international market will provide opportunities to improve productivity through higher specialisation, economies of scale through access to wider markets, the incentive to innovate from higher competitive pressure and access to superior technology inputs and products from abroad. As trade becomes more prevalent, resources can shift toward industries with a comparative advantage or more productive plants within existing industries, resulting in resource reallocation within or between manufacturing sectors. This process can significantly impact the aggregate productivity growth of manufacturing over time, with productivity growth stemming from intersectoral effects and intrasectoral effects. The former is the average productivity growth rate within manufacturing and the latter is the structural change components with productivity growth depending upon worker reallocation across different manufacturing sectors. Using disaggregated Indian manufacturing data, we examined the impact of trade on labour productivity and whether trade has induced efficient allocation of resources that contributed to aggregate productivity during 1991-2018.

The descriptive analysis revealed that the exports and imports of manufacturing have increased significantly, with a shift in the composition of exported products from low-technology to medium-high-technology-intensive products. The study also reveals that the medium to high-technology-intensive industries have shown the highest growth in GVA and wages, whereas the labour-intensive low-technology segment continues to dominate employment generation. The output of manufacturing has grown at a rate of 10 per cent per annum, while the growth rate of employment was relatively modest at 3 per cent per annum, indicating that growth in other factor inputs like wages and fixed capital was higher than employment. In the recent period, the largest contribution to GVA was found in the medium-low to high technology-

intensive manufacturing industries, such as basic iron & steel, pharmaceuticals, chemicals, and botanical products. The textile sector remains an LT segment, with a significant share in employment generation. The study also reveals that the growth rate in employment was the highest in the labour-intensive industries of LT segments. Some of the noteworthy industries with high growth rates included chemicals & pharmaceuticals, weapons and ammunition, parts of motor vehicles, transport equipments and machinery.

We find that the annual growth rate of productivity is largely cyclical, with productivity being comparatively higher during the 2001-2010 and 2011-2018 periods. High-technology-intensive industries experienced higher productivity growth during the 2001-2010 period, while low-to-medium technology industries recorded increased productivity during the 2011-2018 period. In contrast, low to medium-technology industries failed to maintain consistent productivity growth. The productivity decomposition revealed that the majority of productivity gains resulted from within-sector technical change over time. The structural change components were found to be positive for all periods, except for the dynamic shift during the period of 2011-2018. This indicates that productivity growth is primarily driven by technical change within industries and that the majority of industries have not experienced a major reallocation of workers across sectors that contributed to aggregate productivity.

The econometric estimation, based on balanced panel data for 58 manufacturing industries from 1991 to 2018, revealed that the impact of trade on labour productivity varies based on different aspects of trade. The relative price of imports negatively impacts labour productivity, while export intensity has a positive impact, although its magnitude varies across industry groups. Our findings suggest that trade primarily induces intra-sectoral (within productivity) and has a limited impact on productivity through labour reallocation between sectors. This suggests that the impact of trade on aggregate productivity is not substantial and is mainly confined to reallocation within industries. The absence of structural change from trade openness can be attributed to the existence of market frictions and structural rigidities that prevent efficient resource allocation across the manufacturing sector in India.

APPENDIX TABLES

Table A1

Structure and Growth of the ~~Organized~~ Manufacturing Sector: 3-digit level (1991-2018) %

Sl No	NIC-08	Description	Gross Value Added			Employment			Wages			Capital			LPG
			Share		Growth	Share		Growth	Share		Growth	Share		Growth	
			1991	2018	1991-2018	1991	2018	1991-2018	1991	2018	1991-2018	1991	2018	1991-2018	
1	101	Processing & preserving of meat (LT)	0.0	0.1	12.2	0.0	0.2	8.8	0.1	0.1	8.9	0.0	0.1	15.7	3.1
2	102	Processing & preserving of fish (LT)	0.3	0.4	9.0	0.2	0.6	6.6	0.1	0.4	10.0	0.1	0.2	14.8	2.3
3	103	Processing & preserving of fruit, vegetables (LT)	0.1	0.3	14.6	0.2	0.5	6.6	0.1	0.4	9.9	0.1	0.3	16.2	7.5
4	104	Vegetable & animal oils, fats (LT)	1.4	0.7	5.0	1.6	0.7	-0.2	1.0	0.6	2.9	1.2	0.7	8.7	5.2
5	105	Dairy products (LT)	0.6	1.0	9.6	0.9	1.3	4.4	1.1	1.3	5.6	0.5	1.0	13.6	5.0
6	106	Grain mill products, starches & starch products (LT)	1.3	1.8	10.7	3.2	2.6	2.1	1.1	1.3	5.5	0.9	1.0	11.2	8.5
7	107	Other food products (LT)	5.4	3.2	6.4	9.2	5.7	1.1	6.5	4.2	3.4	4.0	3.9	10.8	5.2
8	108	Prepared animal feeds (LT)	0.2	0.4	13.0	0.2	0.5	7.0	0.1	0.5	9.9	0.1	0.3	17.1	5.6
9	110	Beverages (LT)	1.2	1.6	9.5	0.9	1.2	4.2	0.8	1.1	6.2	0.8	1.3	13.2	5.1
10	120	Tobacco products (LT)	2.0	1.3	6.5	6.6	3.0	0.0	2.0	0.7	0.9	0.3	0.2	9.6	6.6
11	131	Spinning, weaving & finishing of textiles (LT)	10.6	4.2	4.6	16.8	8.7	0.4	16.4	6.0	1.2	9.0	4.6	8.2	4.2
12	139	Other textiles (LT)	0.4	1.5	13.7	0.5	2.4	9.1	0.4	1.8	11.0	0.3	1.2	16.9	4.3
13	141	Wearing apparel (LT)	1.6	1.9	9.9	1.8	5.4	7.1	1.1	3.7	10.0	0.4	0.7	13.5	2.6
14	142	Articles of fur (LT)	0.0	0.0	0.2	0.0	0.0	1.0	0.0	0.0	1.2	0.0	0.0	-3.0	-0.8
15	143	Knitted & crocheted apparel (LT)	0.4	0.8	10.2	0.5	2.5	9.6	0.3	1.5	11.7	0.1	0.4	15.1	0.5
16	151	Tanning & dressing of leather, luggage, handbags, saddlery & harness, dressing & dyeing of fur (LT)	0.5	0.3	7.9	0.7	0.8	3.6	0.5	0.6	5.8	0.2	0.2	9.4	4.1
17	152	Footwear (LT)	0.6	0.7	10.4	1.0	1.9	5.5	0.7	1.3	7.1	0.4	0.3	9.0	4.6
18	161	Sawmilling & planing of wood (LT)	0.1	0.0	1.7	0.3	0.0	-4.1	0.1	0.0	-1.9	0.0	0.0	7.3	6.1
19	162	Wood, cork, straw & glazing materials (LT)	0.3	0.3	9.8	0.5	0.6	3.4	0.3	0.4	7.0	0.2	0.2	12.0	6.2
20	170	Paper & paper products (LT)	2.5	1.8	7.5	2.1	2.1	2.9	2.2	1.9	4.3	3.0	2.1	9.5	4.4
21	181	Printing & service activities related to printing (LT)	0.5	0.9	10.6	0.8	1.0	3.8	0.7	1.1	7.1	0.3	0.8	14.6	6.6
22	191	Coke oven products (MLT)	0.5	0.1	3.7	0.4	0.3	1.7	0.5	0.2	0.2	0.5	0.3	8.7	1.9
23	192	Refined petroleum products (MLT)	3.2	5.2	9.4	0.4	0.9	6.2	1.0	2.3	8.4	3.7	15.2	16.9	3.0

Sl No	NIC-08	Description	Gross Value Added			Employment			Wages			Capital			LPG
			Share		Growth	Share		Growth	Share		Growth	Share		Growth	
			1991	2018		1991-2018	1991		2018	1991-2018		1991	2018		
24	201	Basic chemicals, fertilizer & nitrogen compounds, plastics & synthetic rubber in primary forms (MHT)	8.6	5.9	7.7	2.8	2.3	2.1	5.2	3.6	3.6	12.0	7.4	9.0	5.4
25	202	Other chemical products (MHT)	4.5	4.9	10.2	3.5	3.0	2.3	3.1	3.4	5.4	2.6	2.2	10.3	7.7
26	203	Man-made fibres (MHT)	-0.1	0.5	6.3	0.3	0.5	4.6	0.9	0.5	2.9	2.1	0.8	6.8	2.0
27	210	Pharmaceuticals, medicinal chemicals & botanical products (MHT)	3.6	8.4	13.3	2.1	5.0	6.2	3.3	7.3	8.2	2.0	4.4	14.2	6.6
28	221	Rubber products (MLT)	1.9	1.5	9.0	1.3	1.7	3.7	1.5	1.8	5.6	1.6	1.5	10.6	5.1
29	222	Plastics products (MLT)	1.4	2.9	13.9	1.3	3.7	7.1	1.0	3.3	9.7	1.1	2.4	14.1	6.4
30	231	Glass & glass products (MLT)	0.8	0.4	6.2	0.9	0.5	0.5	0.8	0.5	3.1	0.6	0.5	10.6	5.6
31	239	Non-metallic mineral products ~~o.e.c~~ (MLT).	6.6	5.6	8.6	5.7	6.4	3.3	4.0	4.4	5.4	6.8	6.7	10.8	5.1
32	241	Basic iron & steel (MLT)	7.1	8.6	9.5	6.0	5.0	2.2	6.5	6.7	5.1	24.2	17.4	9.6	7.1
33	242	Basic precious & other non-ferrous metals (MLT)	2.2	2.1	8.8	0.9	0.9	2.9	1.3	1.5	5.4	3.1	3.6	11.5	5.8
34	243	Casting of metals (MLT)	1.2	1.3	9.7	1.8	1.7	2.8	1.7	1.5	4.5	0.9	1.1	12.2	6.7
35	251	Structural metal products, tanks, reservoirs & steam generation (MLT)	2.4	1.3	6.7	2.5	1.7	1.4	2.8	2.0	3.7	1.2	0.8	9.1	5.2
36	252+304	Weapons and ammunition+ military fighting vehicles (MHT)	0.0	0.0	22.5	0.0	0.0	7.0	0.0	0.0	13.4	0.0	0.0	33.6	14.5
37	259	Other fabricated metal products; metalworking service activities (MLT)	1.4	2.0	12.2	1.6	2.8	5.0	1.5	2.6	7.1	0.9	1.2	11.9	6.9
38	261	Electronic components (MHT)	0.4	0.6	13.6	0.4	0.6	4.6	0.4	0.6	6.6	0.6	0.2	6.3	8.6
39	263	Communication equipment (MHT)	1.6	0.6	8.1	0.8	0.4	0.3	1.3	0.8	3.0	0.6	0.3	8.2	7.8
40	264+268	Consumer electronics+ magnetic & optical media (MHT)	0.9	0.2	6.1	0.5	0.1	-2.3	0.6	0.3	2.7	0.6	0.1	3.3	8.5
41	265	Measuring, testing, navigating & control equipment watches & clocks (MHT)	0.8	0.6	10.4	0.7	0.4	1.0	0.8	0.8	5.0	0.6	0.1	5.1	9.3
42	266	Irradiation, ~~electromedical~~ & electrotherapeutic equipment (MHT)	0.0	0.1	7.6	0.0	0.1	-4.2	0.0	0.1	0.9	0.0	0.0	2.8	12.3
43	267	Optical instruments & equipment (MHT)	0.0	0.0	8.4	0.0	0.0	-0.7	0.1	0.0	1.3	0.0	0.0	5.8	9.2
44	271	Electric motor, generator, transformers & electricity distribution and control apparatus (MHT)	3.5	1.6	7.3	2.3	1.5	1.3	4.2	2.2	2.6	1.3	0.8	9.1	6.0
45	272	Batteries & accumulator (MHT)	0.3	0.5	11.5	0.2	0.4	5.4	0.3	0.4	6.8	0.1	0.3	14.3	5.9
46	273	Wiring & wiring devices (MHT)	0.9	0.9	11.7	0.5	0.8	4.6	0.7	0.8	5.6	0.7	0.4	8.7	6.7
47	274	Electric lighting equipment (MHT)	0.4	0.3	13.2	0.3	0.5	4.4	0.4	0.5	6.0	0.3	0.2	10.5	8.4
48	275	Domestic appliances (MHT)	0.2	0.4	13.0	0.3	0.4	3.0	0.3	0.4	5.4	0.1	0.2	12.8	9.7
49	279	Other electrical equipment (MHT)	0.2	0.4	11.4	0.2	0.4	6.0	0.3	0.5	7.6	0.1	0.2	13.6	5.1

Sl No	NIC-08	Description	Gross Value Added			Employment			Wages			Capital			LPG
			Share		Growth	Share		Growth	Share		Growth	Share		Growth	
			1991	2018	1991-2018	1991	2018	1991-2018	1991	2018	1991-2018	1991	2018	1991-2018	
50	281+282	General purpose machinery+ computers & peripheral equipment (MHT)	3.8	3.8	10.2	2.7	3.3	4.0	3.9	3.3	6.4	2.1	2.1	10.9	6.0
51	282	Special-purpose machinery (MHT)	3.6	3.3	9.5	3.3	2.8	2.2	4.4	3.8	4.4	1.9	1.7	10.3	7.1
52	291	Motor vehicles (MHT)	4.4	3.9	9.4	2.7	1.4	0.5	5.0	3.2	3.3	2.9	3.1	11.2	8.9
53	292	Bodies (coachwork) for motor vehicles; trailers & semi-trailers (MHT)	0.1	0.5	14.7	0.2	0.5	6.6	0.2	0.7	10.1	0.1	0.3	14.5	7.7
54	293	Parts & accessories for motor vehicles (MHT)	0.0	4.7	15.3	0.0	5.3	8.3	0.0	5.8	9.7	0.0	3.1	13.3	6.5
55	301	Building of ships & boats (MHT)	0.2	0.1	8.3	0.3	0.1	-1.6	0.4	0.1	1.5	0.1	0.3	14.3	10.0
56	302	Railway locomotives & rolling stock (MHT)	1.6	0.3	3.6	3.1	0.3	-5.4	4.1	0.4	-4.1	1.1	0.2	4.0	9.5
57	303	Air & spacecraft-related machinery (MHT)	0.2	0.2	12.2	0.1	0.2	3.6	0.5	0.3	2.5	0.1	0.1	13.9	8.3
58	309	Transport equipment N.E.C. (MHT)	1.6	2.8	14.1	1.4	1.9	4.0	1.7	2.1	5.9	1.1	1.0	10.7	9.8
59	10-30	Manufacturing Sector	100.0	100.0	10.0	100.0	100.0	2.9	100.0	100.0	5.0	100.0	100.0	10.9	6.9
60	MHT	Medium-High & High Technology	41.4	45.4	12.2	29.0	32.6	5.1	41.5	43.6	7.1	33.4	29.7	17.0	8.1
61	MLT	Medium Low Technology	28.8	31.1	13.1	22.9	25.7	4.2	21.3	25.8	6.3	44.7	50.8	15.2	9.0
62	LT	Low Technology	29.9	23.5	12.8	48.1	41.8	5.6	37.2	30.6	8.8	21.9	19.5	16.0	8.1

Note: The growth figures are Compound Annual Growth Rate (CAGR) in per cent. The technology-intensive classification of manufacturing activities is based on OECD (2011), Weiss (2015) and Bijesh (2019; 2023); LPG denotes Labour Productivity Growth in per cent

Source: Author calculation based on Annual Survey of Industries (A.S.I.), various issues & EPWRF Time Series data

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Notes

¹ The new trade theory suggest significant productivity gains at the sectoral level from plant level heterogeneity (see Melitz and Redding, 2014 and Bernard et al., 2003).

² The intrasectoral component arises from increased capital accumulation, technological change or efficient resource allocation across plants. The intersectoral effect operates through the movement of workers from less productive to more productive activities (see Konte, 2022; Rijesh 2023).

³ Wacziarg and Wallack (2004) empirically explored the impact of trade liberalisation on structural change and found that that trade openness has led to marginal intersectoral labour reallocation at the 3-digit level of industrial classification. Pavcnik (2002) find evidence of within productivity improvements in the Chilean plants in the import-competing sector. In most cases, the aggregate productivity improved from the reshuffling of resources and output from less to more efficient manufactures.

⁴ The FGLS estimator is derived by estimating a variance-covariance matrix of the error term, which takes into account the potential heteroscedasticity and serial correlation in the data. This estimator is then used to transform the original data, such that the transformed errors are homoscedastic and uncorrelated. For a recent exposition of FGLS in panel data, see Bai et al (2021).

⁵ This is similar to the framework by Konte et al (2022).

Innovation and marketing in the catch-up of Chile's natural resource-based industries: a micro-level analysis of exporting firms

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Abstract

Natural resources-based industries are key industries in which several countries, particularly in Latin America and Africa, attempt to catch-up. These industries are characterized by geographic specificity and knowledge idiosyncrasy, and are often considered 'low-tech' industries, in which innovation and R&D do not play a major role in the catching-up process. This paper takes the opposite view. It examines the food and beverages and the wood and paper industries in Chile in the period 1995-2013 and, using a very large database of 12,169 firms, develops a firm-level analysis. The paper considers exports as an indicator of catch-up and shows that exports of domestic firms in natural resource-based industries take place not just because of the mere abundance of local natural resources to be exported at a low price. Rather, domestic firms catch-up when they couple the use of domestic natural resources with innovation efforts, marketing strategies and the use of local intermediate inputs, regardless of firms' size and age. These results provide strong evidence and useful policy indications on the key factors that are at the base of catch-up and increase exports in natural resource-based industries.

Keywords: marketing strategies, firm-level, innovation, catching-up, MNEs, domestic firms, natural resource-based sectors.

JEL codes: F14, F23, F61, M31.

I. Introduction

This paper analyzes the catching up by Chilean firms examined at the exports level during the period 1995-2013. In particular, it investigates the factors that operate at the base of successful production for export and the main strategies that exporting firms follow to innovate in relation to natural resource- based sectors. We examine firms in terms of type of production for end markets (exporter and non- exporters) and type of ownership (domestic or foreign owned). We utilize data from Chile's industrial survey ENIA as well as the latest available versions of the country's biennial innovation survey. By doing that we build an unique dataset that has information on key industrial variables and on innovation activities of exporting manufacturers.

Our results suggest that, in the context of natural resource-based industrialization, production for foreign markets takes place because domestic firms couple the abundance of locally produced inputs with skilled labor, innovation and marketing efforts. In fact, the more Chilean firms produce for exports the more they spend in R&D and use more highly skilled labor. Our contribution provides convincing empirical evidence about existing studies that have previously examined catching-up in Chilean manufacturing. For instance, Álvarez and Crespi (2007) studied catching-up dynamics between domestic and foreign owned firms through the analysis of total factor productivity indicators, which were computed at the firm-level but lack specific emphasis on exporting firms. On the other hand, Izuka and Katz (2015) as well as Morrison and Rabellotti (2017) documented the increasing presence of salmon and wine Chilean exports in foreign markets through detailed case studies that relied on aggregate information but that did not account for the different type of firms engaged in exporting.

With respect to the literature mentioned above, this paper provides three contributions. First, we devote special attention to the role played by natural resource-based industries within the more general catching-up trajectory of Chile's exporting sector. We provide world and country level empirical evidence on the emergence of two leading export subsectors for Chilean manufacturing (food and beverages as well as wood and paper products) and examine the set of factors that influence their increasing presence in global markets.

Second, the study of innovation related indicators across exporters and non-exporters represents another novel element of this paper. We provide additional insights on the firm-level elements that shape the innovation performance of the

firms operating in these natural resource-based sectors. These elements include R&D intensity, the composition of innovation expenditures, the type of innovation strategy, the use of highly-skilled labor as well as the relevance of sales of new and old products.

Finally, the econometric analysis of the impact of capital, labor productivity, use of domestic intermediates and marketing expenditures on the production for exports generated by domestic and foreign owned plants constitutes another novel element of this research. The main point here is that export promoting policies should not only be limited to account for factors such as higher access to capital and/or tighter integration with local suppliers of intermediate inputs. The role played by marketing expenditures as well as by the acquisition of knowledge outside the local boundaries are also relevant for catch-up.

This paper is structured as follows. Section II reviews the literature on the link between catching-up, exports and marketing strategies and briefly describes current quantitative work studying the role played by natural resource-based industries on the catching-up process by Chile and other key emerging economies. Section III provides empirical evidence on the performance of exporters at the world as well as at the national level, while section IV presents descriptive indicators on the innovation activity followed by firms according to their type of ownership and type of end market orientation (domestic or foreign demand). Section V introduces the main source of micro-level information, the operationalization of key dependent and independent variables. It then shows our main micro econometric results. Section VI presents our robustness results and section VII the confirmation of our analysis coming from a novel dataset that merges information from industrial and innovation surveys. Finally, section VIII concludes the paper.

II. Literature review.

Catch-up describes a phenomenon in which latecomer firms manage to achieve similar or superior economic or technological performance compared to the incumbent leaders of the industry. In the last decades, the analysis of catch-up has been quite broad and has concerned various levels of analysis, - the firm, industry and country level-. For a general discussion see Lee and Malerba (2017), Malerba and Lee (2021) and Lee *et al.* (2020).

Domestic firms are the key players in the catch up of industries and countries. Here the analysis has been centered on the capabilities of domestic firms. Authors, such as Mathews (2002), Hobday (1995), and Bell and Figueiredo (2012) define latecomer firms from emerging economies as resource-poor late entrants.

Latecomer firms have to learn how to utilize existing resources effectively but also, more importantly, how to acquire and develop the critically lacking resources. These resources include first of all, human capital, then physical capital, R&D, networks and connections, management skills and finally brand. These key resources may be different across firms and across countries. As shown by Lee and Temesgen (2009), for firms with low levels of capabilities, growth is mainly due to basic resources such as physical capital and basic human capital. On the contrary for high levels of capability, growth is driven by R&D and management skills. This fits very well with the theory of the stages of catch-up by latecomer firms, which according to Kim (1997) goes through three stages: duplicative imitation, creative imitation and innovation.

The entry in the global economy is a key moment in the catch-up process, and the access to international markets through exports is a key aspect (Ernst and Guerrieri, 1998; Sturgeon and Gereffi, 2009). Learning through exporting in the form of feedbacks on blueprint and designs, quality control, and technical advice is a major element of capability building for catch-up firms (Dahlman *et al.*, 1985; Rhee *et al.*, 1984). In general, exporting has been found to be the most important strategy for firm catch-up. (Lee and Temesgen, 2009). For most latecomer countries export variety is a determinant of their ability to catch-up with the most advanced countries (Saviotti *et al.*, 2010).

As a consequence, a great number of studies has relied on export-related indicators as measure of catching-up. According to this approach, catching-up is the closing of an existing gap between incumbents and latecomers through the analysis of world market shares or unit values, underscoring global trends in prices or quality. Empirical research includes the analysis of Indonesia's catching up in pulp and paper manufacturing with respect to the global technological leader (Finland) (Van Dijk and Szirmari, 2011); the rise of Korean manufacturing in the production of passenger cars, telecommunication equipment and steel (Lee and Lim, 2001; Hodbay *et al.*, 2004; Lee and Ki, 2017); the emergence of India's pharmaceutical industry as a global leading supplier of generic drugs (Kale and Little, 2007); the emergence of Brazil as a major pulp exporter through a process of capability building and the innovative use of eucalyptus forests (Figuereido, 2010); the spectacular performance of Argentina, Chile and South Africa as newcomers in the production of wine by closing the gap with respect to top exporters (Farinelli, 2007; Cusmano *et al.*, 2010; Morrison and Rabelotti, 2017), the technological leapfrogging of China within the telecom industry (Mu and Lee, 2005), the catching up dynamics between domestic and foreign owned firms located in China in the context of the integration into global supply chains (Blomingen and Ma, 2010; Lyu *et al.*, 2019). On the basis of these studies, it can be then concluded that information on exports of firms, industries and countries represents a tool in the analysis of catch-up which highlights shifts in the world leadership of industries

together with the identification of the set of factors at the base of catch-up.

In general, catch-up is often the result of the right combination of technology and marketing strategies (Malerba *et al.*, 2017). For example, in sectors with segmented markets and generational technological changes (such the one of mobile phones in China examined by Li *et al.*, 2019), domestic firms may focus first on a segment of the market that allows them to survive (such as a low-end market) (Mu and Lee, 2005). Later, generational technological changes open up windows of opportunities in new product segments, so that domestic firms that successfully accumulate and upgrade their technological capabilities move from the low-end market to the high-end market. Relatedly, Kumaraswamy *et al.* (2012) find that latecomer firms often adapt their catch-up strategies from strategies that focus on sourcing technologies to strategies that focus on developing customer relationships.

These studies therefore confirm that also marketing strategies matter for catch-up (Kaplan & Norton, 2008; Nedelko and Potočan, 2016). The analysis of marketing is part of the general discussion on managerial goals, changes in operations and behavior and business process reengineering (Newman, 2000). In this respect, managerial upgrading includes the acquisition of organizational and managerial tools and the reorganization of existing managerial activities in order to facilitate internal and external learning which can lead to improved firm-level efficiency, effectiveness and innovation (Yoruk, 2019). Managerial upgrading also underlies the upgrading of organizational capabilities related to marketing (Salazar-Elena and Guimon, 2019). But managerial upgrading is often difficult because there is rarely an incentive to undertake upgrading (Yoruk, 2019). Thus upgrading is an internally driven process, requiring firms to put into place incentives for employees to apply their skills and efforts to organizational objectives and allocate resources for catch-up (Aridi *et al.*, 2020). Within capabilities and managerial practices, marketing capabilities¹ are expected to influence firm's performance positively because they are related to firm's capability to successfully manage information and adapt to the environment. When catch-up by firms and in particular exporting firms are examined, Leonidou *et al.* (2002) concludes that marketing mix capabilities are utilized to develop and implement the company's product, pricing, distribution, and promotion strategy in export markets and that they are key elements to superior export performance. Thus, firms that enjoy superior marketing capabilities have been found to have a better international performance (Khurshid *et al.*, 2013). From the viewpoint of industrial economics, marketing innovation (in the form of strong brand image and customer loyalty) constitutes a source of competitive advantage difficult for competitors to imitate (Edeh *et al.*, 2020). Marketing and internationalization strategies are also then linked to higher overall innovation performance as the search for new global markets niches strengthen the cooperation and communication between the different functions of the firms (information technology, operations, executive management and so forth) (Ren *et al.*, 2015).

A final note regards catch-up in natural resources industries, such as the case of Chile. Natural resource industries are characterized by geographic specificity and knowledge idiosyncrasy, and are often considered 'low-tech' industries. However, Figueiredo and Cohen (2019) show that in these industries catching-up firms have advanced technological and market capabilities. A characteristic of natural resource industries is that due to their geographically specific and idiosyncratic nature, firms cannot just absorb knowledge from leading incumbent countries. Latecomer firms have to develop distinct knowledge and technologies which are appropriate to the specific natural conditions of their industries. As Figueiredo and Cohen (2019) remark, in these industries catch-up firms have idiosyncratic in-house learning efforts that create quite effective capabilities. However, following Katz (2006) and Iizuka and Soete (2011), some of these resource-rich countries experience a resource curse due to the fact that these countries have limited investments in knowledge and weak institutions that do not support the processes of learning, upgrading and diversification in related manufacturing and services (Lundvall, 2016). In the case of Chilean salmon farming, Iizuka and Katz (2011) show that a country has to develop a set of appropriate institutions that can monitor and manage the exploitation of a common pool of resources under conditions of long-term sustainability. These institutions have to maintain close and effective interactions with the natural resource industries in order to foster environmental sustainability. Lebdioui et al. (2020) confirm this view, by examining the success of Chile in several resource-based sectors. With regard to the Chilean mining industry, Navarro (2018) and Stubrin (2018) provide in depth analyses on the interplay amongst exporting activity, value chain participation and learning and innovation competences across local mining firms.

In addition to the Chilean case, other quantitative research has aimed to describe strategies for successful natural based industrialization at key emerging economies. For instance, Ghebrihiwet (2019) highlights the relevance of cooperative agreements across natural resource companies in South Africa. Here local firms specialized in these types of sectors are more likely to participate in activities for product and process innovation if they engage on research partnerships with other foreign customers or suppliers. Figueiredo and Piana (2021) further confirm the pivotal role played by domestic firms in the catching up process of Brazilian firms in natural resource-based industries. Leading domestic mining firms (which heavily dominated this industry) have successfully managed to implement technological learning strategies in response to changing windows of opportunities, consequently placing Brazil at world class technological and market standards. Finally, Indonesia's specialization on cocoa manufacturing underscores the need to reformulate policies for natural resource-based industrialization to

explicitly account for current trends in global production networks. According to Neilson *et al.* (2020), Indonesia's industrial policy has not only to align to the strategies of leading firms but also to the country's position on the cocoa and chocolate value chain as well as on the existing regional and institutional settings across the neighboring economies.

III. An introduction to the recent performance of Chilean exporters

In order to examine the international performance of Chilean exporters over recent years, we have identified the country's leading sectors and the role they play in shaping national catching-up, defined here as manufacturing production for foreign markets. To assess the international performance of Chilean exporters, we examine the share in world's exports of the country's top product categories, their main geographical destination by major region of global economy, as well as their evolution in terms of quality (the ratio of value of exports per unit of volume). Our analysis runs from 1995 to 2013. This period includes major events in the world economy (global financial recession in the early 2010's) and as well as in Chile (major trade agreements in the early 2000's and impact of the earthquake in Chile in 2010).

According to Table (1), Chile's main manufacturing product categories for export belong to natural resource-based sectors. Their shares in global markets have steadily increased over time. Non-ferrous metals stand out as the product category exported by Chilean producers with the highest share in world exports. Its predominant role in global markets is largely explained by the importance of the mining sector for the overall economic activity in Chile.

Table (1). Share (%) of Chile's top exporting goods in world's total exports (1995-2013).

SITC rev. 3 (two-digit level)	1995	2000	2005	2010	2013
Non-ferrous metals	5.2	4.6	6.4	8.5	6.8
Fish (not marine mammals)	2.3	3.1	3.6	2.8	3.5
Vegetables and fruit	2.0	2.2	2.6	2.7	2.7
Beverages	0.6	1.7	1.6	2.0	1.9
Cork, wood manufactures	0.5	0.8	1.1	1.4	1.2
Meat and meat preparations	0.1	0.2	0.8	0.6	0.6
Paper, paperboard, etc.	0.2	0.2	0.3	0.4	0.4
Cereals and cereal preparations	0.2	0.2	0.2	0.2	0.3
Metals manufactures, nes.	0.1	0.1	0.1	0.1	0.1

Source: UN Comtrade database

Note: Exports of goods are ranked according to the values reported by Chile in 2013. Shares here reported refer to the share of Chile's exporting good in world's total exports of that same good.

Table (1) also highlights that Chile's wood industry (cork, wood and paper) has doubled its global marketshares from 1995. Along with Brazil, Chile is one of South America's largest manufacturing exporters of forestry products. Its recent expansion on the production of pulp, paper, tissue and paperboard mills have made the country become a truly global player (UNECE/FAO, 2013). Even more so, it is worth noting here the increasing presence in global markets of other product categories within the food and beverages industry. As Iizuka and Katz (2015) point out, the Chilean salmon industry has dramatically expanded since the 1980s thus leading the country to become the second largest global producer before Norway. Table (1) indicates that Chilean exports of beverages are three times larger in 2013 than they were in 1995. Local Chilean wine producers (along with producers in other emerging economies such as South Africa) have taken advantage of recent changes on international demand and have successfully managed to expand their production for exports thus challenging the position of well-established wine producers such as Italy (Morrison and Rabelloti, 2017).

The analysis of the main destination markets of the key exports of a country is essential for understanding the process of catching-up, as higher production for exports to advanced countries may highlight the upgrade of local producers to compliance to strict demand specifications (Grossman and Helpman, 1991; Gereffi, 1999). Information on Chile's main destination market is introduced in table (A.2.1) exclusively for non-mining related product categories. We observe that (with the exception of paper products) the main destination markets from Chile's top product categories are not South America but major advanced regions elsewhere (North America, Europe and Asia). Such pattern of production for exports beyond Chile's immediate neighbors has been already present since 1995, even before the country's signing of major free trade agreement with South Korea and the EU (2003) and with the United States (2004).

The higher quality of Chilean production for top international markets is also confirmed by the increasing unitary value of exports reported in table (A.2.2). From this table it can be concluded that the food related product categories are the ones that have experienced the most substantial and steady increases on the quality of their production. The respective ratios for wood products, on the other hand, have been constant over time. It is also worth noting that Chilean export prices (here associated to quality ratios) do not seem to have increased more than the export prices of other countries, as observed in the generally higher world average quality ratios also reported for each product category on this latter table.

This consolidation of two leading resource-based sectors for the production for global markets (food and beverages and wood manufacturing), and a constant expansion of the exporting sector with respect to the non-exporting one (in terms of higher output, gross value added, use of labor, and productivity increases)

characterizes Chile. In line with Table (2), we observe that the sectoral composition of manufacturing exports in Chile remained basically unaltered over the period (with food and beverages and wood and paper products accounting of more than 60% of total exports from 1995 to 2013). Such empirical finding highlights Chilean firms' strategy to progressively produce for foreign markets by strengthening its traditional pattern of manufacturing specialization based upon key factor endowments and the country's competitive advantages. We regard this strategy as a process of natural resource-based industrialization and catch-up where two leading manufacturing subsectors (food and beverages and wood and paper products, in this case) managed to steadily increase the country's production for exports over time. As from table (A.2.3), this strategy is reflected from the mobilization of resources in favor of the exporting sector away from the non-exporting one. For instance, while in 1995 non-exporters accounted for nearly

$\frac{3}{4}$ of the total output, gross value added and labor employed in Chilean manufacturing, by the end of the 2000s, Chilean exporters generated nearly half of the total output and gross value added in total manufacturing by employing $\frac{1}{4}$ of the available working force.

Table (2) (%). Sectoral shares in Chile's total exporting output.

Manufacturing sectors (ISIC, rev. 3)	1996	2000	2005	2010	2013
Food products, beverages, tobacco	39	36	26	35	39
Wood, paper, paper products, printing	24	27	23	22	21
Chemicals and non-metallic mineral	10	16	21	22	20
Basic metals and fabricated metals	19	15	27	18	17
Rest of sectors	8	6	3	3	3
Total manufacturing exports	100	100	100	100	100

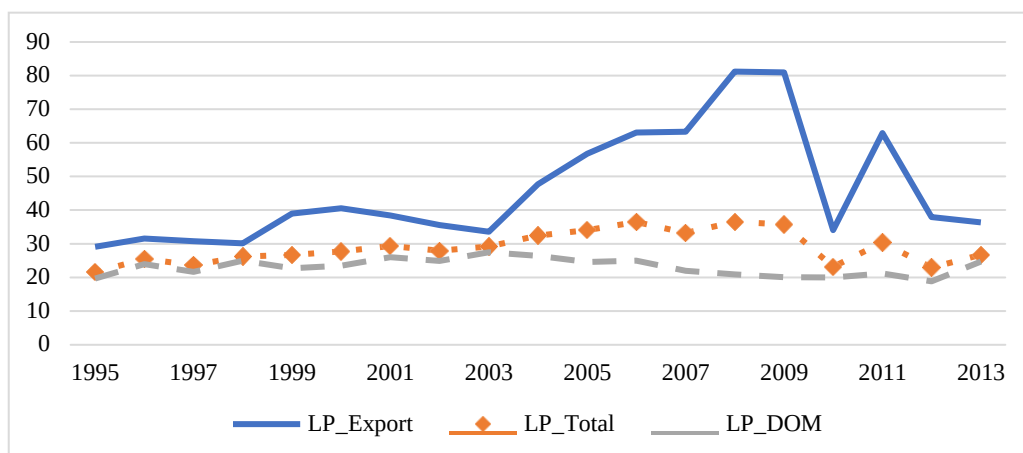
Source: Banco Central de Chile. Sistema de Cuentas Nacionales.

Figure (1) describes labor productivity trends from 1995 to 2013 (in Chilean constant prices of 2009) for exporters, non-exporters and manufacturing producers. This figure confirms that Chilean exporters register higher labor productivity levels than other non-exporters (Bravo-Ortega *et al.*, 2014), also with respect to the other manufacturing producers. The productivity gap between exporter and non-exporters considerably widened during the immediate years that followed the country's accession to bilateral free trade agreements with Europe, South Korea and

the USA (i.e. beyond 2003).

Figure (1). Evolution of labor productivity in Chilean manufacturing: 1995-2013.

Thousands of Chilean pesos in constant prices (2009=100).



Source: Authors' calculation based on ENIA (2018 update).

Note: Labor productivity is here measured (in constant Chilean pesos of 2009) as the ratio of gross value added to labor. "LP_Export" stands for the labor productivity of exporting firms, "LP_Total" indicates the productivity of all manufacturing firms in Chile, while "LP_DOM" describes the productivity of firms mostly producing for the domestic Chilean market. (i.e. the non-exporters).

Such considerable productivity improvements reveal the stiff competitive pressures that Chilean exporters faced when export tariffs were lowered and full access to major end markets in the world economy had been finally granted. More importantly, following the findings from Linarello (2018), such important advances in productivity can also be explained by the higher purchases of foreign machinery and equipment made by exporting firms (given the availability of lower import tariffs) in response to the pressing demand to update technological capabilities and cope with the new and increasing production for global markets. In addition, the dramatic decrease of labor productivity faced by exporters at the end of 2000s was the result of the 2008 financial crisis and the consequent global recession, as well as the 2010 earthquake that severely affected Chile. Positive signs of recovery on labor productivity levels by 2011 were offset by sluggish growth in some of Chile's key trade partners (mostly the EU and China) (ECLAC, 2013). As can be seen from Figure (1), the most important negative outcome from such events is that by 2013 the labor productivity levels of Chilean exporters were slightly higher than those achieved in 2003, but still lower than those at the end of the 1990s.

In sum, Chile's strategy to catching-up in international markets was built under the premise of a process of natural resource-based industrialization aimed to further consolidate the exporting activity of two already leading manufacturing subsectors (food and beverages as well as wood products). Fueled by lower trade tariffs, full access to key markets of the global economy as well as by changes on international demand, Chilean exporters of these subsectors expanded their presence in global markets, consolidated their predominant role in total manufacturing and became the driving force behind substantial productivity increases with respect to non-exporters. Negative external and domestic shocks severely compromised the positive expansion and performance of the exporting sectors by the early of 2010s with limited signs of recovery in the years thereafter. Having discussed the role of global and domestic factors in influencing Chile's exporting sector, we now proceed to discuss the role of innovation related activities in these processes.

IV. The role of innovation and marketing activities in Chilean natural resource-based sectors

The previous general discussion indicates that a country's strategy to catch-up at international markets can be analyzed at the micro-level by examining the different set of factors that influence a given firm's decision to increase their production for exports. Therefore, to explore these factors, our analysis on this section will include different groups of firms. First of all, our analysis of innovation related indicators will include a comparison between exporters and non-exporters. Such comparison is conducted to not only highlight the pivotal role played by exporting firms on the expansion of Chilean natural resource-based sectors but also to indicate the various challenges being faced by non-exporters in their attempt to improve their industrial performance, produce for international markets and close the existing gap with leading exporting firms.

Our proposed categorization by exporters and non-exporters will also include the analysis of domestically owned firms given their strategic role in the catching-up process of industries and countries. Their performance as latecomer firms will be assessed through a comparison with key players in the country (multinational enterprises -MNEs) as well as with the entire manufacturing. Finally, this section will jointly consider the trends on food and beverages and wood manufacturing as a single natural resource-based sector driving the increasing presence of Chilean manufacturers in the global economy.

For this section, our main source of information has been the biennial micro-level innovation surveys compiled and produced by Chile's Statistical office (the 7th and 8th updates of the *Encuesta Nacional de Innovación*). Appendix (A.1.1) provides details on the specific type of information available within those innovation surveys as well

as on the specific approach here followed to categorize firms.

As from Table (3), domestically owned plants operating in resource-based sectors (both exporter and non-exporters) invest a higher amount of R&D over sales than MNEs. Such higher R&D intensity by domestic plants is a consequence of the higher efforts to acquire and generate knowledge with respect to MNEs, which usually have advanced technologies already available from within the company. Table (3) also highlights the fact that exporting firms have a higher R&D ratio than that of non-exporters. In addition, even though innovation expenditures decrease over the years for all type of firms (due to the drastic decreases in productivity and in output by Chilean manufacturing during the late 2010's), the higher R&D intensity by domestic plants with respect to that of MNEs remain relatively unaltered.

Table (3). R&D to sales ratio by type of firm: Natural resource-based sectors.

<i>Year</i>	<i>All exporters</i>		
	<i>Total</i>	<i>Domestic</i>	<i>MNE</i>
2010	0.67	0.77	0.42
2012	0.64	0.66	0.61
<i>Year</i>	<i>Non exporters</i>		
	<i>Total</i>	<i>Domestic</i>	<i>MNE</i>
2010	0.62	0.64	0.44
2012	0.52	0.56	0.41
Source: INE, Encuesta Nacional de Innovación (7ma and 8va).			
Note: Natural resource-based account for the information jointly reported by food and beverages as well as by wood and paper manufacturing.			

While expenditures on machinery, equipment and software stand out as the predominant type of R&D expenditure across all types of resource-based firms, exporting Chilean firms invest more in marketing than exporting MNEs, as Table (4) shows. Foreign owned exporters, in turn, do not seem to allocate financial resources to marketing but spend more on other R&D components such as purchases of complementary machinery² as well as on designing and training activities. On the other hand, MNEs seeking to produce for Chile's domestic market nearly invest 1/3 of their total innovation expenditures on marketing strategies, a share much higher than the one for non-exporters.

Table (4). Composition of R&D expenditures by type of firm (2012).

Natural resource-based sectors				
All exporters				
	<i>R&D expenditure</i>	<i>Total</i>	<i>DOM</i>	<i>MNE</i>
Mach, Eq. Soft.		85.9	86.0	40.7
External knowledge		0.3	0.3	0.0
Training act		1.4	1.4	11.3
Marketing		8.1	8.1	0.0
Designing		1.3	1.3	10.2
Other inno (new equip.)		3.0	2.9	37.8
Total		100.0	100.0	100.0
Non exporters				
	<i>R&D expenditure</i>	<i>Total</i>	<i>DOM</i>	<i>MNE</i>
Mach, Eq. Soft.		82.4	82.8	68.0
External knowledge		2.0	2.0	0.0
Training act		2.5	2.5	3.3
Marketing		4.2	3.6	28.7
Designing		3.9	4.0	0.0
Other inno (new equip.)		4.9	5.1	0.0
Total		100.0	100.0	100.0

Source: INE, Octava Encuesta de Innovación (2013)

Note: Natural resource-based sectors as described on table (3)

Table (A.2.4) also highlights that exporting firms have more skilled labor than non-exporters (Bravo- Ortega *et al.*, 2014). However, during the period 2010-12 of economic turbulence both exporters and non-exporters have also progressively reduced their use of skilled labor.

From Table (5) another interesting difference emerges. A higher use of skilled workers seems to allow foreign owned firms to implement more technologically complex innovation strategies such as product innovations. Process innovation, on the other hand, remains the main type of innovation pursued by domestic plants. Two additional insights come from Table (5). The first one is that there is a higher share of innovators within the group of exporters compared to non-exporters. However, for the reasons advanced above, non-exporters MNE that have to focus

on the local market pursue more intensive innovation strategies than exporting MNEs, because of adaptation policies.

The second insight from Table 5 is the difference in marketing expenditures. The share of domestically owned exporting firms implementing marketing strategies is higher than the one for exporting MNEs. It is also much higher than the share of domestic non-exporters. Interestingly enough, also non-exporting MNEs follow relevant marketing strategies: the percentage is higher than the one of other non-exporters and of exporting MNEs, respectively.

Table (5). (%) Share of firms in respective sample that report following different innovation activities (2012)

<u>Natural resource-based sectors</u>		<u>All exporters</u>	
<i>Innovation activity</i>	<i>Total</i>	<i>Domestic</i>	<i>MNE</i>
Product	30	27	48
Process	34	35	24
Organizational	34	34	33
Marketing	26	27	14
Non exporters			
<i>Innovation activity</i>	<i>Total</i>	<i>Domestic</i>	<i>MNE</i>
Product	18	17	71
Process	23	23	43
Organizational	19	18	43
Marketing	16	16	29

Source: INE, Octava Encuesta de Innovación (2013)

Note: The numbers here reported refer to the share of firms (within their own total sample) that report following each respective innovation activity. The reader should also note that innovation strategies are not mutually exclusive (i.e. one firm that reports following product innovation can, at the same time, report following process innovation, and so forth). Natural resource-based sectors are defined in table (3).

Finally, Table (6) examines the composition of firms' total sales in terms of the production of new goods and old goods by destination market. Old products represent the main type of exporting good being sold by Chilean plants. This tendency is observed both for the case of firms operating in natural resource-based sectors as well as for those representing the entire manufacturing. MNE exporters have a different pattern: foreign owned exporters specialized in resource sectors mostly sell new goods abroad and exports of new goods account for more than

half of their respective total sales.

Table (6). Composition of total sales (%) by type of product, destination market and type of manufacturing firm (2012)

Type of exporter	Type of manufacturing activity	Sales at home		Sales abroad		Total Sales
		New product	Old products	New product	Old products	
All exporters	NRBS	8.7	43.8	15.6	31.9	100
Domestic (x)	NRBS	8.8	44.3	14.5	32.4	100
MNE (x)	NRBS	5.8	26.6	54.7	12.9	100
All exporters	All manuf.	13.1	39.5	8.0	39.4	100
Domestic (x)	All manuf.	13.1	39.1	7.6	40.2	100
MNE (x)	All manuf.	12.8	48.0	15.9	23.3	100

Source: INE, Octava Encuesta de Innovación (2013).

Notes: “New” refers to those goods and services whose production is both new to the firm and to the market. On the other hand, “Old” refers to those goods and services whose production has either been slightly modified or that have not suffered any major change. “NRBS” refers to natural resource-based sectors (see table 3 for details) and “All manuf.” indicates all manufacturing firms.

In sum, our results point to an interesting finding: exporting firms operating within resource-based sectors are usually more innovative than non-exporters, not only in terms of number of innovators, but also in terms of higher use of skilled workers and higher R&D intensity. Our results also highlight that the turbulent negative period experienced by the Chilean economy during the early 2010’s had a severe impact on the innovation performance of manufacturing firms, as both exporters and non-exporters greatly reduced their use of skilled labor as well as their R&D expenditures. When compared to domestically owned firms, foreign owned plants (specially exporting MNEs) sell more innovative products and use more skilled labor and more complementary capital goods. Our results also highlight another interesting aspect: firms’ focus on their main destination market influences the decision to spend relatively more on marketing strategies. While domestically owned exporting firms allocate more financial resources to marketing strategies than exporting MNEs, non-exporting MNEs spend a lot more on marketing strategies for the Chilean market than the rest of non-exporting plants.

V. Econometric analysis

In the previous section we have examined innovation and marketing strategies associated to Chile's exporting firms in the context of natural resource-based industries. Now we broaden the analysis to inquire which are the micro-level factors at the base of catch-up within these subsectors. We therefore conduct an econometric analysis at the firm level of the factors that affect production for exports. Subsection V.1 briefly explains the main features of the firm-level dataset used for this analysis: the 2018 update of Chile's industrial survey (ENIA). Subsection V.2 introduces the main dependent and independent variables used in our econometric regression as well as their operationalization and expected sign. Finally, subsection V.3 presents the results for resource-based sectors during the period 1995-2013.

V.1. Dataset

As of 2018, Chile's National Statistical Office (INE) released a new panel dataset version for the *Encuesta Nacional Industrial Anual*, a national industrial survey known as ENIA. This dataset includes relevant micro-level information for manufacturing firms employing more than 10 employees for the period between 1995 and 2015³. Such new panel dataset was built based on the former ENIA panel dataset (1995-2007) (INE, 2018). Additional details on the variables and on the specific deflators used to report information in constant Chilean pesos of 2009 are shown at appendix (A.1.2) and (A.1.3) respectively.

V.2. Operationalization of variables

For the econometric analysis, the main dependent variable is the logarithm of gross exports reported by firms. The main independent variables are (1) labor productivity, (2) capital deepening, (3) use of imported inputs and, (4) expenditures on marketing. The information for this set of independent variables is available in the ENIA panel dataset from 1995 to 2013. Details on the specific operationalization of these variables, as well as basic statistics on those same indicators are provided on appendix (A.2.5) and (A.2.6), respectively. labor productivity in our econometric regressions: we expect a positive sign. Capital deepening is measured as the ratio of capital stock to labor. According to Baldwin and Gu (2003), the process by which firms progressively learn to substitute capital for labor reflects the development of special skills inside the plant. Therefore, we expect a positive impact of capital deepening on the production for exports. When combined with a specialized labor force, imported intermediate inputs provide opportunities for improvements in firms' performance. For the specific case of Chilean manufacturing, and utilizing an older version of the ENIA dataset,

Kasahara and Rodrigue (2008) found a positive link between imported intermediate consumption and labor productivity. However, following the arguments discussed in the previous sections, domestic intermediates could be relevant for a presence in global markets. Considering these factors, in our regressions we take into account the impact of imported intermediates in terms of the share of foreign inputs on total intermediate consumption, with no specific expectations on its sign.

Expenditures on marketing-related activities can also reflect firms' attempt to increase their knowledge about market penetration in terms of development of new marketing practices, new ways to promote products as well as the targeting of new market segments (OECD, 2005). Therefore, we expect a positive impact of these expenditure (measured in terms of logarithm of marketing expenditures) on exports

Our regressions consider firm size (and size squared) as well as firm age (and age squared) as control variables. Size is measured as the total amount of labor employed by the firm, while age is here computed according to the years of existence as reported by each establishment.

V.3 Econometric results

Table (7) presents the output from our fixed effects econometric regressions⁴ for the case of key resource-based sectors in Chile. Econometric results for the total sample of exporting firms operating on these sectors are presented in the first column, while the second and third column indicate the results for domestically owned firms and for exporting MNEs, respectively.

Results show that higher labor productivity, higher consumption of domestic intermediates (lower use of foreign inputs) and increasing expenditures on marketing activities are positively associated with higher production for exports for domestically owned exporters. The variable accounting for labor productivity (*ln_lp*) reports the largest positive and statistically significant effect on our dependent variable. This may mean that the substantial productivity

by the early 2000's played a major role in inducing higher exports. The positive impact of higher consumption of domestic inputs can be explained by the large demand of these type of intermediates that characterizes the industrial production of food and beverage and wood manufacturing. Along these lines, the high marketing expenditures by domestic exporters plays a complementary role in affecting higher production for exports. Capital deepening does not seem to be of high relevance for exports of resource-based firms. This can be associated to the

low capital intensity that characterizes the fabrication of food and wood products relative to other subsectors in Chilean manufacturing (such as basic and fabricated metals).

On the other hand, the only variable that is found to be statistically significant for exporting MNEs is that of labor productivity. With regard to the other factors the main reason for their not being statistically significant can be related to the knowledge and expertise that MNEs have already. In fact, exporting MNEs may already use machinery and equipment that efficiently produce goods with a high content of locally produced inputs. This is reflected by the composition of R&D expenditures for exporting MNEs, in which expenditures on machinery (other innovation) are higher than on marketing. Finally, for all types of exporting firms age (age squared) and size (size squared) do not seem to play a major role in inducing higher production for exports.

Table (7): Econometric regressions.
Firm level determinants of production for exports (ln_exports).
Natural resource-based sectors in Chilean manufacturing: 1995-2013.

	(1)	(2)	(3)
Independent variables	All exporters	Domestic exporters	MNE exporters
ln_size	0.212	0.235	0.239
	-0.17	-0.214	-0.252
ln_size_squared	0.036*	0.031	0.04
	-0.016	-0.022	-0.023
ln_age	-0.054	-0.027	-0.118
	-0.082	-0.106	-0.117
ln_age_squared	0.065*	0.062	0.072
	-0.029	-0.036	-0.042
ln_capital_labor	0.062*	0.053	0.086
	-0.031	-0.038	-0.053
ln_lp	0.312***	0.329***	0.270***
	-0.028	-0.036	-0.039
ln_imported_ratio	-0.014**	-0.018***	-0.004
	-0.004	-0.005	-0.007
ln_marketing	0.019***	0.022***	0.016
	-0.006	-0.007	-0.008
Constant	10.121***	9.863***	10.521***
	-0.541	-0.656	-0.825
Observations	5,482	3,885	1,597
R-squared	0.144	0.133	0.185
Number of firms	782	573	209

Note: Robust standard errors in parentheses. Natural resource-based sectors

as described on table (3). Exporting firms are here regarded as those reporting an average exporting ratio (gross exports to gross value of output) higher than 5% during the entire period that they stay in the market. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

VI. Robustness analysis

To further support our empirical findings, we provide supplementary analyses. Subsection (VI.1) briefly describes our approach to account for potential endogeneity concerns (system GMM analysis), while section (VII) provides descriptive empirical evidence on the link between higher production for foreign markets, innovation, marketing and increasing productivity levels across Chilean exporters.

VI.1 GMM analysis

To deal with potential endogeneity problems that might arise when assessing the interplay between exports and labor productivity (reversed causality, unobserved heterogeneity and so forth), we applied an instrumental variable approach which was built in the context of a system GMM estimation⁵. These econometric results are reported in Table (8) for each of the firms introduced on previous sections.

Table (8): GMM system econometric regression.
Firm-level determinants of production for exports (ln_exports).
Natural resource-based sectors in Chilean manufacturing: 1995-2013

Independent variables	(1) All exporters	(2) Domestic exporters	(3) MNE exporters
ln_exp_ratio _(t-1)	0.413*** (0.059)	0.401*** (0.061)	0.629*** (0.199)
ln_size	-0.078 (0.183)	-0.109 (0.181)	0.189 (0.866)
ln_size_squared	0.042* (0.018)	0.046** (0.018)	0.012 (0.072)
ln_age	-0.918 (0.674)	-0.625 (0.701)	-0.089 (1.095)
ln_age_squared	0.138 (0.194)	0.052 (0.197)	0.046 (0.272)

ln_capital_labor	-0.016 (0.030)	-0.016 (0.032)	-0.018 (0.071)
ln_lp	0.234*** (0.024)	0.248*** (0.026)	0.150** (0.059)
ln_imported_ratio	-0.010** (0.004)	-0.011** (0.004)	-0.006 (0.017)
ln_marketing	0.012* (0.005)	0.014** (0.005)	0.026* (0.014)
Years controlled	Yes	Yes	Yes
Industry controlled	Yes	Yes	Yes
p-values			
AR(1)	0.00	0.00	0.02
AR(2)	0.67	0.69	0.84
Hansen	0.51	0.58	0.42
Observations	4,427	3,953	474
Number of firms	743	658	85

Notes: Asymptotically robust standard errors in parentheses. Year dummies are included in each model specification. ln_exports (t-1) refers to the first lagged of the dependent variable. First lagged and earlier were used as instruments for all the explanatory variables accounted for by the system-GMM estimation procedure. First lagged differences were then also used as instruments for the level equation of the model. Hansen test for overidentifying restrictions evaluates the null hypothesis that instruments are not correlated with the residual. AR(1) and AR(2) are test for first and second second-order serial correlation in the first differenced residuals. The null hypothesis for the second-order serial correlation test indicates that errors in the first differenced regression do not show second-order serial correlation. See table (3) for details on the operationalization of natural resource-based sectors. Exporting firms as defined in table (7). *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Overall, the system GMM estimators corroborate our general findings on the positive effect of labor productivity, domestic intermediates, and marketing on the production for exports by domestic firms. Marketing expenditures and imported intermediates remain statistically significant and still hold their respective positive and negative sign on the regressions. Labor productivity also stands as key determinant for exports across all type of firms. Given the magnitude of the coefficients there reported, productivity improvements then seem to play a major role in inducing higher production for exports in Chile⁶.

The validity of our regression coefficient is confirmed in Table (8) by the Hansen test (which reveals nocorrelation between instruments and errors), as well as by the

AR(1) and AR(2) tests (which indicate no evidence of second order serial correlation in the model).

VII. Additional evidence on the innovativeness of the exporting firms

The current version of the ENIA panel dataset does not include information useful to conduct detailed analyses on the innovation performance of firms. When compared to its older version for the period 1995-2007, the ENIA micro level information for highly skilled workers is no longer reported individually but it is lumped into a single category with other low-skilled workers. On the other hand, the other dataset used in this paper – the Innovation Surveys – does not prioritize the analysis of manufacturing firms (and thus of manufacturing exporters) and does not generate information directly compatible with the ones of the national accounting system (such as gross value added and gross output). Moreover, the innovation datasets are not publicly available on panel format thus preventing researchers from more longitudinal analyses on the innovation performance of firms over time. Given these limitations, we have built a new panel dataset from 2007 to 2013 that merges supplementary yearly firm-level information (from official ENIA data not reported however in a panel format) with that of the innovation surveys. Specific details on the methodology and general features on this ENIA-innovation extended micro-level dataset are presented at appendix (A.1.4).

As indicated in Table (9), exporting innovators (those with at least one type of innovation strategy within the innovation survey) are on average more productive, employ more qualified labor and, spend more on marketing strategies than the respective exporting non-innovators. These trends remain valid as firms with higher productions for exports are considered in the table (e.g., cohorts of firms reporting different export to sales ratios that range from more than 10 to more than 20 and 30%).

Table (9): Average firm-level information for exporters (innovators and non-innovators) (2007-2013)

Natural resource-based sectors				
Export ratio	Type of exporting firm	Ln (LP)	HSL ratio	Ln (marketing)
10%>	Non-innovator	7.37	18.90	6.92
	Innovator	7.66	19.63	8.08
20%>	Non-innovator	7.43	20.27	6.45
	Innovator	7.67	22.26	7.05
30%>	Non-innovator	7.44	19.29	6.60
	Innovator	7.55	22.74	7.07

Source: Author's calculation based on the ENIA-innovation extended dataset.

Note: Innovators are those firms within our sample that declared following at least one type of innovation strategy. Export ratio indicates the respective percentage share of export in firms' total sales. HSL ratio corresponds to the share of highly skilled labor with respect to total working force. Natural resource-based sectors as defined in table (3).

Table (10) confirms that as Chilean natural resource-based manufacturers increase their export to sales ratio, they become more innovative and also increase their productivity levels. For example, firms in with an export to sales ratio higher than 30% during the 2007-2013 period are, on average, more productive than the rest of firms (with ratios lower than 30%), tend to have more R&D expenditure as a proportion of their total sales and utilize more highly skilled workers (both in total average number and as share in total labor with respect to non-skilled workers).

Table (10): Average firm-level indicators for exporters (2007-2013).
Natural resource-based sectors

Export ratio	(a)R&D to sales ratio (%)	(b)Ln (LP)	(b)HSL ratio
10%>	10.4	7.45	23.4
20%>	12.1	7.46	23.6
30%>	12.7	7.48	23.8

Source: Information provided in (a) column is based on Innovation surveys, while for (b) columns they are computed from the ENIA-innovation extended dataset. Export and HSL ratios as indicated in table (9). Natural resource-based sectors as defined in table (3).

VIII. Conclusions

This paper has examined the catch-up and the innovation and marketing strategies of Chilean firms in natural resource based sectors during the period 1995-2013, focusing on exports and on domestic firms and MNEs. Unlike previous research on Chile, this study has followed an approach in which world- economy, country and micro-level data are jointly considered over a long period of time. The key results can be summarized as follows.

Chile aimed for an integration in global markets through a process of natural resource-based industrialization focused on further strengthening the technical capabilities of two already successful subsectors: food and beverages as well as wood manufacturing. Even before the country's signing of the relevant free trade agreements by the early 2000's, these subsectors (specially food and beverages) had a sizeable participation in some key product categories in world's exports and experienced an increase in the quality of output sold. At the national level, the

expansion of the exporting sector implied moving resources away from the non-exporting sector and was characterized by substantial productivity improvements that further widened the already existing innovation and efficiency gap between exporters and non-exporters.

The focus of this paper is on innovation, R&D and marketing. At the micro-level, we find that with respect to non-exporters, domestic exporters spend more on R&D as a proportion of their total sales, allocate more resources to marketing strategies, pursue strategies of process innovation, and mostly deliver abroad products that are not new to the market (old products). This may be explained by the higher efforts to acquire and generate knowledge, the use of marketing to enter foreign markets and the focus on increasing efficiency. Exporting MNEs, on the other hand, invest less on R&D but employ more highly skilled workers, allocate more R&D expenditures on the acquisition of machinery, product innovation strategies and thus mostly generate new products for consumption outside Chile.

Our results strongly indicate that marketing expenditures, together with R&D and higher consumption of domestic intermediates, are associated with production for exports by domestically owned firms. This complementarity between innovation, marketing and reliance on domestic inputs represents a key driver of catch-up in natural resource-based sectors. On the contrary increasing labor productivity is the only independent variable within our econometric regression that is statistically significant and positively associated to higher output for exports by exporting MNEs. This may be due to the prior knowledge and familiarity that MNE exporters already have on marketing and the other factors that affect exports. Our descriptive robustness analysis, which consisted in merging firm-level data on innovation surveys with that of industrial census, empirically confirms the positive influence of R&D intensity and innovation with regards to exporting firms.

These general findings have strong policy implications for those developing countries that attempt to integrate in global markets through a process of natural resource-based industrialization. The Chilean case suggests a key role for policies of support of the development of locally produced domestic inputs, particularly if related to natural resources⁷. However our quantitative analysis suggests that export promoting policies on these sectors should not only be limited to account for productivity improvement and increasing capital stocks or for the support of R&D and a tighter integration with local suppliers. Marketing activities have to be considered fundamental on the devising of industrial policies for exporters as these represent some of the critical resources that firms need to acquire and develop to penetrate foreign markets. In sum, financial resources should therefore be devoted to support marketing activities as a key pillar of catch-up in these sectors, in order to better position exporting output and better understand and meet global foreign demand.

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Appendix: A.1

A.1 Data on Chilean manufacturing.

A.1.1 Innovation datasets.

The *Encuesta Nacional de Innovación* (produced by INE) provides information on innovation strategies for firms within the agricultural, mining, manufacturing and service sector. Data on foreign and domestic ownership, production for exports and for the domestic market, and on the implementation of different innovation strategies are here reported by firms within the sample for two consecutive years. Our research relied on the 7th (2009-2010) and 8th (2011-2012) innovation surveys and noted that these differ in terms of updates (on concepts and on methodologies) and in terms of the availability of subsectoral information (which are only available as of the 7th version). Average indicators for two consecutive years (on level of ownership and on production for exports) are here used to categorized firms according to domestically owned exporters (and non-exporter) and MNE exporter (and non-exporter)

A.1.2 Firm-level information.

ENIA provides yearly plant-level information on gross output, gross value added, labor, wage remunerations, value of exports, domestic and imported intermediate consumption, investments on machinery and equipment (and on the rental of buildings). All this information is available from 1995 to 2013 and reported in line with the ISIC (rev. 3). As of 2014, recent updates on these firm-level are reported following the ISIC (rev. 4). Average indicators for the entire period whereby the firm is present on the sample (on level of ownership and on production for exports) are here used to categorized firms according to domestically owned exporters (and non-exporter) and MNE exporter (and non-exporter).

A.1.3. Deflators.

Gross output and gross value added are reported in millions of Chilean pesos in constant prices of 2009. These two were deflated using specific deflators for gross output and for intermediate consumption that were both available per manufacturing sector at the 4-digit level (ISIC. Rev 3). INE constructed each of these deflators from 1992 to 2006 (base year 2003) with information from the ENIA dataset, among other relevant sources (INE, 2009). Given that our period of analysis goes beyond 2006, we extended the time coverage (up to 2013) and change the base year (from 2003 to 2009) for those specific deflators following official information and methodology suggested by INE (2011). Once we obtained all this, and finally deflated our information on gross output and intermediate consumption, our

research also deflated the information on gross value added by means of the standard method known as double deflation.

A.1.4. Building extended ENIA dataset and linking such information with innovation datasets.

In order to build an ENIA extended-innovation dataset that jointly report information on key industrial variables and the innovation activity of exporting firms, our research had to follow two steps. The first one was linking innovation surveys with the yearly supplementary information on the ENIA dataset (presented in a non-panel format and available as of 2008). Unlike the 2018 update of ENIA panel-dataset, its yearly supplementary information contains variables that are fully compatible with variables reported within innovation surveys. For instance, for a given firm at innovation surveys the value of gross exports was found to be the exact same (within the exact same year) for a given firm within the supplementary ENIA datasets. Additional compatible variables within each respective dataset (categorizations on the organization of firms, ownership, as well as regions and subsectors where they operate, when available) were used to ensure the consistency of the linking procedure using gross value of exports. Following the methodology proposed by Aitken and Harrison (1999) on their firm-level analysis of Venezuelan firms, we managed to produce the ENIA-extended innovation dataset in a panel format by linking beginning-of-the-year and end-of-the-year inventories as reported by the supplementary dataset. Our main outcome was generating a dataset that represents 8% of the total available firms within the 6th, 7th and 8th innovation surveys.

Appendix A.2

Table (A.2.1). Top Chilean manufacturing exports by region of destination.

Region	Fish (not marine mammals)		
	1995	2005	2013
North America	23.3	31.6	31.4
Europe	17.3	20.8	11.8
Asia	53.7	40.5	39.1
South America	3.9	5	15
Other	1.9	2.1	2.6
Total	100	100	100
Region	Vegetables and fruit		
	1995	2005	2013
North America	34	53.6	38.8
Europe	24.3	24.9	22.9
Asia	12.9	11	22.5
South America	27.1	9.8	14.6
Other	1.7	0.7	1.2
Total	100	100	100
Region	Beverages		
	1995	2005	2013
North America	36	27.2	24.3
Europe	36.3	54.2	41.5
Asia	2.7	9.1	23.2
South America	23.2	9	10.1
Other	1.8	0.5	1
Total	100	100	100
Region	Cork, wood manufactures		
	1995	2005	2013
North America	2.7	24.7	21.6
Europe	38.9	17	16.4
Asia	8.2	54.5	51.8
South America	50.2	3.6	9
Other	0	0.2	1.2
Total	100	100	100
Region	Meat and meat preparations		
	1995	2005	2013
North America	2.7	24.7	21.6
Europe	38.9	17	16.4
Asia	8.2	54.5	51.8
South America	50.2	3.6	9
Other	0	0.2	1.2
Total	100	100	100
Region	Paper, paperboard, etc.		
	1995	2005	2013
North America	1	18.6	20.2
Europe	0.9	10.8	14.4
Asia	2	3.3	1.9
South America	96.1	66.8	62.5
Other	0	0.6	1
Total	100	100	100

Source: UN COMTRADE.

Table (A.2.2). A comparison between the quality ratios reported by Chilean top exports and their respective World averages.

Subsector	1995		2000		2005		2010		2013	
	Chile	World	Chile	World	Chile	World	Chile	World	Chile	World
	*	*	*	*	*	*	*	*	*	*
Fish, crustaceans and molluscs	0.1	0.52	0.17	0.43	0.19	0.61	0.37	0.45	0.43	0.49
Fruits and vegetables	0.75	0.86	0.74	0.76	0.86	0.87	1.5	1.14	1.8	1.25
Beverages	1.37	1.32	1.4	1.1	2.07	1.05	2.09	1.83	2.22	1.6
Cork and wood manufactures	0.42	0.56	0.39	0.48	0.44	0.58	0.46	0.93	0.5	0.94
Meat and meat preparations	1.82	2.41	1.99	2.19	2.5	2.67	2.86	2.97	3.01	3.42
Paper, paperboard, etc.	0.97	0.92	0.61	0.83	0.62	0.91	0.79	1.36	0.93	1.47

Source: FAOstat. Note: Quality ratios are here defined as the ratio of export value (1000 \$US) to quantity (ton). *World average quality ratios.

Table (A.2.3). Chile's export sector:

(%) shares in total manufacturing, 1995-2013.

Year	Gross Output	Gross value added	Labor
1995	25.0	27.2	20.2
2000	29.7	36.5	24.9
2005	38.4	49.2	29.5
2009	42.8	58.5	25.9
2012	36.7	35.6	21.5

Source: Authors' calculation based on ENIA (2018 update)

**Table (A.2.4). Share of highly skilled labor employed by type of firm:
Natural resourced based sectors in Chile**

Year	All exporters		
	Total	Domestic	MNE
2010	23.63	23.72	23.06
2012	13.87	13.31	24.88
Year	Non exporters		
	Total	Domestic	MNE
2010	17.77	18.21	15.69
2012	12.42	11.67	18.40

Source: INE Encuesta Nacional de Innovacion (7ma and 8va). Natural resource-based sectors as defined in table (3).

Table (A.2.5). Operationalization of firm-level independent variables included in econometric regressions.

Independent variable	Name in regression (expressed as logarithm)	Operationalization
Investment		Purchases of machinery and equipment and, the rental of buildings
Initial capital stock		In line with Timmer (1999), initial capital stocks are here measured by applying the average of incremental capital value added ratios (ICVARs) in the first five years of the series to total value added in the initial year.
Capital stock		Capital stock (K_{t1}) measured following the Perpetual Inventory Method (PIM): $K_{t1} = [(1 - \delta)K_{t0}] + I_{t1}$ Where K_{t0} = initial capital stock; δ = depreciation rate; I =firm-level investment. Depreciation rates as suggested by Fernandes and Paunov (2012) and Pombo (1999).
Size	ln_size	Labor employed by the firm.
Age	ln_age	Number of years reported by the establishment
Capital	ln_capital_labor	The ratio of capital stock to labor

deepening		
Labor productivity	ln_lp	The ratio of gross value added to total labor
Use of imported intermediates	ln_imported_ratio	The ratio of imported intermediate consumption to total intermediate consumption
Marketing	ln_marketing	Firm's expenditures on publicity, market research and representation costs.

Natural resource-based sectors

Table (A.2.6). Descriptive statistics for firm-level variables included in the regression.

Variable	All Exporting firms				
	Mean	Std. Dev	Variance	Skewness	Kurtosis
ln_exports	14.65	1.99	3.96	-0.58	3.60
ln_size	4.68	1.29	1.67	-0.36	3.24
ln_size_squared	23.54	11.76	138.21	0.44	2.77
ln_age	1.56	0.86	0.73	-0.43	2.14
ln_age_squared	3.16	2.45	6.02	0.37	1.98
ln_capital_labor	2.45	1.92	3.67	-0.48	4.58
ln_lp	7.25	1.45	2.10	0.33	5.15
ln_imported_ratio	-1.12	2.55	6.51	-3.96	22.62
ln_marketing	-2.06	2.01	4.05	-0.81	3.14

Variable	Domestic (Exporters)				
	Mean	Std. Dev	Variance	Skewness	Kurtosis
ln_exports	14.46	2.06	4.26	-0.48	3.51
ln_size	4.62	1.25	1.57	-0.12	2.77
ln_size_squared	22.89	11.56	133.56	0.54	2.77
ln_age	1.53	0.86	0.73	-0.39	2.10
ln_age_squared	3.06	2.43	5.92	0.43	2.04
ln_capital_labor	2.31	1.98	3.91	-0.33	4.25
ln_lp	7.08	1.36	1.84	0.15	5.40
ln_imported_ratio	-1.02	2.49	6.20	-4.03	23.36
ln_marketing	-2.10	2.02	4.07	-0.80	3.19

Mine Exportes

Variable	Mean	Std. Dev	ariance	Skewness	Kurtosis
ln_exports	15.12	1.70	2.91	-0.70	3.64
ln_size	4.82	1.38	1.91	-0.86	4.29
ln_size_squared	25.17	12.09	146.16	0.20	2.88
ln_age	1.64	0.85	0.72	-0.54	2.26
ln_age_squared	3.40	2.49	6.20	0.24	1.87
ln_capital_labor	2.80	1.71	2.92	-0.86	6.20
ln_lp	7.68	1.57	2.48	0.44	4.48
ln_imported_ratio	-1.38	2.69	7.22	-3.84	21.12
ln_marketing	-1.95	2.00	4.01	-0.85	3.02

Source: Authors' calculation based on ENIA (2018 update). Natural resource-based sectors as defined in table (3).

Notes

¹ Following Morgan et al. (2009) marketing capabilities include seven distinct features related to firms' pricing strategy, product development, distribution management, marketing communications, selling, marketing planning as well as marketing communication.

² In line with OECD/Eurostat (2018), this expenditure category includes those other complementary capital goods (tangible and intangible assets) that were excluded from the category "Mach, Eq. Soft. for Inno" as they were not purchased with the specific purpose of pursuing R&D activities and that, therefore, are also not part of the concept of intra-mural R&D. This category of complementary capital expenditures also includes capitalized non-production assets that are not specifically for R&D (in-house produced capitalized software, capitalized development costs, etc.).

³ In order to ensure the consistency between the information retrieved from innovation surveys (latest available year 2013) and those of the ENIA dataset, we decided to conduct our econometric analysis by only studying the 1995-2013 period.

⁴ For every specification, Hausman tests (not reported here) prefer fixed effects over a random effects specification.

⁵ GMM models (Generalized Method of Moments) remove endogeneity in panel datasets through a statistical process whereby a given variable's past value is removed from its present value, reducing in that way the number of observations and enhancing the consistency of the results (Roodman, 2009; Woolridge, 2010). Following Blundell and Bond (1998), the system-GMM instrumental variable approach combines the lagged level of dependent variable and of explanatory variables as instruments for the first difference equation being regressed, as well as first differences acting as instruments for the equation in levels thus generating consistent and efficient parameter estimates that have better asymptotic and finite sample properties than other models.

⁶ The claim that the direction of causality runs from labor productivity to exports across Chilean manufacturers is also further confirmed by our study through the computation of complementary system GMM regressions. This econometric analysis (not here presented but available upon request) was built in the context of an Error Correction Model specification (ECM) following the reasoning and method put forth by Yasar et al. (2006).

⁷ One specific example of a country-level marketing program aimed to promote the image and brand of domestically produced goods in global markets is the strategy of Sectorial Brands devised by ProChile (Chile's export promoting agency). ProChile's Sectorial brands program is largely composed of natural resource-based products (such as wine, olive oil, pork, fruits and cherries, seafood etc.) and seeks to create economies of scale in branding by sharing the cost markets studies, marketing and position tactics between public and private entities so as to improve the awareness and identification of those sectors in global markets.

A qualitative comparative analysis (QCA) of the evolution of innovation and corporate catching-up in China

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Abstract

This study extends on the analysis of innovation and corporate catching-up in China's photovoltaic and wind power equipment manufacturing industries from a configurational perspective. In particular, a case-oriented set-theoretic methodology is applied. In empirical terms, the longitudinal analysis unravels the modal complexity of innovation and corporate catching-up and (some of) the temporal context in which it is embedded, including the modal interplay among localized internal and international external learning on the one hand and among international external learning on the other. Configurations of learning orientations are found to differ not only across firms but also across firm performance classes. Compared to international strategic technology alliances, the temporal context of modal investments in international technological M&As seems to be of minor relevance in explaining very high techno-economic firm performance. In methodological terms, the added value of applying configurational, set-theoretic logic to latecomer development research is demonstrated. This includes demonstrating the potential use and usefulness of a novel patent analytic approach to periodizing individual firm-specific consecutive learning phases in the techno-economic catch-up process of firms.

Keywords: Latecomer, Catching-up, Technological capability building, QCA, China

1. Introduction

In China, the industrial transition from a largely manufacturing-based towards a more sustainable, innovation-driven development path has become a key priority of economic reform. Extensive government effort has been directed at promoting the development of emerging new energy industries of strategic importance (Hepburn et al., 2021). Also, and in particular, China's techno-industrial policy has focused on facilitating the upgrading process in the photovoltaic and wind power equipment manufacturing industries, with Chinese firms being intended to forge ahead and succeed on a global scale (Dent, 2015). To this ambitious end, a seminal challenge facing the aspirant latecomer firms has been to acquire the technological competencies enabling them to catch-up with the top tier of incumbent industry leaders – and, eventually, to keep asserting themselves within technologically dynamic, highly competitive business environments. Nowadays, there are several examples of Chinese photovoltaic and wind power equipment manufacturing firms that have managed to rise to the forefront of international competition. China's dominance in global PV module supply has basically commenced in 2011 (REN21, 2020), with firms like Jinko Solar, Trina Solar, Longi Green Energy, JA Solar, and Canadian Solar leading the industry for some time now (see InfoLink, 2018, 2019, 2020, 2021, 2022, 2023). Chinese Goldwind advanced to become the global leader in wind turbine supply in 2015 (BloombergNEF, 2016) and again in 2022 (BloombergNEF, 2023). Firms like Envision Energy, Mingyang Smart Energy, and Zhejiang Windey also appear to have already established themselves among the world's leading wind turbine manufacturers in recent years (see BloombergNEF, 2018, 2019, 2020, 2021, 2022, 2023). Against this empirical background, the salient question arises as to the particular ways and means in which the stipulated techno-economic transformation from 'Manufactured in China' to 'Made in China' is put into practice at the level of individual firms: How is this process of innovation and corporate catching-up – best – being brought about?

The strategic pathways of technology-related corporate catching-up of latecomers have been studied mainly from two closely related and partially overlapping angles, with an initial accent on the Asia-Pacific and Latin America regions. The first angle centers around basic business-level strategies to emerge from the doldrums of laggardness and backward industrial settings. Such studies are particularly interested in the sources and remedies of latecomer advantages and disadvantages, usually illuminating strategic latecomer firm development from a more general cross-functional (Amsden & Chu, 2003; Cho

et al., 1998; K. Lee, 2019; Luo & Child, 2015; Sturgeon & Kawakami, 2012) or a more specific internationalization perspective (Hennart, 2009, 2012; P. P. Li et al., 2022; Luo & Bu, 2018; Luo & Tung, 2007, 2018; Mathews, 2002). The second angle is oriented towards deciphering technology strategies used by latecomer firms, surrounding the regularities of learning, technological capability building, and innovation at the center of interest. There are a number of stage-model approaches to mapping and characterizing the technological evolution of firms, essentially along continuums from imitation or production to innovation (Altenburg, 2021; Dutrénit, 2004; Forbes & Wield, 2002;

L. Kim, 1997; K. Lee, 2005; K. Lee & Lim, 2001). A large and varied collection of studies provides empirical insights into the nature and dynamics of innovation and corporate catching-up processes in latecomer industries (Amsden & Chu, 2003; Choung et al., 2000; Choung et al., 2014; Ernst, Mytelka, & Ganiatsos, 1998; Hobday, 1995; Hobday et al., 2004; Mathews et al., 2011; Miao et al., 2018; Wong, 1999a, 1999b), including increasingly China (Duysters et al., 2009; Ebersberger et al., 2023; P. Fan, 2011; Fu et al., 2011; Mu & Lee, 2005; Nahm & Steinfeld, 2014; Zhang & Duysters, 2010; Zhang et al., 2012), numerous of which dwell on the accumulation of technological capabilities and the learning processes and mechanisms associated with it (Bell & Figueiredo, 2012; Biggs et al., 1995; Dantas & Bell, 2009, 2011; Figueiredo, 2017; Katz, 1987b; Kiamehr, 2017; Lall, 1987; Lim et al., 2013; Wong, 1999a, 1999b). It becomes very clear that technological capability building by latecomer firms is based on a variety of combinations of different types of learning processes and mechanisms involving different types of knowledge sources, whether internal or external, domestic or foreign. However, the literature specifically addressing multi-modal compositional patterns of learning processes is far more limited (Hansen & Ockwell, 2014; L. Kim, 1997, 2001; X. Li & Wu, 2010; J. J. Liu et al., 2006; Thakur-Wernz & Bosse, 2023; Wang et al., 2014), with relatively few studies taking a more explicit and systematic perspective on compositional pattern change (Figueiredo et al., 2013; Hansen & Lema, 2019; R. Lema & Lema, 2012; Quitzow et al., 2017; Reinauer & Hansen, 2021; Tacla & Figueiredo, 2006). Corresponding formal-objective temporal measurement concepts for change-related framing of multi-modal compositional patterns also tend to be neglected in the prevailing periodization approaches. Typically, periodization follows a qualitative-interpretative logic and is rather informal-subjective, focusing on universal industry-wide (L. Kim, 1997, 2001; R. Lema & Lema, 2012), universal cross-case (Figueiredo et al., 2013), or especially single case-by-case measurement concepts (Dantas & Bell, 2009; Hansen & Lema, 2019; Reinauer & Hansen, 2021). Configurational approaches suitable for exploring the interplay of different learning processes, learning mechanisms, and knowledge sources from a systemic comparative perspective are extremely scarce. Surprisingly, few such studies seem to be scattered across adjacent topical areas, sometimes more and sometimes less loosely related to the analysis of evolutionary patterns of learning, technological capability building,

and innovation in the context of latecomer development and firm-level technological catching-up (Avioutskaa & Tensaout, 2020, 2022; Chen et al., 2021; Ding & Wu, 2022; D. Fan et al., 2016; Kwak et al., 2018; Yi Li et al., 2022). Taken together, much about how learning mechanisms are strategically combined by Chinese firms – and latecomer firms in general, for that matter – and how these combinations of learning mechanisms may evolve during techno-economic catching-up processes still remains to be sufficiently understood, including the modal interplay among local(-ized) internal and international external learning on the one hand and among international external learning on the other. In this evolutionary change-related context, there is also room and need for formal-objective temporal measurement concepts for periodization. In particular, alternative concepts should allow for and facilitate systematic firm-specific comparative analyses across heterogeneous sets of firms and industries as well as larger-scale case-based applications. The dearth of relevant configurational analysis in the study area is striking. Accordingly, greater analytic potential of such studies for providing novel insights into learning processes related to multi-modal compositional patterns and compositional pattern change is evident.

This study now aims at exploring the evolutionary ways and means in which Chinese latecomers have (more or less ‘successfully’) gained in techno-economic competitive performance through the lens of local(-ized) internal learning and international external learning mode choice. Adopting a learning trajectory-based view on innovation and corporate catching-up in China, our analytical interest is in unraveling the (temporal) structure of firms’ modal investments in (international) learning, technological capability building, and innovation by identifying and systematically comparing time-related modal configurations of learning orientations across firms and industries. The analytical focus is on local(-ized) internal learning and international external learning mode choice, focusing exclusively on external learning from foreign sources. The underlying methodological aim is to create, map, and comparatively examine empirical configurational typologies using a generative approach to configurational fit.

The study applies qualitative comparative analysis (QCA), a set-theoretic configurational method that is, to our knowledge, new to research on latecomer development and firm-level technological catching-up. The unique strength of this method lies in enabling the analysis of the complex interplay underlying (changing) modal configurations of learning orientations by establishing similarities and differences among multiple cases of firms from different industries through systematic comparison. The longitudinal context of learning is conceptualized as consisting of two consecutive firm-specific learning phases, an imitative and an innovative learning phase. A time-related working model of latecomer development is derived and applied to periodize corresponding learning orientations using formal-objective temporal measurement based on

patent analysis.

The empirical setting is the Chinese photovoltaic and wind power equipment manufacturing industries, which are also the subject of several other comparative analyses of varying interest (e.g., R. Lema & Lema, 2012; Nahm, 2021; Nahm & Steinfeld, 2014; Quitzow et al., 2017). The two industries have undergone rapid and accelerated techno-economic catch-up development almost simultaneously (Nahm, 2021), albeit with varying degrees of global market penetration (Quitzow et al., 2017) and global technological competitiveness (R. Lema et al., 2021). Both industries also encompass the entire spectrum of technological and manufacturing-related characteristics associated with virtually all modern industry. On the one hand, photovoltaic and wind power technology systems include a number of well-established traditional industrial activities, such as the manufacture of standard steel towers for wind turbines or the use of basic chemical processes for solar cell manufacturing. On the other hand, they also include technological frontier activities, such as the application of advanced aerospace designs for turbine blades or the development and incorporation of advanced nanomaterial coatings for solar cells. In general, the manufacturing processes for PV modules and wind turbines range from electromechanical to electrochemical fabrication, from basic manual assembly to advanced engineering design and management of complex technology systems. Some portions of each of these processes are labor-intensive, while others are extremely technology- and capital-intensive (Nahm & Steinfeld, 2014). At the same time, however, the fundamental technological characteristics of the photovoltaic and wind power industries are very different. This results in different technological requirements and challenges for manufacturing and engineering with different implications for learning, technological capability building and innovation (Nahm, 2021) and associated (international) technology transfer (Quitzow et al., 2017). According to R. Lema et al. (2021), differences in technological characteristics related to technological maturity and tradability are reflected in different patterns of appropriate responses at the firm, industry, and policy levels. The (current) technological maturity and the tradability of manufacturing equipment/inputs or finished goods is rather high for photovoltaic technology and rather medium and low or medium, respectively, for wind power technology (R. Lema & Rabellotti, 2023; United Nations Conference on Trade and Development, 2023). In general, high-maturity technologies can be acquired and absorbed on market terms and are less demanding in terms of indigenous R&D preconditions. High tradability of manufacturing equipment/inputs requires strong production capabilities in related technology areas for effective technology acquisition and absorption, while high tradability of finished goods also means higher competition in domestic and global markets. Low technological maturity and low tradability demand strong indigenous R&D preconditions as well as strong production capabilities in related industries for component technologies, with lower competition in domestic markets (R. Lema & Rabellotti, 2023). By the same

token, supply chains tend to be less transnational in the wind power industry than in the photovoltaic industry (Nahm, 2021). Several studies emphasize differences in techno-industrial policy needs (e.g., R. Lema et al., 2021; Quitzow et al., 2017; United Nations Conference on Trade and Development, 2023). China is a prime example of divergent market-based policy approaches towards the two technologies. The development of the domestic solar power market received increased policy attention only after Chinese firms already dominated the global PV industry with exports to all major markets. In contrast, China's wind power industry has relied primarily on state-driven domestic market development and only gradually turned to global export markets (Quitzow et al., 2017). Accounting for such technology-related differences is of particular interest for comparative analysis, as it helps demonstrate that the patterns of learning, technological capability building, and innovation underlying the evolutionary catch-up process of firms may, or may not, cut across technologies and industries.

The remainder of the paper is structured as follows: Section 2 puts our study in the theoretical context of innovation and corporate catching-up. Section 3 introduces the methodology. Section 4 describes our sample and data, while section 5 presents the results of our empirical analysis, including robustness analyses. Section 6 concludes.

2. Innovation and corporate catching-up

2.1. Catching-up in firm-level technological capabilities

In an attempt to shed new light on the issue of latecomer development in China, the phenomenon of catching-up and corporate catching-up, respectively, shall be conceptualized as an evolutionary process and strategic direction of learning, technological capability building, and innovation. According to this view, technological – and thereby economic – development is rooted in a specific set of change-generating inputs and resources, i.e. 'capabilities', that, essentially, emerge from indigenous learning processes and the strategic accumulation of knowledge (see Bell & Albu, 1999; Bell & Pavitt, 1993; Lall, 1992).

There are various similar approaches to conceptualizing the accumulation of technological capabilities as a means of capturing differences in the ability of backward firms to develop and advance technologically (Bell & Pavitt, 1993; Dahlman et al., 1987; Enos, 1991; Katz, 1984, 1987a; L. Kim, 1980; Lall, 1992). In essence, technological capability can be understood as the ability of firms to make effective use of technological knowledge, including the internalization of knowledge external to the firm, to assimilate, use, adapt, and change existing product and process technologies as well as to develop new ones (L. Kim, 1997). This entails the ability of firms to leverage technological knowledge to gain and secure strategic

advantages in a competitive business environment, including and especially competitive advantages (Jin & Zedtwitz, 2008; Rush et al., 2007; Zahra & George, 2002). Absorptive capacity associated with technological capabilities implicates that the creation and exploitation of technological knowledge for commercial purposes is path-dependent and closely linked to both past and present technological efforts (Cohen & Levinthal, 1989, 1990). According to Zahra and George (2002), a distinction can be made between potential and realized absorptive capacity. Potential absorptive capacity involves knowledge acquisition and assimilation, but does not necessarily guarantee knowledge exploitation. Realized absorptive capacity, in turn, is a function of knowledge transformation and exploitation, reflecting a firm's ability to ultimately use absorbed knowledge to create value. Martin et al. (2003) argue that the transformation dimension of absorptive capacity is particularly related to the ability to combine and integrate existing and new knowledge for knowledge development.

The conception of technological capability is generally not limited to mere (technological) knowledge. As suggested by Bell and Pavitt (1993), technological capabilities can rather be viewed as all the various inputs and resources required for the use and operation as well as the generation and management of change in technology; this involves skills and knowledge, but also machinery and equipment, product specifications, workforce, institutional structures and linkages, and so on. While many of these inputs and resources are technical in nature, some are fundamentally not (Dutrénit, 2000). In terms of technology and technical change, a predominant commonality among the various conceptual frameworks of technological capability refers to the application of a combination of two kinds of technological gaps: production capabilities and innovation capabilities (Bell & Figueiredo, 2012). Typically, production capability is conceptualized as a set of routine-based operational capabilities for product and process organizations. Such kind of capabilities includes the skills and knowledge to produce industrial goods with a given level of efficiency and input combinations using existing production techniques. The concept of innovation capability typically refers to the skills and knowledge enabling technical change. This involves not only the introduction of technology in new products or processes, but also the gradual adaptation and improvement of existing products and processes already in use (Bell & Pavitt, 1993, 1995; Lall, 1992, 1994). Bell and Figueiredo (2012) argue the case for a fuzzy boundary interlinking production and innovation. On the one hand, firms can catch-up in terms of production capabilities. That is, the performance characteristics of the products offered may gradually approach the world product technology frontiers, at some point possibly matching or even outdoing the leading products on the market. Or similarly, the production performance may become more and more competitive, perhaps one day matching or even outdoing the performance of leading firms operating at, or nearby, the world process technology frontiers (Bell & Figueiredo, 2012; Wong, 1999a, 1999b). On

the other hand, firms can also catch-up in terms of innovation capabilities, increasing their potential to implement change in product and process technologies. This innovation potential may evolve from lower states of imitation to higher states of increasingly sophisticated and creative innovation, which could eventually enable firms to compete successfully at the world technology frontiers (Bell & Figueiredo, 2012; L. Kim, 1997).

2.2. Evolution of latecomer technological learning

The literature dealing with the modal characteristics of latecomer technological learning emphasizes that processes of learning, technological capability building, and innovation rely on a variety of organizational arrangements, that is, learning mechanisms. These learning mechanisms bring together the two distinct but partially overlapping domains of learning and knowledge acquisition within and across organizations. It becomes clear that interactions between internal and external learning are essential and can take place throughout the catch-up process (e.g., see Bell & Figueiredo, 2012; Dutrénit, 2000; Hobday, 1995; L. Kim, 1997; Pietrobelli & Rabellotti, 2011; Wong, 1999b). The dynamics of learning processes and the mechanisms underlying these processes are considered to be closely related to the dynamics of technological development (Choung et al., 2006). Bell (2006) argues that the trajectories of technical change, the evolution of their capabilities, and the various internal and external forces affecting these trends may change, to a greater or lesser degree, over time. A number of studies report on the transformation of learning focus at different stages of the catching-up process, in particular from process- to product- and production- to innovation-oriented technological capabilities (Dutrénit, 2000; Hobday, 1995; Hobday et al., 2004; K. Lee, 2005; Mathews, 2002). According to Figueiredo (2007), technological progress is associated with deliberate and effective discontinuity in the key features of technological capability building. Such discontinuity may refer to changes in the specific functioning, intensity, or composition of the mechanisms of technological learning, which may include systemic changes in the way they interact with each other. In this sense, it is argued that firms need to reconsider and change the nature and direction of their technological learning as they (are to) accumulate different types and higher levels of technological capability – so that the relative importance of learning mechanisms is dynamic and can evolve in line with technological progress. Figueiredo et al. (2013) find that the relative importance of internal and external learning mechanisms changes, particularly as firms approach world-leading levels of innovation capability, suggesting that certain change is required to achieve certain technological capability levels. Reinauer and Hansen (2021) argue that shifts in the relative importance of different types of learning mechanisms tend to follow a co-evolutionary pattern involving shifts within and across learning mechanisms drawing on different sources of knowledge, namely firm-internal, domestic firm- external, and foreign firm-external knowledge. L. Kim (1997, 1998, 2001) argues that in order

for firms to be able to maintain and increase the effectiveness of their technological efforts, they should continuously seek to expand their learning frontiers by shifting the focus at some point from imitative to innovative learning processes. Other research points to the role of competition and the dynamics of the market environment in technological progress. Forbes and Wield (2002) advance the view of a learning hierarchy in catching-up. This hierarchy can be understood as a structured approach to technology-related opportunities, options, and actions, where the learning focus of latecomers evolves based on what kinds of capabilities firms need at specific points in time relative to international best practice. At the heart of this argument is the recognition that sooner or later during the catching-up process, firms face the challenge of becoming more and more innovative, not only but also in response to changing market and competitive conditions (Bell & Pavitt, 1995). As pointed out by Ernst, Mytelka, and Ganiatsos (1998), especially the more advanced firms come under increasing pressure to diversify their products and processes into more sophisticated technology areas in a reasonably (cost-)effective and timely manner.

A related aspect worth highlighting concerns the transformation of latecomers from catching-up to leadership status, which is critically related to managing the dynamics of technological learning. This phase of technological catch-up development can be described as a transition process to build advanced capabilities in innovation (Dutrénit, 2000, 2004) during which firms may evolve from technology users to technology generators (Choung et al., 2000; Choung et al., 2006). At the same time, however, firms may still lack knowledge or have larger knowledge disparities between related technology areas (Dutrénit, 2007), which can lead to a balancing act in which firms are well advanced in certain areas while still needing to catch-up in others (Dutrénit, 2000, 2004). From a purely technological point of view, one of the fundamental transition challenges for firms is to dynamically adapt to and deal with the duality of the leadership and latecomer elements underlying the modalities of the learning approaches being pursued (Dutrénit, 2007; Hobday et al., 2004). The transition to leadership is seen as entailing massive innovative efforts (Bell & Figueiredo, 2012) and the adoption of different types of learning strategies (Tacla & Figueiredo, 2006). In particular, the case is made for a strategic shift in learning focus towards creative innovation and research-based learning (Choung et al., 2014; L. Kim, 2001). Hobday et al. (2004) argue that the transition to leadership inevitably requires more intense and aggressive R&D strategies. According to Figueiredo et al. (Figueiredo et al., 2013), limited efforts to change not only the intensity but also the very quality of internal and external learning over time can constrain the accumulation of advanced innovation capabilities – and firms get stuck as followers instead of becoming world-leading innovators (Figueiredo et al., 2013). Taken together, embracing modal change and development also, and in particular, seems to enable the more technologically advanced latecomers to eventually evolve into major players in technology and

innovation, thereby improving their techno-economic competitive position in the global marketplace (Chuang, 2014).

2.3. Learning and international technology transfer

There is little or no doubt that externally mediated local and foreign knowledge is central to the accumulation of technological capabilities in firms (R. Lema & Lema, 2012). In general, external knowledge (especially specialized capabilities) is a crucial source for latecomers to facilitate diversity and depth as well as flexibility and speed of technological development (Ernst, Mytelka, & Ganiatsos, 1998). Advanced knowledge from abroad, in particular, is seen as essential for catching-up to become a significant process (Bell & Figueiredo, 2012; Bell & Pavitt, 1993; K. Lee, 2005). Two important technology trends make mechanisms of latecomer internationalization even seem increasingly important. First, technology is ever becoming more complex, with interdependencies across sectors and firms. International technology communities play an increasingly crucial role for latecomers to access complementary assets, especially given less diversified industry structures. Second, the rate of technical change is accelerating. Latecomers increasingly need to engage internationally to keep pace with worldwide technical change (Marin & Arza, 2009).

The technology strategy of latecomer recipients is, on the one hand, framed by the technology transfer strategy of technology owners and the resulting technology and transfer mode options (Luo & Tung, 2007). In general, the bargaining position of technology owners in technology transfer negotiations can be seen as focal (Lall, 1993; 1997; United Nations Conference on Trade and Development, 1999; 2005) and stronger than that of latecomer technology recipients (United Nations Conference on Trade and Development, 2005) – although the bargaining power of latecomers may increase with the availability of complementary local resources (Hennart, 2012; Hennart et al., 2015), including techno-economic development (prospects) in terms of firms and industries (L. Kim, 1997; Lall, 1993; 1997) or markets (R. Lema & Lema, 2012). However, it is also the more technologically competent latecomer firms that are increasingly facing barriers to international technology transfer (Hobday et al., 2004; L. Kim, 2001). In particular, it may become increasingly difficult and expensive – and eventually inadequate or even impossible – for them to obtain commercially and/or technologically significant technologies on market terms (United Nations Conference on Trade and Development, 1999). Strategically addressing such technology challenges usually requires major technological efforts involving extensive R&D and/or alternative, often outward-oriented modes of technology transfer. Alternative modes may include subcontracting, M&As, strategic technology alliances, or internationalization of R&D, as the examples of India, China, South Korea, and Taiwan show (R. Lema & Lema, 2012; United Nations Conference on Trade and Development, 1999).

On the other (related) hand, the latecomer technology transfer strategy is essentially based on technological capability and absorptive capacity requirements related to technology needs and associated learning orientations (L. Kim, 1997). The work on technological transformation in latecomer industries tends to emphasize that the essence of international technology transfer for latecomer development is localized learning (Evenson & Westphal, 1995; J.-S. Shin, 1996/2015) and technology mastery (R. Lema & Lema, 2012; Wie, 2005). Understood in this way, technology transfer is essentially a learning process that builds on absorptive capacity and the ability of recipient latecomers to transform external knowledge, including tacit knowledge and its technical and non-technical constituents, into firm-specific technological capabilities according to local contextual needs and constraints (Ernst, Ganiatsos, & Mytelka, 1998; B.-W. Lin, 2003).¹ In other words, technological capabilities need to be built and acquired locally, drawing upon the technology being 'transferred' (Lall, 1993). This may and usually does require substantial technological effort by technology recipients and interaction with technology owners, with some technologies and also transfer modes requiring more substantial (interactive) technological effort than others (R. Lema & Lema, 2012). It is long known that especially those transfer relationships that involve close and frequent personal interactions can have a positive impact on the effectiveness of technology transfer processes, even more so if the incoming technology should be particularly sophisticated, unfamiliar, or tacit – thus complex (Sexton & Barrett, 2004; Steensma, 1996). As Howells (1996) argues, especially the less explicit and codified tacit elements of technologies cannot be transferred directly and easily. Against the backdrop of this discussion, therefore, the case is often argued for the benefits of more socially embedded forms of transferring knowledge, such as via subcontracting or strategic alliances, where learning is enabled, though not guaranteed, through reciprocal organizational ties in network-like relationships between firms (Ernst & Kim, 2002; P. P. Li, 2010; Narula, 2003; Radošević, 1999). The positive effect of social personnel linkages is also noted for relationships between firms and research institutions (Azevedo Ferreira & Rezende Ramos, 2015; Cyert & Goodman, 1997).

Overall, it can be assumed that technology inflows tend to become qualitatively more advanced as latecomer countries and firms approach higher levels of techno-economic development (Enos, 1989; Enos et al., 1997; Hoekman et al., 2005; Maskus, 2004; World Bank, 2008), also and especially depending on development needs (Wie, 2012). Studies such as that of Duysters et al. (2015) point to the importance of moving from 'simpler' technology transfer modes such as reverse engineering or technology licensing to more 'sophisticated' transfer modes such as M&As or strategic alliances as the latecomer learning focus shifts to more higher-quality, innovation-oriented technological activities. L. Kim (1997, 1999, 2001) focuses on the study of the case of South Korea. Overall, the catch-up experiences of firms there indicate that reverse engineering and

other informal sources of technology transfer can be an important building block of the early latecomer technology strategy, especially if the technology to be mastered should (still) be quite mature and less complicated. However, as technological needs and requirements increase, the technology transfer strategy ought to co-evolve in ways facilitating the uptake of (foreign) technology. This may initially include expansion to more effective formal transfer modes such as technology licensing, technical consultancy, reverse brain drain, or turnkey plants. Later on, M&As, strategic alliances, or R&D internationalization may become increasingly important for gaining access to frontier technologies and fostering innovation (L. Kim, 1997, 1999, 2001). R. Lema and Lema (2012) report on the catching-up experience of Chinese and Indian firms. Similarly, less interactive transfer modes such as trade in goods, inward foreign direct investment, or technology licensing are found to be particularly important for industry formation and take-off, with technology licensing often serving as a springboard. More interactive transfer modes such as outward foreign direct investment through M&As, strategic alliances, or R&D internationalization may gain in importance as the catch-up process and technological capability accumulation progress. There is indication of synergies among external modes of learning on the one hand as well as internal and external modes of learning on the other. Complementarity in external technology sourcing finds empirical support at a general level. Keil et al. (2008) show that increasing innovative performance is associated with increasing complementary use of different external modes of learning, such as non-equity strategic alliances, equity strategic alliances (i.e., joint ventures), and corporate venture capital investments. According to van de Vrande et al. (2011), the combination of corporate venture capital investments with non-equity strategic alliances, equity strategic alliances, and M&As positively affects the innovative performance of investing firms. Sabidussi et al. (2014) demonstrate that the combination of M&As and strategic alliances is more conducive to innovation than unilateral specialization, especially when specialization is focused on M&As. Such multi-modal insights also support the general conclusion of Radosevic (1999), who argues that effective technology transfer for catching-up is not just a matter of identifying a single best channel. Rather, technology transfer is described as a dynamic and cumulative result of the bundling of various transfer modes, the individual appropriateness of which highly depends on technology and changing levels of technological development, among many other factors internal or external to the firm. Hence, technology transfer in general and transfer mode choice in particular can hardly be understood in isolation, especially considering that external technologies and internal learning are conjugative technology transfer elements that can and should be combined synergistically to maximize technology acquisition (Cohen & Levinthal, 1989; 1990) and catch-up with technology (Bell & Figueiredo, 2012; L. Kim, 1997; R. Lema & Lema, 2012). General empirical evidence such as that of Cassiman and Veugelers (2006) strongly supports the complementarity of internal and external learning activities, suggesting that the marginal return of

one activity may increase with the level of the other activity. As Bierly and Chakrabarti (1996a, 1996b) note, a successful learning strategy is, hence, one in which internal and external learning are balanced in a way to maximize a firm's overall learning performance. With some exceptions (e.g., Min et al., 2023), most studies specifically looking at latecomer firm development also agree that internal and external learning can be complementary. In particular, there is case-based evidence that combining internal and external learning tends to be more effective for technological capability building than relying solely on internal learning (Hansen & Lema, 2019; Hansen & Ockwell, 2014; Reinauer & Hansen, 2021). According to Figueiredo (2010), firms fostering both internal and external R&D at the early stages of innovation capability building are more likely to exhibit comparatively higher innovative performance. Similarly, the modal composition of internal and external learning is associated with the achievement of certain levels of technological capability, particularly in terms of world-leading innovation capabilities (Figueiredo et al., 2013).² More generally, it becomes clear that technological capability building by latecomers is not limited to any single type of learning mechanism, but rather involves the combined use of complex and interrelated sets of different types of learning mechanisms. These sets include combinations of mechanisms drawing on different sources of knowledge, internal or external to the firm, domestic or foreign (Hansen & Lema, 2019; Reinauer & Hansen, 2021).

In summary, given the complex interplay of various combinations of internally and externally as well as locally and internationally mediated modes of learning, technological capability building, and innovation, the study of the modal nature and dynamics of latecomer catch-up development is inherently configurational and, therefore, predisposes to configurational thinking and theorizing. Such recognition also seems to be corroborated by a variety of studies dealing more broadly with innovation and techno-economic firm development from a configurational perspective (e.g., Covin et al., 2016; Fiss, 2011; Greckhamer & Gur, 2021; Reichert et al., 2016; L. Zheng et al., 2021). In general, the unique strengths of configurational analysis, specifically QCA, are highlighted in addressing various issues relevant to research in science, technology, and innovation (Fernández-Esquinas et al., 2021) and business and management (Meuer & Fiss, 2020), including international business (Fainshmidt et al., 2020).

3. Methodology

3.1. Configurational data analysis

A set-theoretic configurational approach is applied to analyze the data. Originally developed in the political and social sciences by Ragin (1987, 2000), the method of qualitative comparative analysis (QCA) has also been finding increasing acceptance and use in various other disciplines and areas of research,

including business and management studies. A more recent trend is in fuzzy-set applications (Kraus et al., 2018; Roig-Tierno et al., 2017). We choose to use fuzzy-set QCA (fsQCA) as a method for three major reasons. First, our analysis is case-oriented and based on a small- to intermediate-N universe of cases ($N = 23$). We therefore seek to bridge the gap between qualitative and quantitative methodologies by combining the strengths of qualitative within-case knowledge and cross-case quantitative empirical inquiry. Second, our primary aim is to build, map, and comparatively investigate empirical configurational typologies. More specifically, our interest is in exploring the nature and evolution of multiple sets of different combinations of modal conditions that jointly contribute to a particular outcome, rather than in assessing the explanatory value (or 'net effect') of single conditions at any point in time. To this end, QCA and Boolean (or fuzzy) algebra are effective means of identifying and comparing empirical clusters and of discerning their key underlying similarities and differences – by analyzing asymmetric, equifinal configurations and subdividing similar and different groups of cases (Ragin, 1987; Rihoux & Ragin, 2009; Schneider & Wagemann, 2012). Third, fuzzy-set theory, as a generalization of the conventional Boolean bi- or multivalent logic, allows for a finer-grained quantitative assessment of degrees of set memberships, ranging from full non-membership (membership score of 0) to full membership (membership score of 1) (Ragin, 2000, 2008).

3.2. Explanatory fsQCA framework of innovation and corporate catching-up

Conceptually, the explanatory fsQCA framework is rooted in appreciative theory (Nelson & Winter, 1982), specifically in the theoretical tradition of latecomer development and firm-level technological catching-up (e.g., Amsden, 1989; Dutrénit, 2004, 2007; L. Kim, 1997;

K. Lee & Lim, 2001; Mathews, 2002, 2006, 2007). The concept of technological capabilities is particularly well suited to explaining – differences in – techno-economic catch-up development in developing and emerging economies, including development at the level of individual firms (Lall, 1992; Morrison et al., 2008). A widely used approach is to construe the development of latecomer firms in terms of the cumulative growth of their technological capabilities (Bell & Pavitt, 1995; Lall, 1987), unfolding in an evolutionary process of learning, technological capability building, and innovation (K. Lee & Malerba, 2018).

From studies such as those by Wong (1999a, 1999b), K. Lee and Lim (2001), Mu and Lee (2005), and Bell and Figueiredo (2012), a general input-output relationship can be inferred between the processes and associated mechanisms of learning, technological capability building, and innovation on the one hand and techno-economic firm performance on the other. This is consistent with the notion of plausible configurational fit, which captures the multidimensionality and complexity of configurational relationships linking

interactions among business environment attributes, firm strategy attributes, and organizational attributes with firm performance (Soda & Furnari, 2012).³ The configurational fit of relationships related to learning and organizational capabilities is reflected at a general level in previous studies (Snow et al., 2005; Takeuchi et al., 2003), including configurational studies (Bennat, 2022; Peris-Ortiz et al., 2018). Accordingly, the plausibility of the existence of configurations of learning inputs and corresponding learning outputs seems obvious and justifiable from a theoretical and logical point of view (see Soda & Furnari, 2012).

The explanatory fsQCA framework is exploratory and based on a generative approach to configurational fit, modelling learning mechanisms underlying processes of learning, technological capability building, and innovation as input (i.e., modal learning conditions) and techno-economic competitive performance of firms as output (i.e., market-related learning outcome) of latecomer industrial development. Building on Wong (1999a, 1999b), two strategic technology dimensions related to firms' core business are taken into account: process and product technological capabilities. Process capabilities refer to the ability to manufacture multiple copies of a specific product or to deliver a specific service repeatedly upon given product or service performance specifications. This includes improvements in manufacturing or delivery processes. Product capabilities relate to the ability to create and design new products and services, including improving existing designs and functionality. Following a 'subject' approach (Organisation for Economic Co-operation and Development & European Statistical Office, 1997, 2005), the conceptual focus is on processes of learning, technological capability building, and innovation as a whole, rather than processes directly related to specific process or product/service organizations.

The explanatory fsQCA framework assumes that the development of process and product technological capabilities is ultimately endogenous, and thus localized, but can be mediated by both internal and external efforts of learning (Ernst & Kim, 2002; Lall, 1993).

These internal and external learning efforts are understood as strategic modal investments in the development of the technological capabilities required for the design and implementation of technology strategies and the – effective – execution of innovative activities (Bell & Figueiredo, 2012).⁴ In this light, the (temporal) structure of modal investments, represented by the configuration of learning mechanisms employed, is taken as an indicator of the strategic learning orientation of firms (see Calantone et al., 2002; Hult et al., 2004).

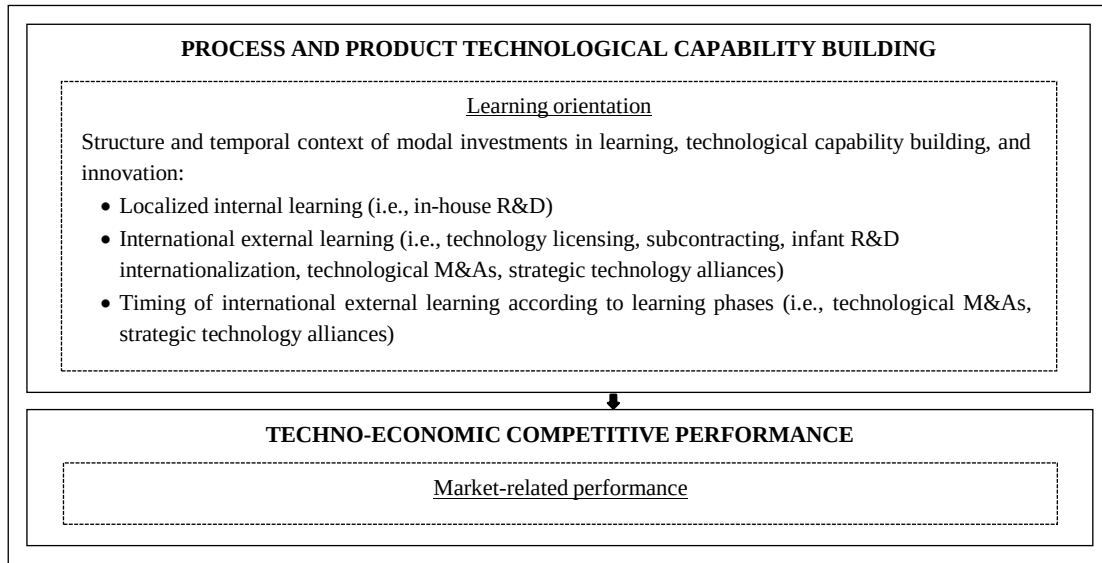
The centrality of foreign technology and internationalization to latecomer development is well known. In particular, firms can adopt international (compositional) springboard (P. P. Li et al., 2022; Luo & Tung, 2007, 2018) and linkage-leverage-learning strategies (Mathews, 2002, 2006) to develop techno-

economically. In this sense, learning orientation is conceptualized in the context of local(-ized) and international firm learning (Hansen & Lema, 2019; L. Kim, 1997; R. Lema & Lema, 2012), in terms of six internal and external learning mechanisms. Internal local(-ized) learning refers to (i) in-house R&D (R. Lema & Lema, 2012), including in-house R&D conducted abroad (Awate et al., 2015; A. Lema & Lema, 2016).⁵ External local(-ized) or international learning involves domestic or foreign technology communities (Hansen & Lema, 2019; L. Kim, 1997; R. Lema & Lema, 2012). It encompasses

(ii) infant R&D internationalization⁶, (iii) technology licensing, (iv) subcontracting, (v) technological M&As, and (vi) strategic technology alliances. All these learning mechanisms are generally counted among the major channels of (international) technology transfer of latecomers (L. Kim, 1997; K. Lee, 2005; Wong, 1999b), including and especially in the Chinese PV-module and wind-turbine manufacturing industries (Gosens & Lu, 2014; A. Lema & Lema, 2016; R. Lema & Lema, 2012; Lewis, 2012; Quitzow, 2015).

The longitudinal perspective aims to investigate into local(-ized) internal learning and international external learning mode choice. Temporality is considered in the specific context of international technological M&As and international strategic technology alliances, which are deemed two distinct sides of the same coin of (Chinese) internationalization (Zhang et al., 2012). Inspired by previous studies (L. Kim, 1997; 1998, 2001; L. Kim & Yi, 1997; Sohn et al., 2009), a time-related working model of latecomer development is construed in which firms evolve from imitation to innovation. Correspondingly, the longitudinal context of learning is periodized and conceptualized as consisting of two firm-specific learning phases, an imitative and an innovative learning phase. Learning phases are conceived as consecutive, with firms transitioning from the imitative to the innovative learning phase during the techno-economic catch-up process. The conceptualization of the explanatory fsQCA framework is outlined in Figure 1.

Figure 1: Explanatory fsQCA framework of innovation and corporate catching-up



Note. Own elaboration based on Wong (1999a, 1999b), Bell and Figueiredo (2012), L. Kim (1997), R.Lema and Lema (2012)

3.3. Measurement and calibration

The issue of calibration is central to all QCA variants, including fsQCA (Schneider & Wagemann, 2012). According to (Ragin, 2008), ideally, cases and their properties should be entirely evaluated in the context of prior theoretical and substantive knowledge. Whenever possible, set membership calibration should be based on agreed-upon, externally known general standards (Greckhamer et al., 2018). Especially the specifying of ‘qualitative’ anchors according to inductively derived empirical benchmarks, such as quantitative measures of central tendency, needs careful motivation (Schneider & Wagemann, 2010).⁷ Our rationale to rely partially on sample-specific industry median and percentile parameters for structuring set calibrations is threefold. First, competitiveness, and with it competitive performance and performance characteristics, is inherently a relative concept that needs to be defined against some other state of the world, such as against different historical points in time, alternative counter-factual positions, or comparator bodies like countries, national industries, or firms (Buckley et al., 1988). A very common and useful practice in comparative firm-level analysis is to evaluate a firm’s competitive properties in the context of other competitively relevant firms according to (absolute or relative) deviations from some kind of positional measure, such as the statistical mean or median (Akben-Selcuk, 2016; Corbett, 1998). Such a measurement approach also proves useful in similar QCA-based studies in business and management (Fiss, 2011; Greckhamer et al., 2008; Jacobs et al., 2016; Linton & Kask, 2017; Misangyi & Acharya, 2014). Second, and relatedly, the use of central tendency or other empirical measures in QCA can be particularly fruitful when extant knowledge is ambiguous and inadequate to guide the

external definition of anchors for (initial) set membership calibration, lacking case-oriented meaning and reasoning (Greckhamer et al., 2013). Third, median and percentile parameters are used as measures rather than, for instance, mean or standard-deviation parameters because these are generally less sensitive to outliers and skewed data in small- to intermediate-N settings (e.g., Maronna et al., 2019; Sachs, 1984).

Our analysis involves three set-theoretic constructs of learning, technological capability building, and innovation: learning outputs (i.e., outcome condition), internal and external learning inputs (i.e., modal learning conditions), and learning phases (i.e., temporal learning context). The details of measuring and calibrating these constructs are provided hereafter.

3.3.1. Outcome condition

Techno-economic performance. The techno-economic competitive performance of firms is measured in terms of market shares. The ultimate key outcome measure of learning, technological capability building, and innovation is the competitive success of the firm (Clausset et al., 2021; Kalmuk & Acar, 2015; Rogers, 1998). As Wong (1999b) notes, in essence, the process of learning, technological capability building, and innovation can be conceptualized as the allocation and leveraging of inputs and resources to use and create technologies to improve the firm's overall competitive capabilities, thus techno-economic performance. A well-established and widely used operational indicator for competitive business performance is product-market performance, determined in terms of market share (Banbury & Mitchell, 1995; Buzzell et al., 1975; Cerrato & Depperu, 2011; Helms et al., 1997). Focusing on market share is particularly useful for business unit-level analysis when consistent financial/accounting or (stock) market-based performance measures are not available (e.g., S.-J. Chang & Singh, 2000), which is the case for Chinese PV module and wind turbine operations. Market share is understood here as the absolute market share in relation to the sample population of firm cases; it is defined as a firm's share of total yearly average shipments from 2015 to 2019 or of total shipments by the end of 2019 (see McKiernan, 2015).

The calibration strategy of the fuzzy-set outcome condition *Techno-economic performance (TEP)* considers measures of very high and not-very high techno-economic firm performance (Fiss, 2011; Misangyi & Acharya, 2014). Consistent with the calibration strategy of Fiss (2011) and other related previous work (Leppänen et al., 2023; e.g., Misangyi & Acharya, 2014), a basic distinction of firm performance is based on the median performance of the respective industry population. Membership in the set of firms with very high performance is coded 0 for firms showing median or below-median performance ($\leq 50^{\text{th}}$ percentile = full non-membership threshold). Membership is coded 1 for firms showing upper-decile performance ($\geq 90^{\text{th}}$ percentile = full

membership threshold), which is arguably very high performance (Leppänen et al., 2023). The 0.5-crossover point (neither in nor out-membership threshold) between these exclusion and inclusion thresholds is determined based on cluster analysis (Bazzan et al., 2022; Y. Kim & Verweij, 2016; Yanwei Li et al., 2016) using the hierarchical clustering technique of Duşa (2019). The absence of very high performance, that is, not-very high performance, is coded as the **negation of the set of very high performance**.

3.3.2. Modal learning conditions

In-house R&D propensity. Following Bierly and Chakrabarti (1996a) and others (Dodgson, 1991; Griliches, 1990), in-house R&D is seen as a primary indicator of firms' (competitive) ability to generate new ideas and knowledge internally, recognizing that internal learning is also a prerequisite for effective external learning (Cohen & Levinthal, 1989, 1990). The level of local(-ized) internal learning is conceptualized as in-house R&D propensity (R. Lema & Lema, 2012) and measured by patenting activity. Patent data are a meaningful source for capturing R&D-based innovative learning activities and efforts at the level of firms and business units (Hagedoorn & Cloudt, 2003; Organisation for Economic Co-operation and Development & European Statistical Office, 2018). Various studies on latecomer development rely on patent analysis, including studies on China (Choung et al., 2000; Ebersberger et al., 2023; K. Lee & Lim, 2001; Wang et al., 2014; Wang et al., 2012). However, the use of patent data in a Chinese patent data context needs some qualification. In China, three different types of patents are issued with different quality examination requirements: invention, utility model, and design patents (X. Li & Mitchell, 2009). Utility model and design patents undergo only formal examination and are broadly criticized for having no or relatively little technical or commercial value (Dang & Motohashi, 2015; Lam et al., 2017). In contrast, invention patents are subject to substantive examination, which requires the highest level of inventive step (He et al., 2018). The invention type of Chinese patents also best meets international standards for patentability and novelty requirements (Jia et al., 2019; Thoma, 2013). Accordingly, the present interest in innovative learning motivates a defining limitation to invention patents. Such a definition is also found in other studies using Chinese patent data (Dang & Motohashi, 2015; Lam et al., 2017). It is noted that, in principle, invention patent applications and granted invention patents can equally serve as innovation-related indicators in the case of China (Dang & Motohashi, 2015). Patent applications are preferred over granted patents here for two related reasons. First, such an approach allows for the analysis of more recent data – as it typically takes several years for patent applications to be granted, if ever (Picci, 2010). Second, patent applications are a more direct indicator of the level of R&D and the innovative learning activities and efforts involved (Popp, 2005). To avoid multiple counting of invention patent applications, patent families rather than individual patents are considered as the patent unit of analysis (Zhou et al., 2016). Patent families

group together individual patents originating from the same or substantially related R&D, even if application or grant years should vary (Nagaoka et al., 2010). There are several types of patent families, one of which is the so-called patent main family. This family type is particularly well suited to capture innovative learning activities and efforts, as it includes a set of invention patent applications filed in different countries to protect the same invention by common inventors; that is, the technical content of these applications is considered to be identical. All applications thus have exactly the same first filing/priority date or combination of first filing/priority dates (LexisNexis, 2021) – with the family member with the earliest filing date being the representative family member here. ⁸With all this in mind, in-house R&D propensity is measured by the number of invention patent family applications related to a firm's core business filed by December 31, 2019.⁹

The calibration of the fuzzy-set modal learning condition *In-house R&D propensity (IRD)* corresponds to that of techno-economic performance. Membership in the set of firms with very high in-house R&D propensity is coded 0 for firms showing median or below-median performance ($\leq 50^{\text{th}}$ percentile = full non-membership threshold) and is coded 1 for firms showing upper-decile performance ($\geq 90^{\text{th}}$ percentile = full membership threshold). Again, the crossover point (neither in nor out-membership threshold) in-between is calculated using statistical cluster analysis (Duşa, 2019). The absence of very high in-house R&D propensity, that is, not-very high in-house R&D propensity, is coded as the negation of the set of very high in-house R&D propensity.

Technology licensing, subcontracting, and infant R&D internationalization. The external learning mechanisms of technology licensing, subcontracting, and infant R&D internationalization are jointly conceptualized as infant technology springboards.¹⁰ Such learning mechanisms are used to technologically jump-start and nurture the catch-up process through early access to (foreign and usually superior) external technology (Wong, 1999a, 1999b) that would otherwise be out of reach, at least for the time being (Mathews, 2002). While early mastery of technologies is a basic common function, imitative and innovative types of learning mechanisms can be distinguished in the context of infant technology springboards. It is fair to say that technology licensing and subcontracting are essentially related to imitative learning (Hobday, 1995; Sohn et al., 2009; Yu, 2005), whereas infant R&D internationalization essentially involves innovative learning (Vrontis & Christofi, 2021).

In this study, technology licensing is defined as inward technology licensing agreements by which a firm is granted access to another firm's technology on market terms (Tsai & Wang, 2007). Subcontracting can generally be understood as the execution of production or related service activities according to (agreed) specifications by client firms (Rama et al., 2003), usually

under medium- to longer-term agreements (Kimura, 2002). The present analytical interest is in OEM/ODM systems as a specific and widespread form of subcontracting (Hobday, 1995). Infant R&D internationalization refers to the establishment of R&D subsidiaries or facilities abroad (Zhao et al., 2022) in the initial phase of the catch-up process for the purpose of infant technology development.¹¹ Regarding internationality, technology licensing and OEM/ODM activities are counted as international learning mechanisms when foreign technologies or technology partners are involved. Infant R&D internationalization is considered per se an international learning mechanism. This is consistent with the understanding of R&D internationalization as a means of international technology transfer (R. Lema & Lema, 2012) and linkage to foreign inputs and resources (Awate et al., 2015; Wong, 1999a, 1999b).

The use of international technology licensing, international subcontracting, and infant R&D internationalization by firms is measured by the (non-)presence of international technology licensing, international subcontracting, and infant R&D internationalization events related to a firm's core business by December 31, 2019. Because international technology licensing, international subcontracting, and infant R&D internationalization operate as functional equivalents in early technology mastery, they are combined into a common higher- order concept (Schneider & Wagemann, 2012). The modal learning macro-condition *International infant technology springboards (IITS)* is calibrated as a bivalent crisp set.

Membership in this set is coded 1 for firms using at least one of the learning mechanisms international technology licensing, international subcontracting, or infant R&D internationalization, and 0 otherwise.

International strategic technology alliances. Building on the concepts of Teece (1992) and Hagedoorn (1990, 1993), strategic technology alliances are narrowly defined as bilateral (or multilateral) inter-firm partnerships in which joint technology development, in the sense of combined innovative activity and/or mutual exchange of technology, for a common technology- focused purpose is sought and agreed; that is, mere production, marketing, supply, or project development arrangements are omitted. This includes co-patenting alliances as a special case of R&D-based technology cooperation (Lecocq & van Looy, 2009). A strategic technology alliance qualifies as international strategic technology alliance if at least two partnering firms of the technology cooperation originate from different countries (Duysters & Hagedoorn, 2000). The use of international strategic technology alliances by firms is measured by the (non-)presence of international strategic technology alliance events related to a firm's core business in a given learning phase by December 31, 2019.

The modal learning condition *International strategic technology alliances (ISTA)* is calibrated as a multivalent crisp set. Membership in this set is coded 2

for firms using at least one international strategic technology alliance each of the two consecutive learning phases, and 1 for firms using at least one international strategic technology alliance in one of the two consecutive learning phases, and 0 otherwise.

International technological M&As. M&As are defined as joint transactions in which two separate firms are combined to form a single firm. Such combinations include both the merger of equals and the acquisition of majority ownership (Hagedoorn & Duysters, 2002); that is, mere technology/asset purchased are not considered. M&As qualify as technological M&As if they can reasonably be expected to focus, among other things, on the acquisition of external technology. In particular, technological M&As are seen as technologically motivated, primarily to develop core technology areas, extend focus to underdeveloped technology areas, or expand into new technology areas (S. R. Shin et al., 2017). International technological M&As are understood to involve cross-border M&A transactions (Cantwell & Santangelo, 2002). The use of international technological M&As by firms is measured by the (non-)presence of international technological M&A events related to a firm's core business in a given learning phase by December 31, 2019.

The calibration strategy of the modal learning condition *International technological M&As (ITMA)* corresponds to that of international strategic technology alliances. It is calibrated as a multivalent crisp set. Membership in this set is coded 2 for firms using at least one international technological M&A in each of the two consecutive learning phases, and 1 for firms using at least one international technological M&A in one of the two consecutive learning phases, and 0 otherwise.

3.3.3. Temporal learning context

The construct of learning phases is not an outcome or explanatory condition, but a contextual means of framing learning orientations in a temporal manner. There are a variety of stage and process models of latecomer development by means of which the nature and dynamics of firm-level learning, technological capability building, and innovation can be analyzed (e.g., Dutrénit, 2000; Ernst, Mytelka, & Ganiatsos, 1998; Figueiredo, 2001; Forbes & Wield, 2002; Hobday, 1995; L. Kim, 1997). However, the periodization approaches used in the change-related application of such models tend to be qualitative-interpretative in logic and rather informal-subjective. Some previous studies more generally assume universal industry-wide (L. Kim, 1997, 2001; R. Lema & Lema, 2012) or universal cross-case phase structures (Figueiredo et al., 2013). Other previous studies discern phase structures more specifically from a single case-by-case perspective, usually drawing on in-depth case knowledge. For instance, different lifetime stages of firms are identified based on biographies of major technological milestones and breakthroughs (Hansen &

Lema, 2019; Reinauer & Hansen, 2021) or major shift patterns in qualitative characteristics in knowledge network development (Dantas & Bell, 2009). The apparent neglect of formal-objective measurement concepts in the prevailing periodization approaches may make cross-case comparability difficult and/or cumbersome to achieve, especially in the presence of substantial heterogeneity across cases. Given the present interest in studying a larger number of heterogeneous cases of firms from different industries, the development of an alternative approach to periodization and periodization measurement seems expedient. In particular, the formal-objective temporal measurement concept is to enable and facilitate systematic firm-specific comparative analyses under increased case heterogeneity on the one hand and extensive case-based applications on the other.

A time-related working model of latecomer development is constructed in which firms move from imitation to innovation, as commonly argued (Altenburg, 2021), evolving from processes of imitative and innovative learning (L. Kim, 1997; 1998, 2001; L. Kim & Yi, 1997; Sohn et al., 2009). The temporal context of learning is periodized correspondingly. A basic distinction is made between two firm-specific consecutive learning phases, an imitative and an innovative learning phase. Imitative learning is more focused on existing knowledge and processes of knowledge utilization, that is, exploitative learning processes and activities in the sense of experienced-based learning-by-doing or learning-by-using. In contrast, innovative learning focuses more on new knowledge and change-related processes of knowledge creation, that is, explorative learning processes and activities in the sense of science-based learning-by-searching (Bell, 1984; Lundvall & Johnson, 1994; Sohn et al., 2009). In particular, innovative learning is guided by the search for inventive knowledge (Suarez-Villa, 1990). Conceptually, firms are considered to individually transition from one learning phase to another as they achieve a path-creating or path-leading catch-up state of technological progress, which is driven by original innovation (K. Lee, 2005) and indigenous knowledge creation (Altenburg, 2021; Porter, 1990). It is argued that firms in transition begin to compete on the basis of knowledge (Dutrénit, 2000, 2004), especially inventive, patentable knowledge (Choung et al., 2000; Kale & Little, 2007; Sohn et al., 2009). Patent knowledge creation is fundamentally linked to trajectories of innovative learning, suggesting significant innovative learning patterns (Cantwell, 2000). In this sense, the working model assumes that the phase transition from imitative to innovative learning coincides with the emergence of proprietary patent knowledge by firms. The operationalization of corresponding transition points can thus be firm-specific and individualized based on initial patenting activities of firms derived by means of patent analysis. Patent data is a widely used and recognized tool for formal-objective measurement purposes (e.g., S.-B. Chang et al., 2009).

The temporal context of the explanatory conditions concerned is

established accordingly. The year of the earliest filing date of an invention patent grant is conceptualized to mark the individual transition point at which a firm moves from the imitative to the innovative learning phase, with the imitative phase ending with the year of filing and the innovative phase beginning the year after the filing¹²

4. Sample and data

At the core of this dissertation is the generation of a unique dataset of indicators on firms' learning outputs, internal and external learning inputs, and learning phases. The overall period of study for data compilation ranges from 01 January 1998 to 31 December 2019. The definition of the upper temporal boundary suggests itself for two conceptual reasons. First, it helps circumvent biases relating to the COVID-19 pandemic gaining global momentum in early 2020, the (potential) market- and industry-related implications of which still need to be adequately understood. Second, relatedly and most importantly, our analytical interest is focused on pre-COVID-19 market and industry developments. The lower temporal boundary is defined by the year of incorporation of the 'oldest' firms in the sample, namely Goldwind and Trina Solar.

The empirical context of learning outputs, including the related selection of firm cases, refers to the techno-economic competitive performance of firms in the period from 2015 to 2019. This time frame corresponds to a typical business planning horizon in strategic management, which is three to five years (Abraham & Leavy, 2007; Alkhafaji, 2003; Kabeyi, 2019; Kaplan & Norton, 1996; Parakhina et al., 2017). Possibly for the same reason, previous firm-level studies often rely on five-year study periods (e.g., Azhar & Ahmad, 2019; Fu & Gong, 2011; Helms et al., 1997; C. Lin et al., 2020; Menna et al., 2019; Monczka et al., 1993). The empirical context of internal and external learning inputs as well as learning phases spans the respective entire lifetime of firms through 2019. Research design and process are framed accordingly.

4.1. Case selection

Case selection and the definition of scope conditions and criteria for inclusion and exclusion of cases are among the fundamental issues in the design of case-based research (Schneider & Wagemann, 2012; Thomann, 2020). Case-based analyses might be sensitive to the (non-)selection of cases, most notably in relatively small-N research designs (Thomann & Maggetti, 2020). Case selection in QCA requires the selection of 'comparable' cases that typically display both similarities and differences in the variables (i.e., conditions and outcome) to be studied. In particular, case selection should ensure variation in the outcome (Rihoux & Lobe, 2009). The present selection of firm cases for analysis is systematic and outcome-oriented. The empirical context of case selection refers to the core business of firms from 2015 to 2019.

Three selection criteria are applied to systematically select relevant firm cases, namely a market performance criterion, a market return criterion, and a business continuity criterion. The market performance criterion refers to a firm's leading techno-economic competitive performance in a respective industry, as determined by placings in top-10 firm industry rankings (see also Anderson & Smith, 2006; Azhar & Ahmad, 2019; Halliday et al., 1997; Jadhav et al., 2022; Steenkamp, 2018). To qualify as a top-10 firm, a firm must have achieved a top-10 placing in global shipments at least once. The market return criterion qualifies a top-10 firm in terms of financial/economic viability (Buckley et al., 1988). As justified above, a top-10 firm must have operated in a financially and economically reasonable manner without jeopardizing the development and continued existence of the business in the longer term (Banbury & Mitchell, 1995). The related criterion of business continuity refers more generally to the continued existence of the business. As in previous studies (S.-J. Chang & Singh, 2000; Defever & Riaño, 2017; Hurtado-Palomino et al., 2022), a top-10 firm must not have become inactive – for whatever reason – but must remain active in the market. On this multi-criteria basis, case selection is performed in two major steps.

In a first step, all top-10 PV-module and wind-turbine firms are identified based on firm industry rankings from single sources. Industry ranking information comes from the Chinese Photovoltaic Power Station Industry Platform and the Chinese Wind Energy Association, both of which provide continual and arguably also the most comprehensive collections of firm statistics for the PV and wind power industries in China, respectively. The Chinese Photovoltaic Power Station Industry Platform is a professional industry platform for PV project development and information services in China (see Chinese Photovoltaic Power Station Industry Platform, 2022). Annual data on and rankings of major Chinese PV-module manufacturing firms based on global shipments are made publicly available. The Chinese Wind Energy Association is a non-profit organization operating under the umbrella of the Chinese Renewable Energy Society (see Chinese Wind Energy Association, 2022). Annual and cumulative data on and rankings of major Chinese wind-turbine manufacturing firms are published annually, separated by domestic and export shipments. Thus, annual global shipments are self-calculated by adding annual domestic and export shipments. Firm rankings are compiled accordingly. On this empirical basis, a total of 27 firms, including 15 PV-module and 12 wind-turbine firms, are identified as satisfying the market performance criterion.

In a second step, those firms that cannot meet the market return and business continuity criteria are identified and excluded from the (preliminary) collection of the 27 classified top-10 firms. It turns out that four firms, three PV-module firms and one wind-turbine firm, have reportedly suffered from prolonged existential financial/economic hardship and/or have discontinued business. PV-module firms Yingli Solar and Hareon Solar both have faced

significant financial difficulties in the past, accompanied by a general decline in market shares and shipments (Chinese Photovoltaic Power Station Industry Platform, 2021). Former national champion Yingli Solar has been undergoing a massive debt restructuring process since 2016. In 2020, the firm officially entered the judicial restructuring process under which the holding company, Yingli Green Energy, was liquidated without debt settlements (Osborne, 2020). Hareon Solar was forced into bankruptcy liquidation in 2018 (Jäger-Waldau, 2018) and ultimately business termination due to bankruptcy in 2021 (Shaw & Hall, 2021). PV-module firm Renesola discontinued its Chinese PV-module business in 2017 and completed a non-cash restructuring to dispose of substantially all assets and liabilities related to production (Renesola, 2018). As a subsidiary of the over-indebted Dunan Group (Wildau, 2018), wind-turbine firm China Creative Wind Energy ceased operations in 2018, with no shipments being made in 2019 (Chinese Wind Energy Association, 2020). Consequently, these four firms are considered ineligible and are excluded from case selection.

As a result of the case selection process, a total of 23 out of the 27 top-10 firms can be confirmed for analysis. These 23 eligible firms include 12 PV-module and 11 wind-turbine firms; among them are the usual Chinese ‘suspects’ that can also be found in other relevant (global) industry rankings, such as those from Solar Media/PV-Tech (<https://marketresearch.solarmedia.co.uk>), InfoLink (<https://www.infolink-group.com>), BloombergNEF (<https://bnef.com>), or Global Wind Energy Council/FTI Consulting (<https://gwec.net>).

Figure 2: List of firm cases considered for analysis

Photovoltaic industry		Wind power industry	
Firm name	Abbreviation	Firm name	Abbreviation
Jinko Solar	Ji	Goldwind	GW
Trina Solar	TR	Envision	EV
JA Solar	JA	Mingyang	MY
Canadian Solar	CA	Guodian United	GU
Longi Solar	LO	Shanghai Electric	SE
GCL System	GC	CSIC	CS
Risen Energy	RE	Dongfang	DO
SFCE	SF	Windey	WI
Chint Solar	CH	XEMC	XE

Talesum	TS	CRRC	CR
Eging PV	EG	Sany	SA
Haitai Solar	HT		

4.2. Data collection and preparation

4.2.1. Data collection on learning outputs

The collection of data relating to the competitive techno-economic performance of firms is based on shipment data releases by firms and industry organization. Data for (calculation and ranking of) annual and cumulative average shipments for PV-module manufacturing from 2015 to 2019 essentially comes from the Chinese Photovoltaic Power Station Industry Platform (2021); data for Chint Solar's 2015 shipments from Chint (2016) and for Haitai Solar's 2018 shipments from the International Energy Agency (2019). Data for (calculation and ranking of) annual and cumulative average shipments for wind-power manufacturing from 2015 to 2019 is collected from the Chinese Wind Energy Association (2016, 2017, 2018, 2019, 2020).

4.2.2. Data collection on internal and external learning inputs as well as learning phases

Data relating to internal and external learning as well as learning phases comes from various sources. Patent analysis and event study methods are used for data collection.

Patent analysis

Data relating to internal and external learning as well as learning phases is collected as part of a patent analysis (Breitzman & Moge, 2002). Patent classification searching is an effective technique for patent data extraction (e.g., Alberts et al., 2017). Many – if not most – of the earlier approaches to patent classification searching appear to rely on the International Patent Classification (IPC) scheme administered by the World Intellectual Property Organization, including the one taken here. In general, wind-turbine technology is one of the particularly well classified renewable energy technologies (Schleich et al., 2017). It is comprised in the IPC subclass F03D, which is also commonly used in related research (e.g., Gosens & Lu, 2014; Hayashi, 2020; Lam et al., 2017; Popp et al., 2011; Schleich et al., 2017;

S. Zheng et al., 2021). This subclass comprehensively covers the main technological mechanism facilities of wind turbines, with a focus on wind motors as well as the directly associated technical fields of installation, energy storage, and monitoring/testing. Related research on PV-module technology is

essentially based on the IPC subclass H01L (e.g., Hayashi, 2020; Liang & Liu, 2018; Popp et al., 2011; Shubbak, 2019; Son & Cho, 2020; Tour et al., 2011; S. Zheng et al., 2021), which is focused on semiconductor devices more generally, including semiconductors adapted for PV applications. While this subclass provides the highest overall concentration of the main technological mechanism facilities of PV modules (Sampaio et al., 2018), coverage of the directly associated technical fields of installation, energy storage, and monitoring/testing is somewhat less comprehensive or diverse, notably as compared to wind-turbine technology. Therefore, the coverage of subclass H01L is selectively expanded to include complementary technical fields of installation, energy storage, and monitoring/testing, following the IPC inventory developed by Shubbak (2019).¹³

The patent analysis is proceeded in four steps. First, a longitudinal database of corporate group-subsidiary affiliations (i.e., ‘patent entity identifiers’) is developed. To correctly detect relevant patents, patent filings by subsidiary firms are aggregated at ultimate corporate group- levels. This is useful for two reasons. On the one hand, patents are often filed under the name of a subsidiary rather than the parent firm (He et al., 2018; Phelps, 2010; Singh, 2005). On the other hand, it can be argued that learning, technological capability building, and innovation is an integrative process usually taking place within a corporate group, in particular through sharing and exchange of advanced subsidiary knowledge to facilitate the techno-economic process of other subsidiaries and the group as such (Awate et al., 2015). Following previous work focusing on China (He et al., 2018), corporate affiliation directories from international and China-based business information providers (i.e., Refinitiv Eikon and Bureau van Dijk Orbis as well as Qichacha) in combination with annual reports are used to create multilingual search lists of firm names. Changes of firm names in English and Chinese are tracked and listed based on historical event information from Refinitiv Eikon, Qichacha, Baidu Aiqicha, and Qixinbao. In addition, firm names gathered in Chinese are machine-converted into Simplified and Traditional Chinese, respectively, and listed for patents to be searched both ways (see, e.g., Z.-C. Lin et al., 2017).¹⁴ Moreover, meaningful short names of firms, including brand/trade and stock names, are listed to account for firm name variations (see Alberts et al., 2017). These short names are derived based on information from Refinitiv Eikon, Qichacha, Baidu Aiqicha, and Qixinbao as well as from annual reports, firm websites, and trade and business news. The resulting collection of patent entity identifiers is then prepared for patent search. In particular, patent entity identifiers are cleaned of obvious misspellings and typographical errors. Firm suffixes (e.g., GmbH, Corporation, LLC, Inc.) of Latin script-based patent entity identifiers are also removed (see Alberts et al., 2017; Clarke, 2018). Finally, patent entity identifiers are divided into batches of (usually) 250 search list lines. In total, the database of patent entity identifiers for all firms in the sample contains 54,524 entries, of which 20,968 entries refer to firm names converted into either Simplified or Traditional

Chinese.

Second, patent data are extracted from the international patent database LexisNexis TotalPatent One. The patent search strategy employed considers patent main families and related invention patent applications filed under the relevant IPC codes through December 31, 2019. To extract patent data, firm-wise batch search queries are performed. All query results per firm are accumulated and stored in firm work folders, with duplicate entries being sorted out by software. In total, 6,500 data points for non-duplicative raw patent family entries are extracted.

Third, the extracted raw patent data are verified and corrected for erroneous entries using multiple sources, most notably Refinitiv Eikon, Bureau van Dijk Orbis, Qichacha, annual reports, firm websites, and trade and business news. Specifically, all patent entries are reviewed for corporate group-subsidary affiliation. This includes reviewing changes in corporate group-subsidary relationships, taking into account the timing of mergers and acquisitions as well as divestments (He et al., 2018; Phelps, 2010). In like manner, co-assigned patent entries with more than one patent-filing firm are identified and reviewed for non-corporate group-subsidary affiliation (Lecocq & van Looy, 2009). The resulting qualified strategic technology alliance activities are then reviewed for internationality based on firm origins using patent assignee information from LexisNexis TotalPatent One.¹⁵ In total, 5,492 data points for patent family entries are considered eligible for analysis, of which 167 entries refer to strategic technology alliance activities, of which 7 entries in turn refer to international activities.

Fourth, the respective first patent filings by firms are identified from the collection of eligible patent family entries. The first filings considered refer to the first earliest patent application for a successfully granted invention patent.¹⁶

Event study

Further data relating to external learning is collected using event study methodology (Eden et al., 2022). The data collection process is threefold. It combines complementary searches in factual business information databases, searches in archival full-text business information databases, and literature-based hand searches.

First, proprietary information about business events is compiled from various factual business information databases. These include major sources also commonly used in related research (e.g., Andrade-Rojas et al., 2021; Eden et al., 2022; Hoppmann et al., 2021; Zámorský et al., 2021), namely: Refinitiv Eikon and Securities Data Company (SDC) Platinum, Bureau van Dijk Orbis and Zephyr, FactSet Mergerstat, MarketLine Advantage, GlobalData, and Qichacha.¹⁷ In addition, patent-related information on strategic technology

alliances is sourced from the patent database LexisNexis Total Patent One by means of patent analysis, the data collection and compilation procedure of which is explained above.

Second, in line with previous work (e.g., Patra & Krishna, 2015; Phelps, 2010), event information is searched in archival databases containing full-text business information. Four major international databases are used because of their relevance to the topic (see, e.g., Drake et al., 2017; Y. Liu & Deng, 2014; Patra & Krishna, 2015; Phelps, 2010): Nexis Uni, ABI/INFORM Collection, RavenPack News Analytics, and Dow Jones Factiva. Overall, this set of databases brings together a wide variety of English and non-English sources from all over the world covering original international records of event information, international records of event information based on original Chinese records, and original Chinese records of event information, including news-related and academic sources. The search strategy for retrieval of event information records from news-related full-text business information databases includes manual keyword searches in Nexis Uni, Dow Jones Factiva, and ABI/INFORM Collection as well as structured keyword searches in RavenPack News Analytics. In developing search terms, a variety of keywords relevant to the search criteria are included to ensure thorough and broad, yet expedient event information retrieval (Eden et al., 2022). To retrieve event information, full-text searches are conducted in English as well as in Simplified and Traditional Chinese in all databases and available content types usually covering a data range from January 1, 1998, to at least January 31, 2020; other date ranges are chosen in exceptional cases, notably taking into account significant M&A activities.¹⁸ In total, this full-text database-assisted part of the event study generates 447,718 data points for event information records, of which 304,295 refer to records in English and 143,423 in Chinese.

Third, extensive literature-based hand searches are carried out. Consistent with related research (Hagedoorn, 1993; Patra & Krishna, 2015; Phelps, 2010), including research on China (Wang et al., 2012; Zhang, 2013), hand searches involve screening information from various literature-based sources reporting on business events. Corporate sources comprise corporate communications such as firm websites, annual reports, or company brochures. Non-corporate sources include academic publications, industry reports, analyst reports, newspapers/news portals, or trade magazines.¹⁹ This also includes targeted searches of specialized media sources in the areas, namely: pv magazine, PV-Tech.org, ENF Solar, China Energy News, Windpower Monthly, and the Wind Energy Magazine of the Chinese Wind Energy Association.

4.2.3. Data preparation

On the basis of the thus collected data, firm-specific external learning orientations are constructed, also taking into account the specifics of

individualized learning phase transitions; the supplementary data on individual transition points of learning phases are derived from the patent analysis as described above. Data are compiled using the Popperian logic of falsifiability. The basic logic behind the falsification principle is that a universal statement can be falsified by a single disconfirming counterexample (see Popper, 1959/2002). With this in mind, the following working assumption is made for each respective firm, external learning mechanism, and learning phase: A given external learning mechanism *is not* used by a firm in a corresponding learning phase. This assumption is then to be falsified by disconfirming counterexamples that demonstrate the respective use of the given external learning mechanism by a firm in a corresponding learning phase. Accordingly, only in the absence of any disconfirming counterexample the assumption of non-use remains, otherwise it is falsified; thus, the falsified assumption is that a given external learning mechanism *is* used by a firm in a corresponding learning phase. The search for disconfirming counterexamples is recursive and informed by the external learning data collected and found to be eligible. The data

eligibility review distinguishes between two types of data sources. On the one hand, data are generally considered eligible if they come directly from corporate sources. On the other hand, following Phelps (2010), data from non-corporate sources are considered eligible only if they can be validated and confirmed in multiple sources.

5. Results

Asymmetry is a central feature in QCA. Asymmetry assumes that explanations for an outcome do not allow conclusions to be drawn about the non-outcome, and vice versa. Accordingly, two separate QCA analyses are carried out, the first for the presence and the second for the absence of the outcome (Jacobs et al., 2016). These are performed in R (version 4.2.3) by using the QCA package by Duşa (2019) (version 3.18) and the SetMethods package by Oana and Schneider (2018) (version 4.0); R statistical programming software is used in the Posit Cloud (formerly RStudio Cloud) cloud-based environment. Consistent with current best practice, the analysis of necessity precedes the analysis of sufficiency (Mello, 2022; Oana et al., 2021; Schneider & Wagemann, 2012).

5.1. Analysis of necessity for very high and not-very high techno-economic performance

The standard measures of fit for considering conditions as necessary for the (non-)outcome are consistency, coverage, and relevance of necessity. The consistency value for necessary conditions should be at least 0.90, preferably higher (Mello, 2022; Oana et al., 2021; Schneider & Wagemann, 2012). While this consistency threshold is now widely accepted, there are (as yet) no firm lower-bound coverage and relevance of necessity threshold requirements

(Haesebrouck, 2019; Mello, 2022). According to Oana et al. (2021), the thresholds for both coverage and relevance of necessity should be at least 0.60 for any condition to be considered potentially necessary at all. As a general rule, however, high(er) coverage and relevance of necessity values indicate high(er) empirical importance (Schneider & Wagemann, 2012), such that some conditions are empirically more important than others (Mello, 2022) – so the higher the values, actually the better (Bazzan et al., 2022). Corcaci (2019) argues for a reasonably high relevance of necessity threshold, preferably of 0.80 or at least 0.75, to discern necessary conditions of unambiguous relevance, along with correspondingly high coverage values. Similarly, Mello (2022) considers values of 0.80 or higher for coverage as well as relevance of necessity as a strong indication for relevant, non-trivial necessary conditions. Consistent with recent studies along these lines (Bazzan et al., 2022; Peng et al., 2022), the thresholds for consistency, coverage, and relevance of necessity are set here at 0.90, 0.80, and 0.80, respectively.

There are no conditions passing these thresholds in both the analysis of necessity for the presence and the absence of the outcome, that is, very high and not-very high techno-economic performance (see Figure 3).

Outcome	inclN	RoN	covN	Non-outcome	inclN	RoN	covN
1 IITS[0]	0.027	0.877	0.063	1 IITS[0]	0.174	0.991	0.937
2 IITS[1]	0.973	0.184	0.334	2 IITS[1]	0.826	0.310	0.666
3 ISTA[0]	0.005	0.915	0.019	3 ISTA[0]	0.122	0.998	0.981
4 ISTA[1]	0.206	0.510	0.118	4 ISTA[1]	0.656	0.886	0.882
5 ISTA[2]	0.789	0.796	0.602	5 ISTA[2]	0.222	0.721	0.398
6 ITMA[0]	0.231	0.420	0.113	6 ITMA[0]	0.770	0.850	0.887
7 ITMA[1]	0.768	0.846	0.659	7 ITMA[1]	0.169	0.740	0.341
8 ITMA[2]	0.002	0.957	0.010	8 ITMA[2]	0.061	1.000	0.990
9 IRD[0]	0.365	0.303	0.149	9 IRD[0]	0.919	0.760	0.883
10 IRD[1]	0.714	0.928	0.789	10 IRD[1]	0.115	0.794	0.298
1 ISTA[2] + ITMA[1]	0.929	0.662	0.532	1 ISTA[1] + ITMA[0]	0.957	0.661	0.858
2 ISTA[2] + IRD[1]	0.976	0.712	0.588				
3 ITMA[1] + IRD[1]	0.937	0.771	0.630				

Note. Abbreviations: inclN = consistency of necessity, RoN = relevance of necessity, covN = coverage of necessity. The necessity of all single conditions is displayed. In addition, the necessity of combinations of a maximum of two conditions passing the thresholds for consistency, relevance of necessity, and coverage of 0.90, 0.50, and 0.50, respectively, are displayed.

5.2. Analysis of sufficiency for very high and not-very high techno-economic performance

The raw consistency threshold used for the analysis of sufficiency is 0.80, which is now a commonly accepted benchmark; raw consistency indicates the strength of the set relation between a single truth table row and the (non-)outcome (Mello, 2022; Oana et al., 2021; Schneider & Wagemann, 2012). In fsQCA, it is also important to consider PRI (proportional reduction in inconsistency) scores to avoid simultaneous subset relations of configurations in both the outcome and the non-outcome. A high PRI consistency threshold of 0.70 is used here to ensure significant consistencies (Greckhamer et al., 2018). There are three types of QCA solutions, namely the conservative, parsimonious, and intermediate solutions. In line with our exploratory approach and the lack of theory-guided hunches linking conditions to the (non-

)outcome, we choose the conservative solution for substantive interpretation. Unlike the intermediate and parsimonious solutions, this solution is not based on simplifying assumptions using logical remainders, but entirely on truth table rows that are deemed sufficient for the (non-

)outcome based on empirical evidence (Schneider & Wagemann, 2012). The analysis of sufficiency follows the enhanced standard analysis protocol of Schneider and Wagemann (2012). The enhanced conservative fsQCA solutions obtained are shown in Figure 4.

Figure 4: fsQCA solutions

Configurational pathways of very high and not-very high performance								
Very high performance				Not-very high				
	1	2	3	4	5	6	7	8
External learning								
IITS	●	●	●	●	●	●		
ISTA	●	●	●	●	●		●	○
ITMA	●	○	●	○		○	○	○
Internal learning								
IRD		●	●		○	○	○	○
Consistency	0.861	1.000	0.946	0.958	0.990	0.959	0.982	0.983
PRI	0.839	1.000	0.943	0.956	0.989	0.957	0.981	0.983
Raw Coverage	0.627	0.122	0.141	0.356	0.480	0.535	0.406	0.119
Unique Coverage	0.627	0.122	0.141	0.060	0.184	0.179	0.110	0.059

Solution Consistency	0.891	0.962
Solution PRI	0.877	0.960
Solution Coverage	0.890	0.948

Note. White circles indicate the absence of a fuzzy/bivalent or multivalent condition (value [0]), half-black circles indicate the presence of a fuzzy/bivalent or multivalent condition with value [1], full-black circles indicate the presence of a multivalent condition with value [2], blank spaces indicate contextually irrelevant conditions. The configurational pathways of solutions 1 to 8 are conveniently sorted to facilitate substantive interpretation; the original order of solutions 7 and 8 from the computed R output is swapped. The coverage of firm cases by the respective configurational pathways of solutions 1 to 8 is as follows: solution 1 = JA, MY, CA, GW, EV; solution 2 = JI; solution 3 = TR; solution 4 = GC, HT, EG, WI, CR, GU; solution 5 = GC, HT, EG, WI, CR, SF, CH, XE; solution 6 = RE, GC, HT, EG, WI, CR, DO, CS, SE; solution 7 = LO, TS, GC, HT, EG, WI, CR; solution 8 = SA, RE.

Analysis of sufficiency for very high techno-economic performance

The first analysis of sufficiency covers the firm cases of JA Solar, Jinko Solar, Trina Solar, Canadian Solar as well as Mingyang, Goldwind, and Envision. It indicates three configurational pathways (solutions 1-3) explaining the presence of the outcome, that is, very high techno-economic performance:

$$\text{IITS}[1]*\text{ISTA}[2]*\text{ITMA}[1] + \text{IITS}[1]*\text{ISTA}[2]*\text{ITMA}[0]*\text{IRD}[1] + \text{IITS}[1]*\text{ISTA}[1]*\text{ITMA}[1]*\text{IRD}[1] \rightarrow \text{TEP}[1]$$

The overall solution consistency is 0.89, which indicates a strong set relation (≥ 0.75) between cases and configurational pathways in an overall solution. The overall solution coverage of 0.89 shows that the configurational pathways of solutions 1-3 explain about 90% of the membership in the outcome, which is an indication of high empirical relevance (≥ 0.50). The unique coverage values of solutions 1-3 are adequately high (> 0.00); unique coverage indicates the proportion of cases expressed by a single configurational pathway (Mello, 2022; Oana et al., 2021; Schneider & Wagemann, 2012). The sufficiency plot of the overall solution is shown in Figure 5.

Solution 1 suggests a pathway leading to very high performance for combinations of international infant technology springboards with consecutive international strategic technology alliances and non-consecutive international technological M&As. Solutions 2 and 3 suggest that the combination of very high in-house R&D propensity with international infant technology springboards and consecutive international strategic technology alliances in the absence of technological M&As is sufficient for very high performance. Solution 3 suggests a very-high-performance pathway for combinations of very

high in-house R&D propensity, international infant technology springboards, non-consecutive international strategic technology alliances, and non-consecutive technological M&As.

Overall, these findings indicate that very high performance is associated with a rather more comprehensive and/or consecutive international external learning orientation, with very high localized internal learning being either contextually relevant or irrelevant. In contrast to international strategic technology alliances, the relevance of the consecutive temporal context of international technological M&As seems negligible for very high firm performance. Only non-consecutive international technological M&As appear to be contextually relevant.

We can think of two overarching explanations for these findings. First, superior performance may be related to complementarity effects unfolding in certain performance- effective configurational multi-modal learning contexts. This proposal confirms and extends previous related studies pointing to synergies in the internal and external processes and underlying mechanisms of learning, technological capability, and innovation (Hansen & Lema, 2019; Hansen & Ockwell, 2014; Reinauer & Hansen, 2021). Internal learning is related to overall learning performance, including maximizing learning from external sources (Cohen & Levinthal, 1989, 1990). In principle, a greater variety of learning mechanisms increases the potential basis upon which synergistic modal interplays among internal and external learning as well as among external learning can occur (Tacla & Figueiredo, 2006). It also allows for a more holistic approach to learning, technological capability building, and innovation, where different kinds of complementary inputs and resources can be acquired from different modal sources, including various sources of (international) technology transfer. Second, the consecutive dynamics of modal learning orientations lead to the proposal that early and persistent external learning through international strategic technology alliances could play a particular performance-enhancing role, at least when embedded in certain configurational multi-modal learning contexts. This is related to the idea that international strategic technology alliances can serve as an early technology springboard in the imitative learning phase of technological development, synergistically complementing international technology licensing, international subcontracting, or infant R&D internationalization. In contrast, all international technological M&As are non-consecutive and relate exclusively to the innovative learning phase. This indicates that international technological M&As become more relevant and thus performance effective later in the catch-up process, also in combination with international strategic technology alliances.

The most populated configurational pathway of very high performance is represented by solution 1, which covers the cases of JA Solar and Canadian Solar as well as Mingyang, Goldwind, and Envision. In particular, this main

configurational pathway emphasizes that a comprehensive international external learning orientation, including learning from consecutive international strategic technology alliances and non-consecutive technological M&As, renders very high localized internal learning contextually irrelevant. The cases of JA Solar as well as Mingyang show that not-very high in-house R&D propensity can still contribute sufficiently to very high firm performance. This finding seems to corroborate previous studies linking internal and external learning efforts (e.g., Cohen & Levinthal, 1989, 1990; Criscuolo & Narula, 2008;

L. Kim, 1997), suggesting that some threshold degree of internal learning is required to adequately harness the potential of external learning and enhance performance. Apparently, JA Solar as well as Mingyang can meet such an internal learning threshold. Another related explanation arises from the same basic complementarity logic (Hansen & Lema, 2019; Hansen & Ockwell, 2014; Reinauer & Hansen, 2021), specifically with respect to the variety and thus the scope of international external learning. Among the very high-performing firms, JA Solar as well as Mingyang exhibit the most comprehensive international external learning orientation, including the use of both imitative and innovative international infant technology springboards. This not only further increases the potential modal synergies among external learning as well as among internal and external learning (Tacla & Figueiredo, 2006). According to Figueiredo (2010), early innovative external learning, such as through infant R&D internationalization, could also provide additional performance synergies.

The two remaining configurational pathways leading to very high performance are individual firm pathways, with solution 2 referring to Jinko Solar and solution 3 referring to Trina Solar. Unlike the main configurational pathway, very high localized internal learning seems to be contextually essential here. In particular, it appears to facilitate complementary substitution within international external learning related to international strategic technology alliances and international technological M&As. The temporal context of international strategic technology alliances seems to matter in that consecutive international strategic technology alliances occur as an alternative to non-consecutive international strategic technology alliances and non-consecutive international technological M&As. More specifically, the international external learning orientation of Jinko Solar is consecutive with a focus on international strategic technology alliances. International technological M&As are not used. In contrast, the international external learning orientation of Trina Solar is non-consecutive but more balanced, using both international strategic technology alliances and international technological M&As. To some extent, this finding is affirmative of previous studies broadly describing strategic technology alliances and M&As as alternative means of technology transfer in general (de Man & Duysters, 2005) and international technology transfer by latecomers in particular (Duysters et al., 2015; Zhang et al., 2012).

From an overarching modal learning condition perspective, the particular contextual relevance of international infant technology springboards for very high firm performance becomes evident, as these are present in all solutions across all cases in one form or another. Jinko Solar, Trina Solar, and Canadian Solar as well as Goldwind use imitative springboards, while Envision uses an innovative springboard. Only JA Solar as well as Mingyang rely on both imitative and innovative springboards. All very-high performing firms also learn from international strategic technology alliances. Jinko Solar is the only firm not using international technological M&As. All other firms use consecutive technological M&As in the innovative learning phase. While all very-high performing firms except Trina Solar have a consecutive learning focus involving international strategic technology alliances, consecutive international technological M&As are not used by any firm. The majority of firms exhibit very high in-house R&D propensity. The exceptions of JA Solar and Mingyang reveal that an above-median in-house R&D propensity can still be considered comparatively high, at least high enough to be contextually conducive to very high firm performance.

Analysis of sufficiency for not-very high techno-economic performance

The second analysis of sufficiency covers the firm cases of GCL System, Haitai Solar, Eging PV, SFCE, Chint Solar, Risen Energy, Longi, Talesun as well as Windey, CRRC, Guodian United, XEMC, Dongfang, CSIC, Shanghai Electric, and Sany. It indicates five configurational pathways (solutions 4-8) explaining the absence of the outcome, that is, not-very high techno-economic performance:

$$\text{IITS}[1] * \text{ISTA}[1] * \text{ITMA}[0] + \text{IITS}[1] * \text{ISTA}[1] * \text{IRD}[0] + \text{IITS}[1] * \text{ITMA}[0] * \text{IRD}[0] + \text{ISTA}[1] * \text{ITMA}[0] * \text{IRD}[0] + \text{ISTA}[0] * \text{ITMA}[0] * \text{IRD}[0] \rightarrow \sim \text{TEP}[1]$$

The overall solution consistency and coverage are 0.96 and 0.94, respectively, and can be considered very high. All unique coverage values of solutions 4 to 8 are > 0.00. The sufficiency plot of the overall solution is presented in Figure 5.

Solutions 4 and 5 suggest a pathway leading to not-very high performance for combinations of international infant technology springboards and non-consecutive international strategic technology alliances in the absence of either international technological M&As or very high in-house R&D propensity. Solutions 6 and 7 suggest that the absence of very high in-house R&D propensity and international technological M&As, either in combination with international infant technology springboards or non-consecutive international strategic technology alliances, is associated with not-very high performance. Solution 8 suggests a pathway of not-very high performance in the absence of very high in-house R&D propensity, international strategic technology alliances, and international technological M&As.

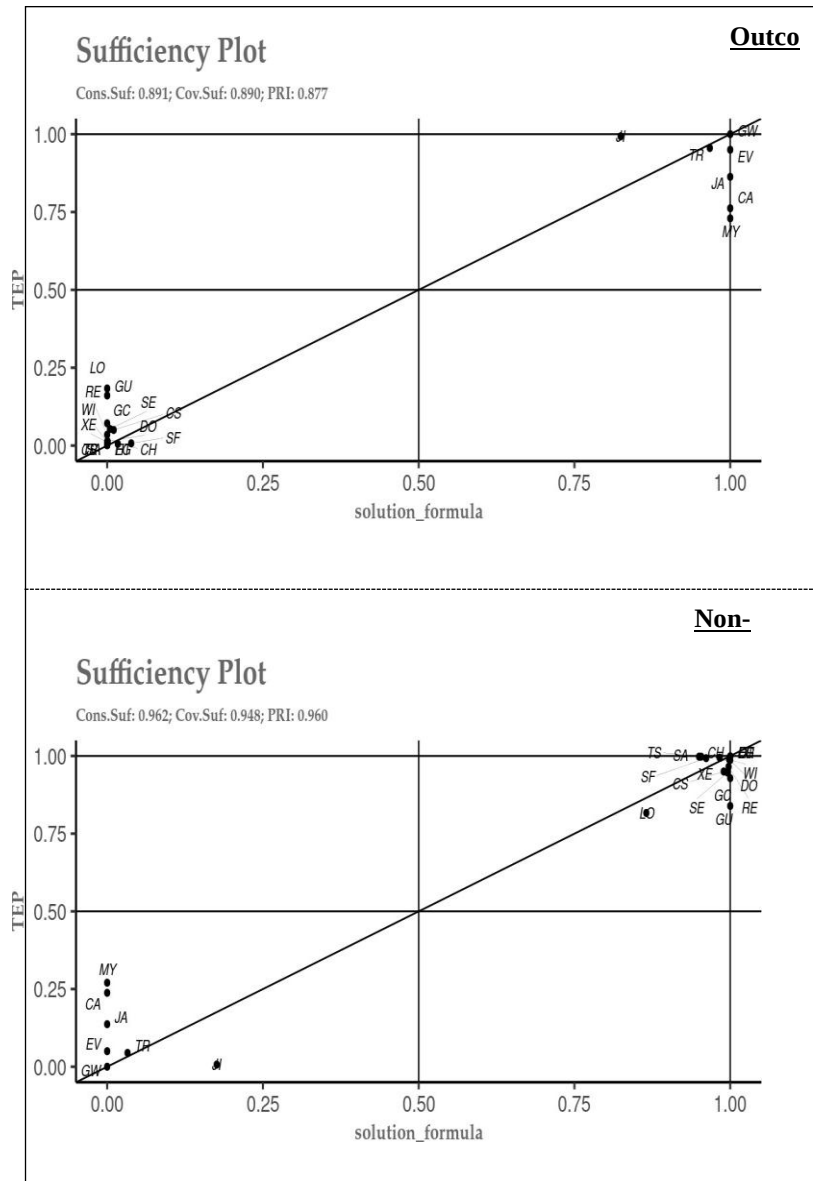
Overall, these findings point out that not-very high performance is related to a rather less comprehensive, non-consecutive international external learning orientation, almost exclusively including not-very high localized internal learning. The temporal context of international strategic technology alliances and international technological M&As seems rather negligible. This is consistent with the overall findings, and proposed overarching explanations, associated with very high performance, essentially reverse mirroring the performance-enhancing configurational multi-modal learning contexts identified earlier. In such a context, superior performance is shown to unfold from a rather more comprehensive and/or consecutive international external learning orientation facilitated by sufficiently high localized internal learning.

The configurational pathways represented by solutions 4 to 7 are jointly covered by the cases of GCL System, Haitai Solar, Eging PV as well as Windey and CRRC. What is common here is a somewhat rather less comprehensive international external learning orientation focused on international infant technology springboards and non-consecutive international strategic technology alliances along with not-very high localized internal learning. The international external learning orientation of SFCE and Chint Solar as well as XEMC in solution 5, of Risen Energy as well as Dongfang, CSIC, and Shanghai Electric in solution 6, and of Longi Solar and Talesun in solution 7 is sometimes more and sometimes less comprehensive. In the absence of very high localized internal learning, co-coverage of these cases makes international technological M&As, international strategic technology alliances, or international infant technology springboards contextually irrelevant. Co-coverage of Guodian United in solution 4 contributes to the contextual irrelevance of very high localized internal learning. An explanation for this latter finding reemphasizes the complementarity of internal and external learning efforts (Hansen & Lema, 2019; Hansen & Ockwell, 2014; Reinauer & Hansen, 2021), implying that localized internal learning 'alone' may not be sufficiently conducive to very high firm performance. The case of XEMC in solution 5 seems to point to the same basic logic, albeit in reverse (e.g., Cohen & Levinthal, 1989, 1990; Criscuolo & Narula, 2008; L. Kim, 1997). XEMC is actually among the firms with the most comprehensive international external learning orientation overall. However, the complementary localized internal learning is not-very high, with a below-lower-quartile in-house R&D propensity apparently not contributing sufficiently to achieving very high firm performance. Overarchingly, solutions 4 to 7 seem to illustrate that the effective alternative use of international strategic technology alliances and international technological M&As in international technology transfer is framed by a multi-modal configurational context involving a more comprehensive and/or consecutive international external learning orientation based on sufficiently high localized internal learning. All solutions 5 to 8 show the absence of very high localized internal learning. The configurational pathway of solution 8 is covered by Risen Energy as well as Sany, which belong to the firms with the least comprehensive, non-consecutive

international external learning orientation. While Risen Energy only uses international infant technology springboards, more specifically an imitative one, Sany relies exclusively on localized internal learning. In this respect, these cases may serve as prime examples of the instrumentality of internal and external learning and (changing) modal configurations of learning orientations for techno-economic competitive firm performance.

From an overarching perspective, the findings related to individual modal learning conditions indicate the particular contextual relevance of not-very high in-house R&D propensity for not-very high performance. Apart from Guodian United, not-very-high performance firms also have not-very high in-house R&D propensity, which becomes evident in 4 out of 5 solutions. Most firms, except Talesun and Longi as well as Sany, rely on international infant technology springboards, almost exclusively on imitative ones. While GCL only uses an innovative springboard, XEMC is the only firm focusing on both imitative and innovative springboards. International strategic technology alliances are used by the vast majority of firms, excluding Risen Energy as well as Sany, most of which are non-consecutive. Only Shanghai Electric, CSIC, and Dongfang learn through consecutive international strategic technology alliances. Consecutive international technological M&As are used exclusively by XEMC. None of the solutions identified contain consecutive international external learning orientations, suggesting that the consecutive temporal context of international strategic technology alliances and international technological M&As is of minor relevance for explaining not-very high performance. The non-consecutive temporal context of international strategic technology alliances is inconsistent and refers to either the imitative or innovative learning phase. This implies an inconsistent contextual link to not-very high performance.

Figure 5: Sufficiency plots of fsQCA solutions



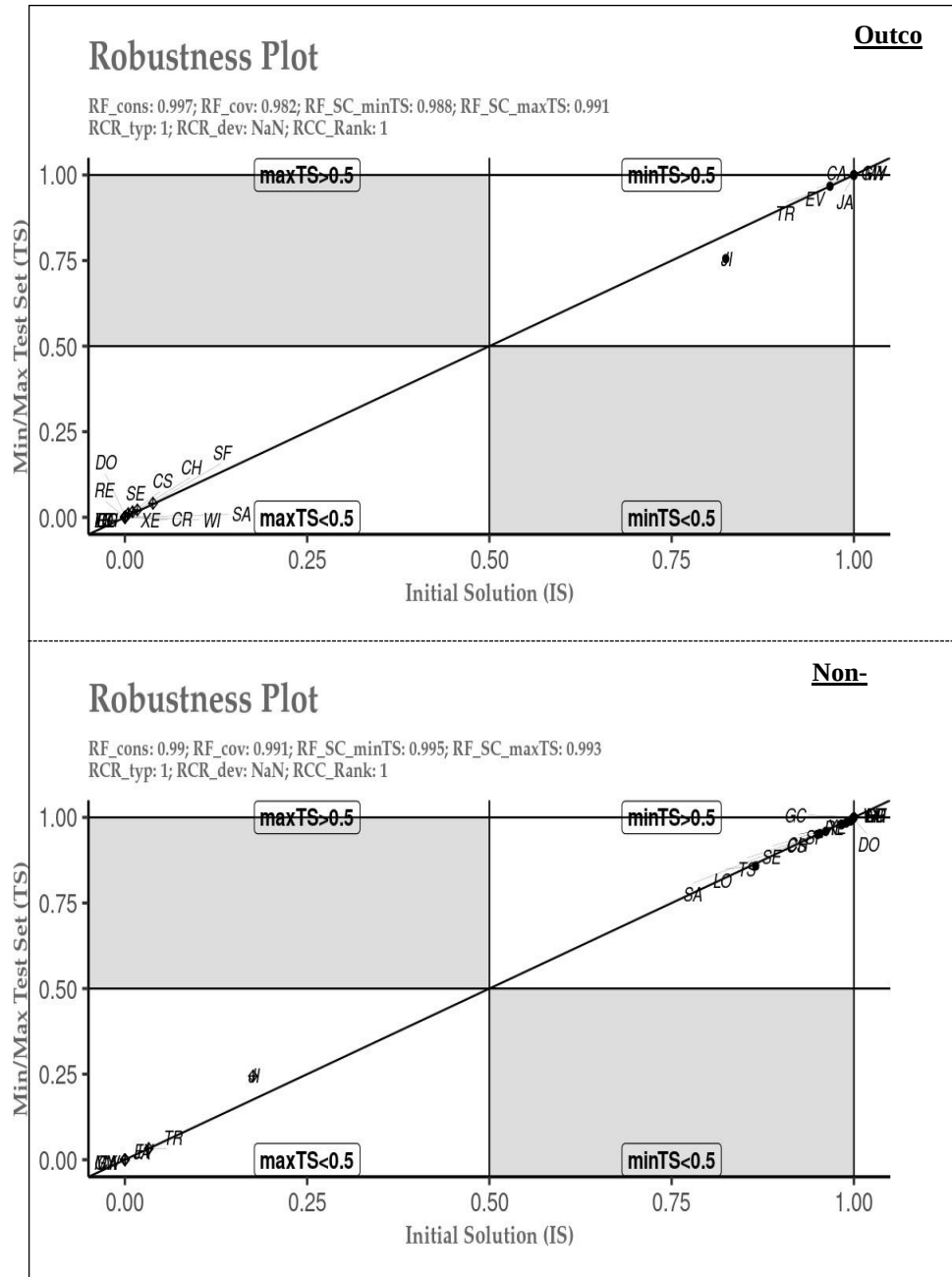
5.3. Robustness analyses

Two kinds of robustness analyses are performed. First, the robustness of the two fsQCA solutions across clusters, that is, the photovoltaic and wind power industries, is determined. The cluster diagnostic analysis confirms that all firm cases are adequately covered by the sufficient solutions terms in a cluster and that the sufficiency patterns found apply to both industry clusters (all consistency distance measures ≈ 0).

Second, a condition- and outcome-based robustness evaluation is conducted. The calculation of sensitivity ranges within which Boolean formulae

stay the same shows that the configurational pathways of both fsQCA solutions are relatively insensitive to changes of raw consistency levels (0.15-0.88 for the outcome and 0.25-0.90 for the non-outcome) within the commonly used frequency thresholds of one case (Mello, 2022). Robustness checks reveal that apart from minor changes to the parameters of fit, the initially found fsQCA solutions remain substantively unchanged under various alternative solution scenarios (see Tables 1 and 2 in the Appendix). Alternative solution scenarios include variations of $\pm 10\%$ of the inclusion, crossover, and exclusion thresholds of all fuzzy-set modal and outcome conditions, an alternative patent counting period until March 31, 2020, an alternative market share performance period from 2016 to 2019, an alternative calibration of the crossover threshold using the P50-P90 halfway mark for all fuzzy-set modal and outcome conditions, and an alternative definition of the learning phase transition point based on the year of the very first invention patent filing, regardless of grant status. Systematic condition-based robustness tests (Oana et al., 2021) demonstrate that both the fit-oriented robustness (all fit-oriented parameters ≈ 1) and the case-oriented robustness (Rob_Case_Rank = 1) is very high. The robustness plots are provided in Figure 6.

Figure 6: Condition-based robustness plots of fsQCA solutions



6. Conclusions

The conclusions to be drawn from this research are both empirical and methodological. Empirically, we have investigated into the link between the structure of modal investments in latecomer learning, technological capability building, and innovation and market-related techno-economic firm performance using 23 firm cases from the Chinese photovoltaic and wind power industries. While this is a first exploratory approach and not (yet) exhaustive, some

interesting initial empirical findings can be derived. The research adds to our understanding of the modal complexity of innovation and corporate catching-up and the temporal context in which it is embedded, while providing extended case-based insights into the configurational interplay between localized internal and international external learning. In particular, the relevance of the contribution of localized internal and international external learning orientations to latecomer development and techno-economic firm performance is demonstrated. Learning orientations are found to differ not only across firms but also across firm performance classes.

The findings indicate that very high performance is associated with a rather more comprehensive and/or consecutive international external learning orientation, with very high localized internal learning being either contextually relevant or irrelevant. The contextual irrelevance of local(-ized) internal learning is attributed to reaching a certain threshold degree of internal learning. In contrast to international strategic technology alliances, the relevance of the consecutive temporal context of international technological M&As seems negligible for very high firm performance. Only non-consecutive international technological M&As appear to be contextually relevant. Moreover, the findings point out that not-very high performance is related to a rather less comprehensive, non-consecutive international external learning orientation, almost exclusively including not-very high localized internal learning. The temporal context of international strategic technology alliances and international technological M&As seems rather negligible. Overall, the empirical findings seem to support the idea that firms should complement 'sufficiently' dedicated internal localized learning with 'sufficiently' comprehensive external learning from international environments, notably combining international infant technology springboards, such as infant R&D internationalization, technology licensing, or subcontracting, with international strategic technology alliances for (early) R&D-based joint technology development and/or international technological M&As.

Methodologically, we have demonstrated the added value of applying configurational, set-theoretic logic and QCA to latecomer development research. In particular, we have demonstrated that the configuration of modal investments in latecomer learning, technological capability building, and innovation – conceptualized as firm-specific learning orientations based on (international) learning mode choice – is relevant for techno-economic firm development. Moreover, we have demonstrated the relevance of the temporal context of modal investments by accounting for individual firm-specific – rather than industry-wide uniform – consecutive learning phases. We have also demonstrated the potential use and usefulness of a to the best of our knowledge – novel patent analytical approach to individually define these firm-specific consecutive learning phases over the course of the techno-economic catch-up process.

To conclude, there are some limitations to be noted when interpreting the findings. One of the major challenges in applied QCA is limited diversity and keeping a moderate ratio of cases to conditions (Mello, 2022; Oana et al., 2021; Schneider & Wagemann, 2012). Given our small- to intermediate-N research design of 23 firm cases, the modal learning conditions of the explanatory model are probably not exhaustive. Moreover, the research is limited to two manufacturing industries. Although it could be shown that the sufficiency patterns found apply to both industries considered, they may be industry-biased. Another potential limitation relates to the data used in this research. The data collection and preparation process for compiling firm-specific learning orientations, while extensive and conducted using triangulation, is essentially building on corporate reporting and may therefore be biased.

Working on these limitations provides some interesting opportunities for future research. By expanding the number of industries and firm cases, the scope of the (longitudinal) explanatory model can be increased and further – combinations of – modal learning conditions can be explored, including the exploration of temporal contexts. Relatedly, extending the research focus to other manufacturing industries can help validate and refine but also expand the empirical findings. Further research could consider other latecomer countries – or even advanced countries – and also focus on high-tech industries, such as information technology, biotechnology, or new medical technology. Finally, scrutinizing cases of ‘unsuccessful’ firms could open another interesting avenue for future research.

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Appendix

Table 1: Overview of robustness checks regarding the outcome

Solution	Solution specifics	Solution sets	Solution configurations	inclS, PRI, covS
<u>Initial solution</u>				
L_IS_y	Base scenario	IRD_1219, TEP_1519	IITS[1]*ISTA[2]*ITMA[1] + IITS[1]*ISTA[2]*ITMA[0]*IRD[1] + IITS[1]*ISTA[1]*ITMA[1]*IRD[1]	0.891, 0.877, 0.890
<u>Condition-based test solution scenarios</u>				
L_TS1_1_y	Crossover threshold +10%	IRD_1219_CPL, TEP_1519	≡ initial solution	0.888, 0.874, 0.882
L_TS1_2_y	Crossover threshold -10%	IRD_1219_CMI, TEP_1519	≡ initial solution	0.893, 0.879, 0.894
L_TS1_3_y	Inclusion threshold +10%	IRD_1219_IPL, TEP_1519	≡ initial solution	0.891, 0.877, 0.877
L_TS1_4_y	Inclusion threshold -10%	IRD_1219_IMI, TEP_1519	≡ initial solution	0.889, 0.875, 0.903
L_TS1_5_y	Exclusion threshold +10%	IRD_1219_EPL, TEP_1519	≡ initial solution	0.894, 0.881, 0.888
L_TS1_6_y	Exclusion	IRD_1219_EMI, TEP_1519	≡ initial solution	0.887, 0.872, 0.895
L_TS2_y	threshold -10% Patent count until March 31, 2020	TEP_1519 IRD_0320, TEP_1519	≡ initial solution	0.892, 0.878, 0.897

Condition-/outcome-based alternative solution scenarios

L_AS1_1_y	Crossover threshold	TEP_1519_CPL, $\equiv$ initial solution IRD_1219	0.856, 0.830, 0.894
L_AS1_2_y	+10% Crossover threshold - 10%	TEP_1519_CMI, $\equiv$ initial solution IRD_1219	0.909, 0.899, 0.870
L_AS1_3_y	Inclusion threshold +10%	TEP_1519_IPL, $\equiv$ initial solution IRD_1219	0.854, 0.827, 0.888
L_AS1_4_y	Inclusion threshold -10%	TEP_1519_IMI, $\equiv$ initial solution IRD_1219	0.932, 0.927, 0.891
L_AS1_5_y	Exclusion threshold	TEP_1519_EPL, $\equiv$ initial solution IRD_1219	0.889, 0.875, 0.921
L_AS1_6_y	+10% Exclusion threshold - 10%	TEP_1519_EMI, $\equiv$ initial solution IRD_1219	0.893, 0.879, 0.860
L_AS2_y	2016-2019 market share performance	TEP_1619, $\equiv$ initial solution IRD_1219	0.888, 0.874, 0.881
L_AS3_y	Crossover threshold = P50-P90 halfway mark	IRD_1219_HW $\equiv$ initial solution M, TEP_1519_HW M	0.867, 0.846, 0.891

Table 2: Overview of robustness checks regarding the non-outcome

Solution	Solution specifics	Solution sets	Solution configurations	inclS, PRI, covS
<u>Initial solution</u>				
L_IS_ny	Base scenario	IRD_1219, TEP_1519	IITS[1]*ISTA[1]*ITMA[0] +IITS[1]*ISTA[1]*IRD[0] + IITS[1]*ITMA[0]*IRD[0] + ISTA[0]*ITMA[0]*IRD[0] + ISTA[1]*ITMA[0]*IRD[0]	0.962, 0.960, 0.948
<u>Condition-based test solutions</u>				
L_TS1_1_ny	Crossover threshold +10%	IRD_1219_CPL, $\equiv$ initial solution TEP_1519		0.957, 0.955, 0.947
L_TS1_2_ny	Crossover threshold -10%	IRD_1219_CMI, $\equiv$ initial solution TEP_1519		0.966, 0.964, 0.948
L_TS1_3_ny	Inclusion threshold +10%	IRD_1219_IPL, $\equiv$ initial solution TEP_1519		0.956, 0.954, 0.949
L_TS1_4_ny	Inclusion threshold -10%	IRD_1219_IMI, $\equiv$ initial solution TEP_1519		0.967, 0.965, 0.946
L_TS1_5_ny	Exclusion threshold +10%	IRD_1219_EPL, $\equiv$ initial solution TEP_1519		0.958, 0.957, 0.953
L_TS1_6_ny	Exclusion threshold -10%	IRD_1219_EMI, $\equiv$ initial solution TEP_1519		0.966, 0.965, 0.941
L_TS2_ny	Patent count until March 31, 2020	IRD_0320, $\equiv$ initial solution TEP_1519		0.965, 0.963, 0.948
<u>Condition-/outcome-based alternative solutions</u>				
L_AS1_1_ny	Crossover threshold +10%	TEP_1519_CPL, $\equiv$ initial solution IRD_1219		0.965, 0.964, 0.934
L_AS1_2_ny	Crossover threshold -10%	TEP_1519_CMI, $\equiv$ initial solution IRD_1219		0.950, 0.947, 0.954
L_AS1_3_ny	Inclusion threshold	TEP_1519_IPL, $\equiv$ initial solution IRD_1219		0.963, 0.961, 0.933

	+10%		
L_AS1_4_ny	Inclusion threshold	TEP_1519_IMI, $\equiv$ initial solution IRD_1219	0.960, 0.958, 0.965
	-10%		
L_AS1_5_ny	Exclusion threshold	TEP_1519_EPL, $\equiv$ initial solution IRD_1219	0.975, 0.975, 0.948
L_AS1_6_ny	+10% Exclusion threshold -	TEP_1519_EMI, $\equiv$ initial solution IRD_1219	0.947, 0.943, 0.949
L_AS2_ny	10% 2016-2019 market share performance	TEP_1619, $\equiv$ initial solution IRD_1219	0.957, 0.955, 0.947
L_AS3_ny	Crossover threshold = P50- P90 halfway mark	IRD_1219_HW $\equiv$ initial solution M, TEP_1519_HW M	0.963, 0.961, 0.939

Notes

¹ For more comprehensive information and background on knowledge inertia and the transferability of capabilities, the interested reader is referred to Kogut and Zander (1992) and Zander and Kogut (1995).

² It should be noted that the question of which specific combinations of learning mechanisms may actually contribute to improved performance is not elaborated by Figueiredo et al. (2013).

³ According to Soda and Furnari (2012), the notion of plausible configurational fit can be understood as the systemic relationship among multiple sets of attributes, either internal or external to an organization, whose multidimensional interactions have positive or detrimental effects on firm performance. For instance, business environment attributes relate to market volatility, technological dynamism, or regulation; firm strategy attributes relate to the degree of diversification, vertical integration, or customer orientation; and organizational attributes relate to organizational structures, integration mechanisms, or people. Plausibility in the context of configurational fit refers to the theoretically informed, logically sound exploration of potentially performance-effective configurations.

⁴ A definition of innovation and innovative activity is in order here. Following the technology-oriented concept proposed by the Organisation for Economic Co-operation and Development and European Statistical Office (1997), innovation refers to the implementation of change in terms of technologically new or improved products and processes. These may be changes that qualify as novel or new to the world, market, country, or the individual firm. In this sense, innovative activity includes all scientific, technological, organizational, financial, or commercial steps that actually lead or are intended to lead to the introduction of innovations. Some of these activities may be innovative in their own right, while others may not be novel or new, but nevertheless help facilitate change in firms (see Organisation for Economic Co-operation and Development & European Statistical Office, 1997, 2005).

⁵ As noted by Awate et al. (2015), in-house R&D conducted abroad is part of and facilitates a firm's localized in-house R&D through reverse knowledge flows from abroad to the home base

⁶ Following R. Lema and Lema (2012), infant R&D internationalization is seen as an external learning mechanism used for the purpose of international technology transfer. It is primarily aimed at tapping foreign sources of knowledge and talent that are external to the firm (Awate et al., 2015; Wong, 1999a, 1999b), as illustrated by the example of Envision Energy (J. Liu, 2019).

⁷ In the qualitative-interpretive approach to (fuzzy-set) calibration, inductively derived, sample-specific empirical positional measures, such as measures of central tendency, can offer a somewhat crude but passive form of structuring calibration. The crudeness of calibration criteria based on empirical positional measures is particularly due to the fact that such criteria do not reflect external generally reliable standards and therefore may vary – more or less – from one sample population to another (Ragin, 2008).

⁸ It should be noted that there are no generally accepted rules for defining a patent family, even though there is widespread agreement on patent family definitions. However, patent databases may apply different rules to patent family construction based on shared reference numbers. The LexisNexis definition of 'patent main family' used here corresponds to the European Patent Office's definition of a 'simple patent family' aka 'DOCDB' (LexisNexis, 2021).

⁹ In addition, invention patent family applications filed by March 31, 2020, are considered for the purpose of robustness evaluation

¹⁰ See also R. Lema and Lema (2012), who consider technology licensing as a stepping stone for Chinese and Indian firms to catch-up in the photovoltaic and wind power industries.

¹¹ It turns out that infant R&D internationalization takes place in the immediate temporal context of the incipient establishment of a firm or corresponding business unit, within a short-term period after establishment of up to three years.

¹² In addition, the year of the very first filing date is considered as an alternative firm-specific transition point for the purpose of robustness evaluation. The very first filing refers to the first

earliest invention patent application overall, regardless of the grant status.

¹³ To extract relevant patent data related to PV-module manufacturing, the following IPC codes are used: H01L, H01G9/20, H02S40/10, H02S40/12, H02S40/20, H02S40/22, H02S40/34, H02S40/36, H02S40/40, H02S40/42, H02S40/44, E04D1/30, E04D13/18, H02S20/00, H02S20/10, H02S20/20, H02S20/21, H02S20/22, H02S20/23, H02S20/24, H02S20/25, H02S20/26, H02S20/30, H02S20/32, H02S30/00, H02S30/10, H02S30/20, H02J7/35, H02S40/38, H02S50/00, H02S50/10, H02S50/15.

¹⁴ Notably in annual reports, firm names in Chinese are given in one way or the other, as the case may be. Also, patent extraction test runs show that relevant patents filings are, in principle, available and detectable either way.

¹⁵ The review for internationality is based on patent assignees' addresses and legal form designations.

¹⁶ In addition, the year of the very first filing date, regardless of grant status, is considered as an alternative firm-specific transition point for the purpose of robustness evaluation.

¹⁷ Information from the FactSet Mergerstat M&A database as well as partially GlobalData (i.e., GlobalData Company Profiles) and MarketLine (i.e., MarketLine Company Profiles, MarketLine Financial Deals Tracker) is accessed via Nexis Uni. Information from GlobalData (i.e., GlobalData Deals and Alliances Profile) is also partially obtained through ABI/INFORM Collection.

¹⁸ The search is supplemented for SFCE with Suntech starting from April 01, 2014, and for Longi Solar with Lerri Solar from December 01, 2014, as both investee firms continued to operate under their own corporate brands. RavenPack News Analytics provided data only from January 1, 2000 (personal communication, October 27, 2020; e-mail correspondence with RavenPack News Analytics customer support to obtain data coverage information).

¹⁹ In addition, industry forums such as [photovoltaikforum.com](https://www.photovoltaikeforum.com) (<https://www.photovoltaikeforum.com>) serve as an initial guide to potentially relevant event information, but are not considered and relied upon as a credible source.

Developing Linkages between Technology-intensive exports and GVC participation: A perspective from India and G20 countries

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Abstract

The G20 representing the world's major developed and developing countries is witnessing a troika for the very first time of developing countries—Indonesia, India, and Brazil. India at the helm of the G20 presidency can strengthen its ties while shouldering the responsibility to lead the world to economic recovery. India's priorities with respect to trade and supply chain resilience can only be understood if there exists a background on the trade relationship between India and the G20 countries. This paper develops the linkage between technology-intensive exports and GVC participation for the period 1995-2018 by using advanced time-series analysis. The results point towards the importance of forward linkages for India's exports of both high and low-tech exports and the backward linkage for medium-tech exports. The results show a connection between technological capabilities and exports to G20 nations through India's participation in the GVC. In light of this, the paper offers guidance for timely and well-informed sector-specific strategies.

Keywords: GVC participation, G20 countries, high-tech exports, ARDL co-integration, FDI, R&D expenditure

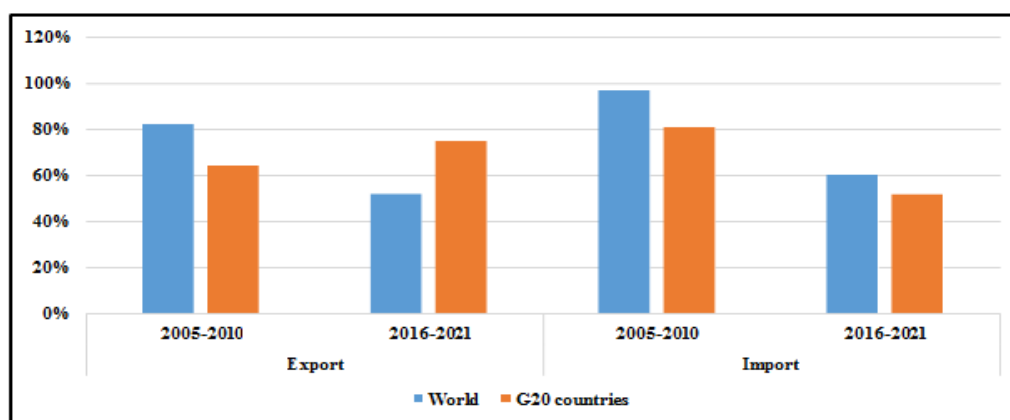
JEL Classification: F14, F60, O19

1. Introduction

With the current India's G20 presidency, an opportunity of connecting and representing the ideas of a developing world and the steps taken towards inclusive, resilient and sustainable economic development take a front seat at the table. The issues and the global challenges surrounding a deeply divided G20 countries is hampering post-pandemic recovery ¹. However, a pragmatic engagement in trade, especially in strengthening the interdependencies through global value chains (GVCs) can provide the needed recovery and momentum (Brenton, et al., 2022). This may be seen in the present, when businesses are considering increasing integration with GVCs despite risks and uncertainty. The COVID-19 epidemic has wreaked havoc on the effective operation of GVCs by causing several bottlenecks in logistics networks, export restrictions on raw materials, intermediates, and supplies. This has highlighted the requirement for both reshoring and source diversification in order to ensure that GVCs operate well with just-in-time component and part availability² (Kano, et al., 2022). Consequently, there is an urgent move globally to look for alternative destinations for manufacturing to increase the resilience of GVCs.

However, as a fastest growing economy in the G20 nations, India is set to play a significant role in converting uncertainties into opportunities (IMF Predictions 2021-2025)³. The trade scenario of the G20 countries is shown in figure-1 below, with global trade rebounding more quickly and strongly than any other aspect of global output (Brenton et al., 2022). The G20 countries' export growth rate from 2016 to 2021 has accelerated dramatically. Although, the import growth rate slowed down which is in tandem with the import growth rate of world, however when the impact of the pandemic first became apparent, G20 members showed leadership as they did in response to the Financial and Economic Crisis of 2008/2009. They pledged to remain open to trade and investment to limit the damage of the COVID-19 pandemic on their economies⁴.

Figure-1 Export and Import Growth Rates

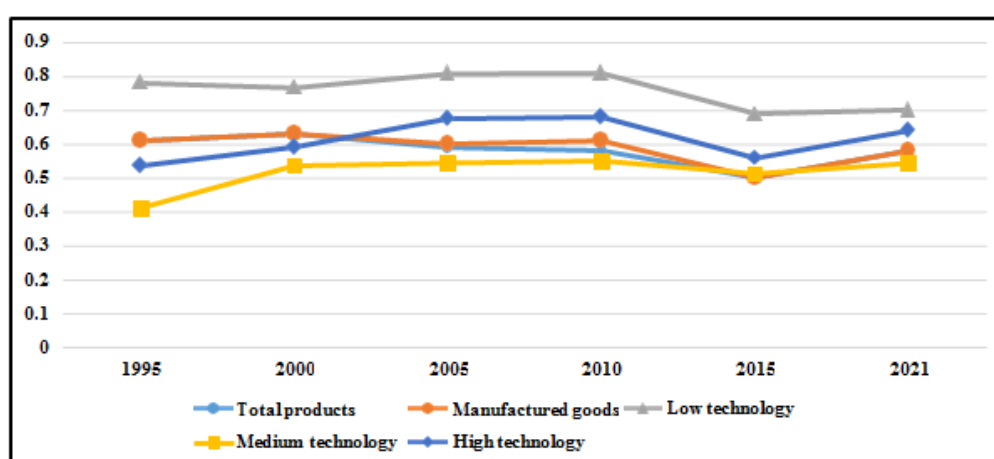


Source- UNCTADStat

Hence, the G20's role as a leading group of major economies becomes even more crucial in shaping the global policy environment. These countries are accounting for around 85% of global GDP and 75% of international trade, and are the major players in the global economy and global value chains⁵. Both as producers of intermediate products and services and as consumers of finished goods and services, these economies dominate. Among the G20 countries, India and developing markets have increased in economic importance. The 10 emerging economies that make up the G20 are China, India, Brazil, South Korea, Saudi Arabia, Argentina, Indonesia, Mexico, Russia, and Turkey. Their combined output share in the G20's overall output increased significantly between 1999 and 2022, rising from 13.6% to 36.5%. India's share increased by more than twofold, from 1.6% to 4%⁶.

When it comes to the trading pattern, India and the other G20 nations are both vital for one another. As seen from the figure-2 below, the trend and pattern of share of India's export to G20 countries in India's total export to world has been more than 50% from 1995 to 2021. Similar case can be witnessed for the manufactured goods. Considering, the technology-intensive trade between India and G20 nations, which can be divided into low-technology, medium-technology and high-technology, and as well as into the manufactured goods⁷ (the definition of technology-intensive products is based Lall (2000), taken from UNCTADStat), it can be observed that the share of India's low-technology intensive exports to G20 countries vis-a-vis to the world, and the share of India's high-technology intensive exports to G20 countries vis-a-vis to the world are quite high, and have been almost 70% in 2021. As a result, the G20 countries have been a big market for India's technology-intensive exports. Low-technology and high-technology intensive products comprise of textiles, garments, footwear and electronics and electrical.

Figure-2 Share of India's Export of technology-intensive categories to G20 Countries

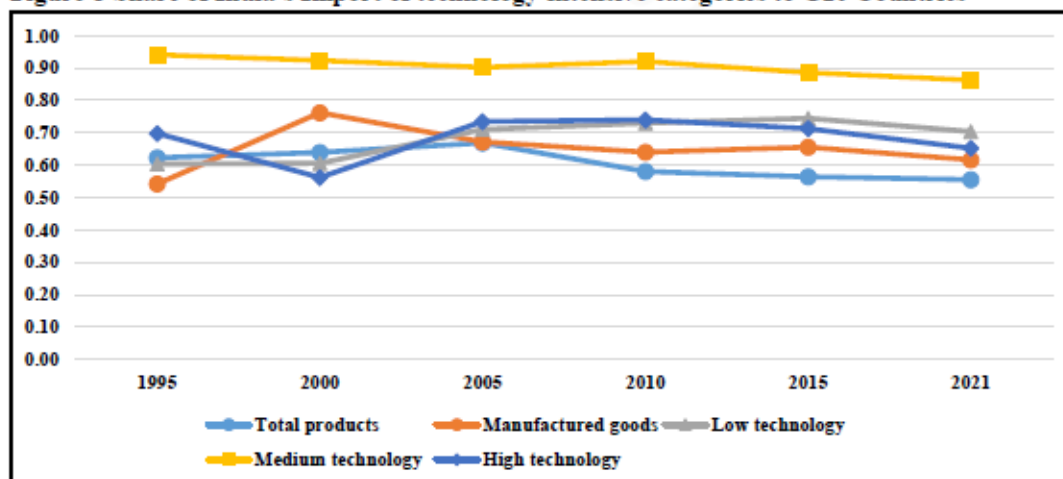


Source- UNCTADStat

Even for G20 countries, India is a big market, as can be seen from figure-3 below. India's share of import of total products from G20 countries vis-à-vis world has

been in the range of 55- 60%, signifying India's dependency. The important observation is the India's reliance on G20 countries for medium-technology intensive imports. Although, since 2015, a fall is seen in the import shares, but still the shares are quite high. Medium-technology intensive products generally comprise of automotive.

Figure-3 Share of India's Import of technology-intensive categories to G20 Countries



Source- UNCTADStat

The structure and pattern of trade linkages between India and G20 countries provide relevance to the work of global value chain participation. In fact, there is a heightened need to increase GVC integration to revive the world economy post the pandemic. G20 countries in the past presidencies have long recognised the potential of trade and competition for boosting economic growth, living standards and employment opportunities. In 2014, at the Brisbane Summit, it was acknowledged that for the countries to connect and develop, GVCs are an important mechanism. The identification of policies that could harness the benefits of GVCs and encourage greater participation and value addition by developing countries was the agenda and this later on became an integral part of Trade and Investment Working Group (TIWG), initiated in 2016. Promotion of inclusive and coordinated GVCs, which would identify policy choices in trade and investment as well as complementary fields for GVC integration by SMEs and LIDCs (Low-Income Developing Countries), has been going around ever since. Sector-wise, Argentina's 2018 presidency focused on stepping up efforts to engage with the private sector, the scientific community, and all other relevant stakeholders to improve value addition, productivity, efficiency, sustainability, and upgradation in Agro-Food Global Value Chains and support initiatives to reduce food loss and waste. In 2020, Saudi Arabia presidency, the need for increasing the sustainability and resiliency of national, regional, and global supply chains and to expand production capacity and trade, notably in the areas of pharmaceutical, medical and other health-related products got recognised. The pandemic related issues and stress were captured in the Italian Presidency of 2021, that focussed on multilateral Trade and Investment Agenda

for a Sustainable Recovery – Strengthening the resilience of the Global Value Chains of medical and pharmaceutical products and vaccines. However, it was in the Indonesian Presidency of 2022, that the focus shifted to digital trade and sustainable GVCs.

Currently, with India's ongoing presidency in 2023, the issues are centred towards responsible trade and resilient GVCs. This is in line with unprecedented strain on account of the pandemic, a ravaging war, geo-political tensions, and the steady weakening of the multilateral trading system. India envisages to develop geospatial mapping of global value chains for essential sectors and products, network restructuring and supply chain management solutions to build resilience towards future disruptions. This study adds to the body of knowledge on the factors influencing India's technology-intensive exports to G20 nations from the perspective of GVC participation by reflecting the interdependence between India and other G20 countries in terms of the significance of export and import. Second, despite the explicit emphasis on the advantages of GVC involvement in some research, as those by Srholec (2007) and Mehrara et al. (2017), these studies' empirical specifications do not effectively or totally account for GVC participation. Using advanced time-series technique from 1995 to 2018 in the form of the auto-regressive distributed lag (ARDL) model, the analysis will be able to examine the long-term relationship between export performance and its determinants. Through causality analysis, this relationship will further provide policy directives in the way of strengthening and determining the factors for export of various technology-intensive products to the G20 countries. This captures the variables' dynamic behaviour across time (Zhang et al., 2017).

2. Certain Stylized Facts

Over the past four decades, the organisation of international trade has undergone a considerable transition that has had an impact on the global economy (Antras and Chor, 2021; Pansera and Owen, 2018; Heeks et al. 2020). The exceptional and excellent export records of some countries, including Japan and South Korea, have convinced some policymakers and experts that export-oriented policies, rather than import-substitution ones, are the best methods for emerging countries to strengthen their economies. It should therefore not come as a surprise that many developing nations pursued export-based growth plans in the late 1970s and early 1980s. This is in line with economists' widely held belief that exports have an impact on productivity and the health of the economy (Bernard & Jensen, 1999; Emery, 1967; Feder, 1983; Grossman & Helpman, 1991a, 1991b; Hausmann et al., 2007). Ideally, exports would boost economic growth and productivity using a variety of strategies, such as economies of scale, technical improvement, capacity utilisation, inflows of foreign currency, and competitiveness (Kalaitzi & Chamberlain, 2020).

But rather than just its level or amount, the export basket's composition or mix would be more significant (Baliamoune-Lutz, 2019; Falk, 2009; Greenaway et al., 1999; Ndubuisi & Owusu, 2021; Ribeiro et al., 2016; Zhu & Fu, 2013). For instance, compared to low technology exports, high technology exports are associated with more beneficial externalities, knowledge transfer, and spillovers (Cuaresma & Wörz, 2005; Ribeiro et al., 2016; Sheridan, 2014). This demonstrates unequivocally the significance of high-tech exports, or export upgrading, particularly for developing countries. Moreover, exports of high-tech goods could assist emerging nations in achieving or maintaining steady, long-term economic growth (Sepehrdoust et al., 2021). Since that it is thought that this sector of global trade is expanding the fastest, high-tech exports ought to be given more consideration (Lall, 2000; Srholec, 2007).

In general, one may argue that a country's export mix or complexity reflects its level of technical development (Can et al., 2022; Hausmann et al., 2007). In other words, a nation with strong technological capabilities might export a lot of high-tech products. Traditional and modern trade theories both support this prediction (Braunerhjelm & Thulin, 2008; Zhang, 2007; Zhu & Fu, 2013). Nevertheless, despite how straightforward this issue appears, it is not. Several studies largely contend that some developing countries export a sizable share of high-tech commodities despite having little capability for producing advanced technology or expertise (Srholec, 2007). Several examples would readily support this crucial fact. For instance, compared to many affluent nations, some developing nations—like the Philippines or Malaysia—have substantially greater high-tech export percentages.

India's exports have steadily diversified in terms of their product offers, similar to other emerging markets, and their percentage of destinations among developing and emerging economies has increased over time (Anand, et al., 2015). But, given the structure of its exports, India is perfectly positioned to benefit from the basic technological advancements and the growing pressures of globalisation. According to some research by Zhang (2007), Srholec (2007), Adarov and Stehrer (2021), the utilisation of foreign value added or intermediates in domestic export is directly related to GVCs or global production sharing. These responsibilities are frequently carried out by sizable multinational enterprises (MNEs), especially from the G20 nations. GVCs have been regarded as one of the most effective methods to industrialise, accounting for 70% of all international trade (OECD, 2020a) (World Bank, 2020). This industrial fragmentation occurs over several sites, with each nation specialising in a condensed section of the value chain, as a result of the sharp cuts in trade and transportation costs brought on by improvements in communication and information technology (Amador & Cabral, 2016; Grossman, Rossi-Hansberg, 2008; Taglioni & Winkler, 2016).

GVCs require customised production, production decisions that are made in a sequential manner by the buyer and supplier, high contracting costs, and global matching of not only products and services but also production teams and ideas (Antràs 2015). Any single good must be completed using components and services from several economies in both the upstream and downstream production stages. As a result, specialisation is more effective because each economy produces the components given its capabilities and cost structure and that certain nations could grow their exports of high-tech goods by merely assembling or processing components without making managerial or technological advancements. Additionally, this kind of global value chain specialisation enables emerging markets to locate more straightforward routes to global production, where they can gain knowledge and upgrade. Thus, participation in GVCs is closely related to the growth and development of a nation's economy (Tian et al., 2022). GVCs offer access to "accelerated learning" and the transfer of tacit knowledge at a rate unimaginable in a traditional trade environment (Baldwin and Yan, 2016). A new category of so-called micro-multinationals, which are small businesses that develop global activities from their inception, has been created as a result of the fragmentation of production. These factors are giving small and medium enterprises new entrepreneurial opportunities to access markets abroad (Mettler and Williams 2011). And in this way GVCs push and deepen the interlinkages between trade and technology in further upgrading the process of production (Arora & Siddiqui, 2020).

Table-1 highlights the importance of GVC for aggregate international trade.⁸ For the 64 nations the Asian Development Bank collects statistics for, GVC trade represents 46% of all trade. Nevertheless, this share was 52% in 2018, illustrating the disruptions in GVCs due to the pandemic as well as the increase in reshoring policies established by an increasing number of countries to encourage domestic manufacturing. Europe has a bigger GVC participation percentage compared to Asia or even America. Roughly speaking, there are two types of GVC participation: backward and forward. When an economy purchases intermediates to manufacture its exports, this is known as the "Buyer" perspective or sourcing side in GVCs. Inputs sent to third economies for additional processing and export via supply chains are captured by the forward linkage to account for the local value added. This is the viewpoint from the "Seller" or supply side in terms of GVC involvement. While Asia lags behind its European rivals, especially in terms of the backward links, in both of these categories. The presence of GVCs has two important policy implications; first, if a country intends to boost its presence in international trade market, then it has to be a part of a GVC and second, GVC also transmits economic, political, and weather shocks from one country or region to the other through the supply chain linkages.⁹

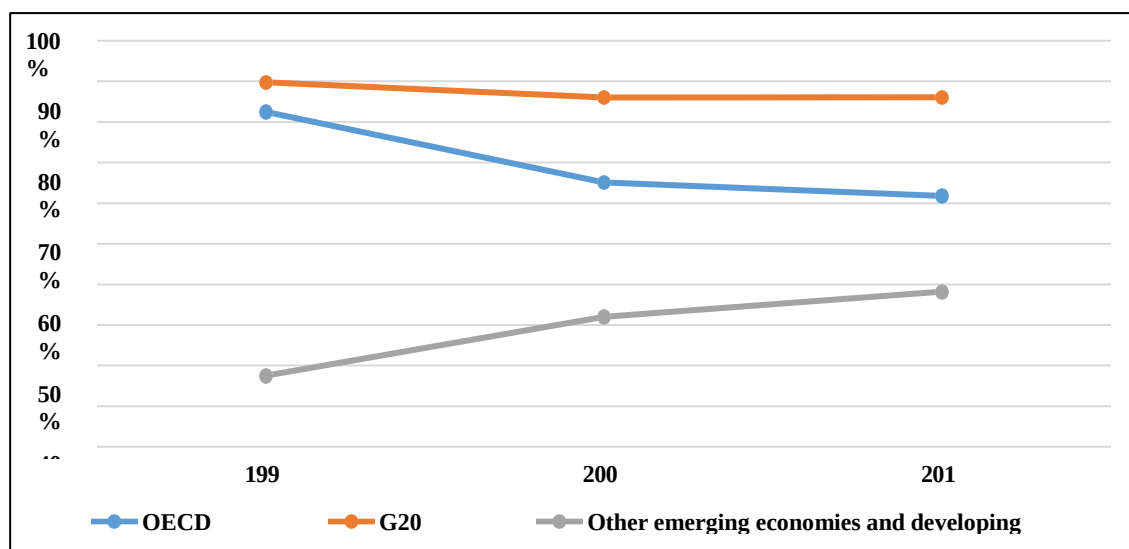
Table-1 Measures of GVC Trade Across Country Groups (2020)

Country	Share GVC Trade in Total Trade (%)	Pure Forward GVC participation (%)	Pure Backward GVC participation (%)	Two-sided GVC participation (%)
Developed countries	42.0	20.2	16.2	5.6
Developing countries	38.3	18.4	16.0	3.9
Americas	40.4	15.8	20.7	3.8
Australia	33.5	22.9	7.8	2.8
Europe	46.7	19.9	19.5	7.3
Asia	38.3	19.9	14.0	4.4
All Countries	46.4	17.2	21.9	7.3

Source- WTO Database

The expansion of GVCs has benefited all G20 economies. Trade-flow revenue inside GVCs, measured as the domestic value added embodied in foreign final demand (also known as "exports of value added"), increased by 266% between 1995 and 2018. (TiVA, 2021). They now make up 38% of all exports with a value added, up from 21% in 1995, 34% in 2009, and 21% in 2018. The growth is more obvious for the G20 emerging economies when compared to other emerging and developing countries. Yet, not all countries were successful in joining global industrial networks. The fact that countries like Africa or Latin America (excluding G20 members) still only account for a small fraction of global GVC income highlights the requirement for new government and industry policies to encourage better access to and upgrading within value chains¹⁰.

Figure-4 Value added exports, as a share of world VA exports



Source- OECD TiVA Database

Now, the issue that is raised is if GVCs can enable lead firms that drive most decisions in leveraging the ability for domestic economic development. Therefore, push for creating and strengthening links with domestic firms that promote benefits from technology sharing, best practices, driving investments and increased value addition in the country is important to ensure that GVC participation benefits are shared widely and hence, GVCs work for development.

3. Literature Review

Studies by Bottega & Romero (2021), Bierut & Dybka (2021), Sandu & Ciocanel (2014), Srholec (2007), Zhang (2007), Braunerhjelm & Thulin (2008), and Tebaldi (2011), have all examined the factors that affect technology-intensive exports. The two main groups of the possible determinants are internal (domestic) and external variables.

Income, human capital, institutional quality, R&D, and capital stock are some internal elements that would significantly contribute to fostering or supporting technological innovation and productive capacity, ultimately leading to a growth in high-tech exports. More income is correlated with stronger capacity and domestic diversity. Also, in order to take advantage of the economies of scale, a huge market or size is necessary (Braunerhjelm & Thulin, 2008). High-tech exports and wealth or size are positively correlated in several research (Güneş et al., 2020; Srholec, 2007; Serti et al., 2015; Mehrara et al., 2017).

Some estimations predict that human capital would have a significant impact on high-tech exports (Zhang, 2007; Tebadli, 2011). Additionally, technical innovation, which fuels high-tech exports, necessitates the growth of abilities and knowledge (Can & Gozgor, 2017). High-skilled labour and knowledge are specifically needed for several parts of high-tech exports, including designing and marketing. Using data from almost 100 countries between 1980 and 2008, Tebaldi (2011) discovered that each additional year of education causes a 0.33% rise in high-tech exports per worker. Abedini (2013) emphasises the benefits of skilled labour for a large sample of nations' high-tech exports in a way comparable to this. Moreover, researchers Güneş et al. (2020) and Mehrara et al. (2017) discover a favourable correlation between human capital and high-tech exports. Increasing the amount of money or personnel devoted to research and development is a significant tactic for accelerating technological advancement (Romer, 1990; Grossman & Helpman, 1991a, 1991b). Hence, increased R&D efforts are anticipated to increase productivity and competitiveness. Many studies, like those by Sandu and Ciocanel (2014) and Braunerhjelm and Thulin (2008), back up the idea that R&D and high-tech exports are positively correlated. For instance, a 1% increase in R&D spending results in a 3% rise in high technology exports for the OECD countries, according to Braunerhjelm and Thulin (2008).

In order to improve their technological and productive capacities, nations may benefit from external variables such as foreign information and technology (know-how) in addition to domestic ones. At the same time, through foreign direct investment (FDI) flows, multinational firms (MNEs), which account for almost a third of worldwide output and world GDP (Cadestin et al., 2018), significantly influence GVCs (UNCTAD, 2013). There are at least three main ways to encourage high-tech exports, depending on the ability of the recipient nations to absorb foreign technology and expertise. In the first place, FDI would boost indigenous technological or productive competence (Newman et al., 2015; Findlay, 1978). In fact, several studies (Zhang, 2007; Güneş et al., 2020; Abedini, 2013) show how beneficial FDI is for exporting high-tech products. For example, according to Tebaldi (2011), a 1% increase in net FDI inflows will lead to a 0.17% increase in high-tech exports per worker.

Second, nations would import intermediate goods and raw resources. It is commonly known that importing intermediate items would boost output and exports (Halpern et al., 2015; Bas & Strauss-Kahn, 2014; Amiti & Konings, 2007). In light of this, it is not unexpected that multiple studies have found that imports are beneficial for high-tech exports (Mehrara et al., 2017; Srholec, 2007; Abedini, 2013). Third, numerous studies demonstrate that joining the GVC would be more advantageous for nations than engaging in traditional commerce (Raei et al., 2019; World Bank, 2020; Criscuolo & Timmis, 2017). Via a number of channels, including increased specialisation, more affordable and high-quality foreign inputs, learning by exporting, and knowledge and technology transfers, participation in GVCs would increase productivity and competitiveness (Altun et al., 2022; Criscuolo & Timmis, 2017; Constantinescu et al., 2019; Raei et al., 2019; Baldwin & Yan, 2016). All of these possibilities would undoubtedly have a significant impact on high-tech exports. According to a recent study by Ndubuisi and Owusu (2021), GVC participation enhances the calibre of exported goods. While backward GVC participation is significant for developing countries, they argue that both forward and backward GVC participation is advantageous for developed countries.

The range of players in international trade and production has expanded thanks to GVCs. It extends past manufacturing. In countries like Vietnam, India, the Philippines, and others, dynamic, knowledge-intensive software has developed and is spreading quickly. The story is no longer just about enormous, international enterprises. More GVCs have evolved as a result of fewer trade barriers and advancements in communication, information, and transportation technologies, allowing companies to unbundle production into activities carried out at numerous locations to take advantage of different factor prices (Grossman & Rossi-Hansberg, 2008). In developed economies, GVCs provide access to more competitively priced inputs, a wider selection, and economies of scale (Baldwin & Javier, 2013). While GVCs are typically seen as a quick road to industrialisation for emerging economies, globally fragmented production

enables them to join existing supply chains rather than creating them. Therefore, these firms from different countries are not simply involved in trade in goods and services, but they collaborate in vertically integrated systems of production, sharing blueprints, technicians, managerial practises, and productivity-enhancing tools and techniques (Taglioni & Winkler, 2016).

By looking at the GVC participation rates from Table-2, there exists a large heterogeneity among G20 countries in GVC participation. Recent supply shocks on account of pandemic has further necessitated that the G20 countries work towards building inclusive and resilient GVCs. On the higher end of GVC participation rate, we find Germany, South Korea, and France with more than 48% of trade. Australia, India, and China lie on the other end with GVC participation rate below 34%.

Table-2 GVC Participation Rates across G20 Countries (2020)

Country	Share GVC Trade in Total Trade (%)
Australia	33.5
Brazil	36.8
Canada	38.1
France	48.1
Germany	49.3
India	33.4
Indonesia	35.0
Italy	44.9
Japan	34.4
Mexico	46.0
People's Republic of China	32.2
Russia	41.2
South Korea	48.6
Turkey	43.5
USA	37.0
United Kingdom	44.3

Source: WITS. Most recent data not available for some countries.

Although China has been in the forefront of GVCs in manufacturing, particularly in labor- intensive sectors, India still plays a significant role in GVCs in the services sector (Stephenson, 2012). However, as China keeps shifting its growth model away from reliance on exports and towards domestic consumption, along with the covid pandemic showing limitations in terms of the country's health infrastructure and supply chain disruptions, the countries are looking for China plus strategy business models in order to diversify the investment from China to other alternative destinations. The geography of the value chain is therefore expected to change due to India's low-cost

manufacturing, hospitable business environment, and encouraging government initiatives to encourage the businesses. Therefore, India's G20 presidency is perceived as a "catalyst for global change", as it comes at a time when it is expected to be the fastest growing major economy in the world.

4. Data and Model Specification

Based on the body of research and hypotheses already in existence, the variables for the study are chosen. As the Trade in Value-Added (TiVA) database of value-added data is available till 2018 internationally (WTO-OECD, 2021), the variables for the 1995–2018 period have been accessed from multiple sources. This research employs an advanced time-series data technique to evaluate the effect of GVC participation on India's technology-intensive exports to G20 nations (low, medium, and high technology). The empirical strategy employs the following model:

$$\text{Tech-intensive\_expt} = \alpha_0 + \alpha_1 \text{Backward\_Participation}_t + \alpha_2 \text{FDInt}_t + \alpha_3 \text{Forward\_Participation}_t + \alpha_4 \text{GDPper\_capt}_t + \alpha_5 \text{hcit}_t + \alpha_6 \text{IQ}_t + \alpha_7 \text{OFDI}_t + \alpha_8 \text{R\&DExpt}_t + \varepsilon_t \quad (1)$$

Where (t: time), *Tech-intensive_expt* is the dependent variable and represents different technology-intensive exports of India to G20 countries as the percentage of manufacturing exports. *Backward_Participation_t* represents the foreign value-added content of exports as a % of gross exports. *FDInt* is inward flows of foreign direct investment as a % of total FDI. *Forward_Participation_t* stands for domestic value added sent to third economies as a % of gross exports. *GDPper_capt* is the GDP per capita in log. *hcit* represents the human capital index. *IQ_t* represents the institutional quality. *OFDI_t* represents the outward FDI flows as a % of total outward FDI. Lastly, *R&DExpt* represents expenditure on R&D as a % of total R&D expenditure in manufacturing sector.

The technology-intensive exports and manufacturing exports between India and G20 countries have been calculated from the UNCTADstat capturing the bilateral trade flow in accordance with the technological classification (SITC Rev. 3 based on Lall (2000)). According to this taxonomy, the Standard International Trade Classification (SITC) Revision 3, the classification for low-technology manufacturers includes textile, garment and footwear; for medium-technology manufactures includes automotive and for high-technology manufactures includes electronic and electrical.

The GVC participation indicators have been taken¹¹ in correspondence with different technology-intensive sectors. Backward participation represents the value added of inputs that were imported in order to produce intermediate or final goods/services to be exported while forward participation refers to the

domestic value added contained in intermediates (goods or services) exported to a partner economy that re-exports them to a third economy as embodied in other products¹²(Kowalski et al., 2015). The FDI data for various years was compiled using the FDI statistics archives at DPIIT, Ministry of Trade and Industry, Government of India. Determining whether FDI and exports are complimentary or interchangeable has been the main focus of research. The report does, however, account for the impact of inward FDI that has assisted various technology-intensive exports to G20 countries for India at the sectoral level by leading to technological spillovers/dissemination. Increased globalisation has made it easier to connect with highly skilled diaspora members (nationals working abroad), improve FDI levels, and access other information networks including those in academia and the media (Arora and Siddiqui, 2022).

The World Development Indicators (WDI) of the World Bank (2021b) provide the information on GDP per capita and FDI outbound flows. The human capital index of the Penn World Table (PWT 10.0) is taken into consideration (Feenstra et al., 2015). The global governance indicators are used to provide the information on institutional quality (2022)¹³. Finally, the expenditure on R&D as a % of total R&D expenditure data for different technology-intensive manufacturers is taken from Industry Outlook, CMIE¹⁴. The generation of new information through investments in R&D was the primary driver of technical development and, consequently, growth, according to endogenous growth theories (Romer, 1990). Technology is a major driver of remarkable growth in newly industrialised countries (Nelson & Pack, 1999). Developing countries like India have been working to advance technology for a very long time through both local and foreign research and development (Basant, 1997).

5. Data Analysis and Results

5.1 Unit Root Tests

First, it is confirmed that the variables used for the time-series analysis are stationary. The Augmented Dicky-Fuller (ADF) tests (Dickey & Fuller, 1979) as well as the Phillips-Perron (PP) tests are both taken into account. The ARDL (auto-regressive distributed lag model)/bound-testing is then performed using Pesaran and Shin (1999) and Pesaran, et al. (2001), presuming that all variables have the order of integration either $I(0)$ or $I(1)$ or are both $I(0)$ and $I(1)$ (1). It is also necessary to verify that ARDL bound-testing variables are not $I(2)$. As there are three regression equations with export of different technology-intensive manufacturers with their corresponding explanatory variables, however, control variables such as outward FDI, human capital index, institutional quality and GDP per capita have not been kept dynamic in nature but they significantly impact the growth of dependent variable (Altun, et al., 2022) to the G20 countries.

Table-3 Unit root tests

Variables	ADF Test		PP Test		ADF Test		PP Test		ADF Test		PP Test	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
High-tech export	-1.23	-4.27*	-1.56	-4.54*								
Medium-tech export					-2.45*	-4.99*	-2.22*	-5.34*				
Low-tech export									-1.12	-5.52*	-1.78	-5.78*
Backward participation	-1.34	-4.31*	-2.34*	-4.86*	-1.67	-4.92*	-1.23	-5.15*	-2.34*	-4.61*	-1.43	-4.89*
Inward FDI	-2.23*	-7.23*	-2.23*	-7.23*	-2.23*	-7.23*	-2.23*	-7.23*	-2.23*	-7.23*	-2.23*	-7.23*
Forward participation	-1.26	-4.38*	-1.23	-4.77*	-1.87	-4.98*	-1.23	-5.16*	-2.21*	-7.23*	-2.21*	-7.23*
GDP per capita	-2.23*	-3.67*	-2.23*	-3.67*	-2.23*	-3.67*	-2.23*	-3.67*	-2.23	-3.67*	-2.23*	-3.67*
HCI	-1.45	-4.92*	-1.45	-4.92*	-1.45	-4.97*	-1.45	-4.92*	-1.45	-4.92*	-1.45	-4.92*
IQ	-1.11	-6.12*	-1.11	-6.12*	-1.11	-6.12*	-1.11	-6.16*	-1.11	-6.12*	-1.11	-6.12*
Outward FDI	-2.25*	-5.91*	-2.25*	-5.91*	-2.25*	-5.9*	-2.25*	-5.91*	-2.25*	-5.91*	-2.25*	-5.91*
R&D Expenditure	-2.54*	-4.21*	-1.98	-5.12*	-1.56	-3.05*	1.78	-3.12*	-1.23	-4.49*	-2.12	-5.01*

*t-statistic for the variables are stationary at 5% level of significance

5.2 Cointegration Bounds tests Tabl-4 Bounds Test

Dependent Variable	F-statistic	Results
High-tech export	7.6	Cointegration
Medium-tech export	3.9	Cointegration
Low-tech export	4.6	Cointegration
Lower Bound at 5%	2.32	
Upper Bound at 5	3.5	

To prevent incorrect regression, which would lead to inaccurate results and conclusions, the series must be stable. The stationarity tests in Table 3 show that for the variables belonging to the three technology-intensive groups, both I(0) and I(1). To find the long- and short-run dynamic interactions among variables, the ARDL cointegration method is used on the model. The estimates are precise and effective if the sample size is small (as it was in this study), the long- and short-run components are estimated simultaneously, autocorrelation and omitted variables are removed, and there is a distinction between explanatory and dependent factors (Arora and Siddiqui, 2022).

The cointegration technique takes ARDL (p, q1, q2.....qk) model as:

$$\begin{aligned}\Delta X_t &= \delta_{0i} + \sum_{i=1}^k a_{1,i} \Delta X_{t-1} + \sum_{i=1}^k a_{2,i} \Delta Y_{t-1} + \delta_1 X_{t-1} + \delta_2 Y_{t-1} + v_{1t} \\ \Delta Y_t &= \delta_{0j} + \sum_{i=1}^k a_{1,i} \Delta Y_{t-1} + \sum_{i=1}^k a_{2,i} \Delta X_{t-1} + \delta_1 Y_{t-1} + \delta_2 X_{t-1} + v_{1t}\end{aligned}$$

-- (2)

In the equation above, the maximum lag order is k and is selected accordingly. In the joint null hypothesis, the F-statistic is carried out and the coefficients of the lagged variables $(\delta_1 X_{t-1}, \delta_1 Y_{t-1} \text{ or } \delta_1 Y_{t-1}, \delta_1 X_{t-1})$ are zero. (δ_1, δ_2) correspond to the long-run relationship, while (α_1, α_2) represent the short-run dynamics of the model. The critical values of the F statistics for a variety of variables (K) and the existence of an intercept and/or trend in the ARDL model are provided in Pesaran (1997) and Pesaran et al. (2001). The narrow data span is the method's guiding principle. Using the Akaike information criterion, a maximum lag order of 1 is given to the conditional ARDL vector error correction (AIC). The limits test is shown in Table-4 together with the F-statistics for makers of high-tech, medium-tech, and low-tech products. The F-statistics critical values were taken from Pesaran et al., (2001) and Narayan and Smyth (2008). And they demonstrate that the factors chosen have a long-term association with gross exports to the G20 nations.

5.3 Long Run and Short Run Dynamics of ARDL Approach

After establishing cointegration, the conditional ARDL ($p, q_1, q_2, q_3, \dots, q_n$) long-run model for (Tech-intensive_expt) can be estimated as follows:

$$\text{Tech-intensive\_exp}_t = \sum_{j=1}^p a_j \text{Tech-intensive\_exp}_{t-j} + \sum_{j=0}^q \delta_j X_{t-j} + \varepsilon_t \quad \text{--- (3)}$$

The orders of the ARDL model ($p, q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8$) in the nine variables are selected by using AIC. Equation (3) is estimated using the following ARDL (1,1,0,1,1,1,0), (1,0,1,1,1,0,0,1) and (1,0,0,0,1,0,1,0) specification for high-tech, medium-tech and low-tech exports. The results of the long-run model are presented in Table-5.

Table-5 ARDL estimated long-run coefficients

Variables	High-tech	Medium-tech	Low-tech
Backward participation	-0.9 (-1.44)	0.7 (0.9)	-1.43 (-1.28)
Inward FDI	0.37*** (3.44)	-0.14 (-0.16)	0.42* (2.03)
Forward participation	0.9*** (3.65)	-0.7 (-0.9)	1.43** (2.28)
GDP per capita	0.028* (2.05)	0.0018 (0.75)	0.07 (1.32)
HCI	-0.13 (-1.65)	0.26 (1.02)	1.23** (2.64)
IQ	-0.05 (-1.57)	0** (0.04)	0.08 (1.43)
Outward FDI	0.001 (0.46)	0 (-0.69)	-0.056*** (-3.6)
R&D expenditure	7.05** (2.51)	2.7 (0.53)	0.9 (0.1)

Figures in () indicate t-statistic, probability statistically significant at 1%, 5% & 10% level are denoted by ***, ** & *

In the long run, it is seen that GVC participation in the form of forward participation significantly and positively impacts gross exports to G20 countries. This pushes for strengthening India's participation in GVCs for the sectors- textiles and electronics in further increasing the exports as integrating a country's domestic suppliers into GVCs increases the possibility for GVC spillovers through exporting to a buyer abroad or supplying to a multi-national in the country (Ndubuisi & Owusu, 2021; Altun et al., 2022; Kummritz et al., 2017; Srholec, 2007; Veeramani & Dhir, 2022). Moreover, FDI from outside has a positive effect on exports in both high- and low-tech industries. Early trade theories and the empirical literature, however, were unable to prove a causal link between FDI and commerce. Scholars have, however, debated whether FDI replaces or enhances international trade. However, if FDI is coming for the purpose of enhancing exports, this will have an impact by increasing productivity and expanding production options in the host country primarily through the transfer of technology and managerial skills, resulting in increased trade (Baldwin and Venables 2010, Kutun and Vuki 2007, Altun et al., 2022). Additionally, there are mutually reinforcing dynamics between FDI and GVC participation. Trade with foreign markets may encourage initial FDI from lead firms by reducing entry costs; lead firms frequently bring their suppliers with them; and a herd effect results in more FDI inflows, which in turn encourages more GVC entry and improvement through spillovers and agglomeration

effects (Kowalski et al., 2015; World Bank, 2020).

According to Altun et al. (2022; Arora & Siddiqui, 2022), per capita GDP and R&D investment have a significant and beneficial impact on high-tech exports, while FDI outflows have a negative impact on low-tech and medium-tech exports (Zhou, 2020; Zhang, 2007). For medium- and low-tech businesses, the cost of R&D is significant (Poldahl, 2012). Also, companies that invest more in R&D focus more on product development with the aim of strengthening the global value chain (Bhattacharya et al., 2021). The other control variables, such as institutional quality and human capital, do not seem to be significantly connected to high-tech exports, but they are positively related to medium- and low-tech exports, according to studies like (Mehrra et al., 2017; Zhang, 2007; Tebaldi, 2011).

Table-6 ARDL-ECM short-run dynamic coefficients

Variables	High-tech	Medium-tech	Low-tech
D(High-tech Export(-1))	0.99*** (3.39)		
D(Medium-tech Export(-1))		-1.32*** (-3.8)	
D(Low-tech Export(-1))			1.02*** (3.33)
D(backward participation(-1))			0.21 (0.16)
D(Inward FDI(-1))	0 (0.02)	-0.02 (-0.63)	0.15 (0.21)
D(forward participation(-1))	0.37 (1.22)	0.26 (1.35)	
D(GDP Per capita(-1))	0.03* (1.98)	0 (0.6)	0.13 (1.51)
D(HCI(-1))	0.09 (1.07)	0.48*** (5.1)	1.55*** (3.06)
D(IQ(-1))	-0.02*** (-3.11)	-0.01 (-2.13)	-0.11*** (-2.46)
D(Outward FDI (-1))	0 (-0.122)	0 (-0.4)	0 (-0.9)
D(R&D Expenditure(-1))	-2.26 (-0.7)	-4.7** (-2.6)	-2.55 (-0.29)
EMC(-1)	-1.6*** (-3.6)	-1.3*** (-3.8)	-1.4*** (-3.8)
Obs	22	21	21
R-squared	0.7	0.82	0.74
Adjusted R-squared	0.5	0.67	0.54
F-statistic	3.23	5.9	3.6
Durbin-Watson stat	2.3	1.53	2.2

Figures in () indicate t-statistic, probability statistically significant at 1%, 5% & 10% level are denoted by ***, ** & *.

Error correction modelling (ECM) is used to analyse the dynamic parameters of the short-run model related to long-run projections (Narayan & Smyth, 2008). A short-run shock's pace of adjustment or correction to the long-run equilibrium is determined by ECM. So, in order to determine the short-run dynamic parameters, we estimate an error correcting model called ARDL that is linked to the long-run estimations (p, q). It can be made in the following way:

$$\Delta Y_t = \delta_0 i + \sum_{i=1}^p \beta_1 \Delta Y_{t-1} + \sum_{i=1}^q \beta_2 \Delta X(1)_{t-1} + \sum_{i=1}^r \beta_3 \Delta X(2)_{t-1} + \sum_{i=1}^s \beta_4 \Delta X(4)_{t-1} + \lambda ECM_{t-1} v_t \quad \text{--- (4)}$$

Here, the short-run dynamic coefficients of the model's convergence back to the specified equilibrium are β_1 and β_2 , β_3 and β_4 . A long-run equilibrium connection is established by the error-correction term ECM_{t-1} , and k denotes how quickly the equilibrium level is reached following a short-run shock. A fraction of the disequilibrium is remedied in the following period, according to the negative sign of ECM_{t-1} . ECM is a technique for balancing short- and long-term behaviour.

Table 6 displays the ARDL-ECM equation's dynamic coefficients for both short- and long- term relationships. The GVC participation indicators forward and backward participation are favourably with high-tech, medium-tech and low-tech, respectively. Yet, in the short-run the R&D investment is negatively associated with all the technology-intensive sectors with gross exports. A company's gradual investment in R&D over the course of one year tends to accelerate its export performance in the following year, according to a prospective examination of the relationship between R&D and exports (Lippodt, 2019). Also, it has been noted that R&D operations in India frequently take an adaptable approach. Domestic companies engage in research and development by either altering imported technology to meet local needs or by reverse-engineering foreign technology or the results of research and development by global organisations (Battelle India and FICCI, 2013). The connection between exports and foreign direct investment (FDI) has only shifted negatively for medium-tech enterprises. Because it takes time to integrate new technology into existing manufacturing, which in turn affects exports, technology factors have a negative influence on gross exports in the short term (Arora & Siddiqui, 2022). Also, all types of technology-intensive exports have ECT coefficients that are significant at a 1% level, indicating that the rate of adjustment to equilibrium following a shock is generally fair.

5.4 Diagnostics and Stability

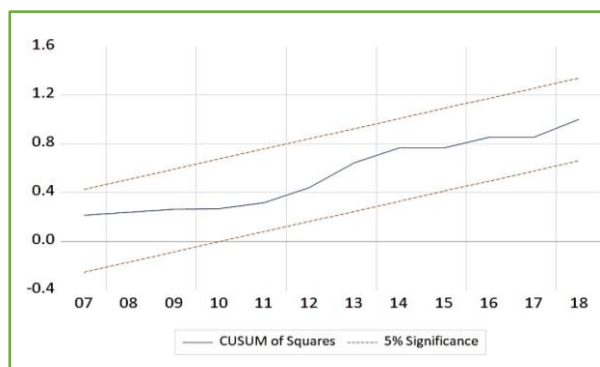
Although the diagnostic tests must be successful, the ARDL equation (2) has a good fit. The tests used to make this determination disprove serial correlation. The findings are shown in Table 7. Additionally, the test for the cumulative sum of recursive residuals of squares (CUSUMSQ) is used to assess the parameter stability of the long-run coefficient confirmed by the short-run dynamics (Pesaran, 1997). Because it charts inside the critical bands of the parameter stability, the CUSUMSQ statistic shows that the coefficients are not unstable. 10% confidence interval.

Table-7 Diagnostic Test- Breusch-Godfrey serial correlation LM test

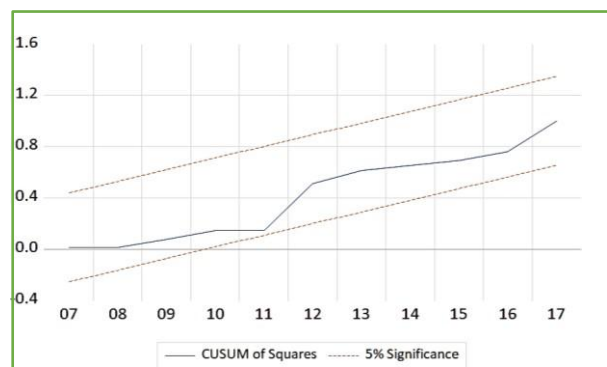
Variables	High-tech	Medium-tech	Low-tech
F-statistic	2.53	3.33	0.934
Prob	0.137	0.097	0.35
Prob Chi-Square	0.05	0.02	0.18

Graph-1 Plot of CUSUMSQ Test

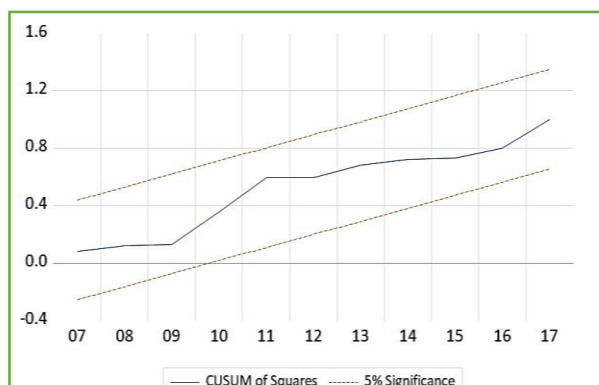
(High-tech Export)



(Medium-tech Export)



(Low-tech Export)



5.4.1 Granger Causality Test

The possibility of causation in at least one direction depends on whether a long-run equilibrium relationship exists. The variables are independent when there is no cointegration between them since they have no impact on one another. A causality test method was developed by Granger (1969) to identify the pattern of such a connection. If the current and lagged values of X make it easier to anticipate what the future value of Y will be, it is said that X "Granger causes" Y.

The multivariate pth order for the vector error correction model (VECM) is demonstrated by: $\Delta X_t = \varphi + \sum_{i=1}^p \Theta_i X_{t-i} + \lambda ECM_{t-1} + \varepsilon_t$

The Θ_i interaction coefficients of the variables are included in the vector of constant terms φ , which is indicated by X_t in this case. For each of the error correction terms, λ is the vector of coefficients, and ε_t is the vector of disturbance terms. Table-8 displays the Granger causality findings for short run pair-wise.

For the high-tech exports, F-statistics show that there exists a uni-directional causality from forward participation to high-tech exports, also the R&D expenditure uni-directionally causes inward FDI and forward participation, therefore underpinning the association between technological capability influencing the exports to G20 countries through India's GVC participation. For medium-tech exports, there exists a uni-directional causality from GDP per capita, HCI, IQ and R&D expenditure to medium-tech exports. Also, forward participation uni-directionally causes outward FDI and outward FDI participation uni-directionally causes R&D expenditure. Therefore, once again the association between technological capability influencing the exports to G20 countries through India's GVC participation gets ascertained even for the medium-technology exports.

Table-8 Results of short run Granger causality

a. High-tech

Variables	High-tech Exports	Backward participation	Inward FDI	Forward participation	GDP per capita	HCI	IQ	Outward FDI	R&D Expenditure
High-tech Exports	-----	0.93	0.25	0.9	0.34	0.56	0.8	0.8	0.8
Backward participation	0.06	-----	0.17		0.51	0.52	0.26	0.94	0.97
Inward FDI	0.51	0.49	----- -	0.49	0.9	0.51	0.94	0.81	0.53
Forward participation	0.03	-----	0.17	-----	0.51	0.52	0.26	0.94	0.97
GDP per	0.13	0.04	0.59	0.04	-----	0.019	0.014	0.38	0.02

capita					---				
HCI	0.63	0.93	0.61	0.93	0.3	-----	0.23	0.03	0.17
IQ	0.19	0.11	0.74	0.11	0.48	0.02	-----	0.24	0.08

Outward FDI	0.42	0.46	0.36	0.46	0.35	0.74	0.54	-----	0.2
R&D Expenditure	0.96	0.45	0.03	0.05	0.91	0.37	0.78	0.45	-----

Notes: (Bold) denote statistical significance at the 5% levels respectively

b. Medium-tech

Variables	Medium-tech Exports	Backward participation	Inward FDI	Forward participation	GDP per capita	HCI	IQ	Outward FDI	R&D Expenditure
Medium-tech Exports	-----	0.78	0.87	0.78	0.17	0.44	0.36	0.51	0.68
Backward participation	0.39	-----	0.58		0.19	0.32	0.79	0.11	0.91
Inward FDI	0.41	0.21	-----	0.21	0.9	0.51	0.71	0.81	0.16
Forward participation	0.39		0.58	-----	0.19	0.32	0.79	0.01	0.91
GDP per capita	0.04	0.63	0.59	0.63	----- -	0.01	0.04	0.38	0.24
HCI	0.013	0.94	0.61	0.94	0.3	----- --	0.03	0.03	0.17
IQ	0.04	0.78	0.88	0.78	0.29	0.39	-----	0.24	0.93
Outward FDI	0.17	0.42	0.36	0.42	0.35	0.7	0.7	-----	0.04
R&D Expenditure	0.03	0.16	0.14	0.16	0.03	0.93	0.93	0.26	-----

Notes: (Bold) denote statistical significance at the 5% levels respectively

c. Low-tech

Variables	Low-tech Exports	Backward participation	Inward FDI	Forward participation	GDP per capita	HCI	IQ	Outward FDI	R&D Expenditure
Low-tech Exports	-----	0.28	0.42	0.28	0.83	0.02	0.23	0	0.01
Backward participation	0.13	-----	0.89		0.21	0.22	0.05	0.1	0.01
Inward FDI	0.4	0.43	----- -	0.43	0.89	0.44	0.43	0.56	0.78
Forward participation	0.03		0.89	-----	0.21	0.22	0.1	0.01	0.25
GDP per capita	0.55	0.55	0.53	0.55	----- ---	0	0.13	0	0.45
HCI	0.72	0.89	0.23	0.89	0.12		----- --		
IQ	0.1	0.89	0.87	0.7	0.31	0.95		0.03	0.07
Outward FDI	0.71	0.7	0.33	0.87	0.16	0.68	0.57	----- -	0.19
R&D Expenditure	0.57	0.87	0.62	0.98	0.04	0.57	0.02	0.13	-----

Notes: (Bold) denote statistical significance at the 5% levels respectively

For low-tech exports, there exists a uni-directional causality from forward participation to low-tech exports and low-tech export uni-directionally causes outward FDI and R&D expenditure. The direct linkages between GVC participation and gross exports of technology-intensive manufacturers is visible.

6. Conclusion and Policy Implications

Strong interdependence may be seen in the trends and patterns of technology-intensive trade between India and the G20 nations. The G20 presidency of India could not have come at a better time to provide significant stability at the most critical stage of geopolitical development and crisis concerns. Even if these problems will only become apparent in retrospect, dealing with such risks and disruptions will inevitably become part of doing business as usual. India, which among the G20 countries has the fastest-growing economy, offers itself as a potential alternative destination for manufacturing as well as a diversified source of supply chain resilience. This paper provides relevance in this perspective by examining the determinants of export of different technology-intensive products to the G20 countries. As the products and services are heterogeneous in their intrinsic value – with exported goods varying considerably in their effect on future growth. The long-run results provide the evidence that forward participation is important for both high-tech and low-

tech sectors and for medium-tech sector, the backward participation is important. Along with GVC participation, R&D expenditure and inward FDI have come out with a positive association with gross exports of high-tech and low-tech sectors.

A nation's economic structure must change for economic progress to occur. The emphasis on the interconnection of economies has caused a shift away from the specialisation of entire industries towards particular activities and stages in value chains. Participating in the GVC could provide a mechanism to get access to these technology and intermediate inputs, giving nations the chance to expand more quickly through export upgrading. According to the paper's findings and the present economic situation, India has the chance to further integrate into global value chains as more foreign investment is being channelled to it as a result of tensions between the United States and China¹⁵. This calls for prudent macroeconomic management where better integration of MSMEs in GVCs can result them to become more export-oriented. Secondly, the lead MNCs can build stronger supply chain management, greater transparency, and supply chain rationalization, with identification of best practices for organizations to mitigate supply chain shocks. The tracking of long-term trends and shifts in GVCs can enable in planning and forecasting, creating buffers and redundancies, thus building resiliency. Thirdly, digitalisation and industry 4.0 are the backbone of the new age GVCs and to successfully integrate into the value chains, there needs to be adoption of technology at a faster pace. Importantly, these technologies allow enterprises, customers, and society to be more adaptable and responsive and to make better informed, data-driven decisions by communicating, analysing, and acting upon information. Last but not least, the sector-specific production linked incentives scheme (PLI) that India has implemented for several sectors can improve MNC-MSME ties, boosting GVC involvement, economic growth, greater productivity, and the transfer of knowledge and technology. As a result, the policies may also involve bettering the business climate, bettering trade and investment promotion policies, adopting competitive exchange rate regimes, bettering favourable and alluring FDI policies, and bettering connectivity.

Abbreviations- Already have been mentioned in the text

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Notes

¹ <https://www.orfonline.org/expert-speak/indias-g20-presidency-bridging-the-north-south-divide/>

² https://www.orfonline.org/wp-content/uploads/2022/07/ORF_GVC-Survey-Report_August.pdf

³ <https://www.imf.org/en/Countries/IND>

⁴ <https://www.oecd.org/investment/investment-policy/26th-OECD-UNCTAD-Report-on-G20-Investment-Measures.pdf>

⁵ <https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1882356>

⁶ <https://www.hindustantimes.com/india-news/economic-importance-of-g20-as-india-takes-its-presidency-101668621970770.html>

⁷ https://unctadstat.unctad.org/en/Classifications/DimSicRev3Products_Ldc_Hierarchy.pdf

⁸ The data is sourced from WITS <https://wits.worldbank.org/gvc/gvc-trade-table.html>. The Asian countries include Brazil, India, Indonesia, Russia, China, Mexico, Turkey while developed countries include USA, UK, South Korea, Japan, Italy, Germany, France, Australia, Canada.

⁹ https://www.wto.org/english/res_e/booksp_e/08_gvc_ch5_dev_report_2021_e.pdf

¹⁰ https://unctad.org/system/files/official-document/unctad_oecd_wto_2013d1_en.pdf

¹¹ https://stats.oecd.org/Index.aspx?DataSetCode=TIVA_2021_C1

¹² https://www.wto.org/english/res_e/statis_e/miwi_e/explanatory_notes_e.pdf

¹³ <https://info.worldbank.org/governance/wgi/>

¹⁴ <https://industryoutlook.cmie.com/>

¹⁵ https://m-economictimes-com.cdn.ampproject.org/c/s/m.economictimes.com/news/economy/finance/window-for-india-to-be-linked-to-global-value-chains-deeply-adb/amp_articleshow/98160749.cms

Argentine Knowledge Intensive Mining Suppliers' (KIMS) participation in the mining value chain: disentangling entry barriers and envisaging policy opportunities for developing mining countries

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Abstract

In association with changes in its industrial organisation, green growth imperatives and an expected unprecedented demand, the mining industry has been envisaged as a potential platform for growth, export diversification and innovation for developing mineral-rich countries. Evidence collected on the spring of Knowledge Intensive Mining Suppliers' (KIMS) in such countries is, however, still rather disappointing. In this paper we contribute to better understanding mining linkages-formation opportunities by assessing micro- and meso-level factors that affect KIMS' participation across different types of mining supplier markets. We explore these issues by proposing a taxonomy of mining supplier markets which we use to analyse original data on Argentine KIMS. Results reveal that KIMS' supplier markets hold significant differences regarding their micro and meso- level dynamics, generating a diverse set of opportunities and barriers for newcomers to participate and become established suppliers. Effective policy interventions should acknowledge and also address supplier markets' diversity to become more effective.

1. Introduction

In the last decade or so how to turn mining activity into a platform for growth, export diversification and innovation has increasingly concentrated more attention in developing mineral-rich countries (Perez, 2010; Marin et al; 2015; Pietrobelli et al 2018; Barcena, 2018; CAF, 2018; Meller & Parodi, 2017; Obaya et al 2014). In particular, "how to build linkages" to local suppliers has been at the centre of policy strategies in those countries (Dietsche, 2014; IGF, 2018). These policies were to a large extent inspired by the emergence of a dynamic sector of knowledge intensive mining suppliers (KIMS) in Australia, which rapidly became global players (MTSAA, 2002; Scott-Kemmis, 2013; SCIRO, 2017; Comisión de Minería y Desarrollo de Chile, 2014). However, despite the increasing interest and policy efforts to promote domestic technologically-dynamic suppliers associated with mining, development of this sector has been limited in most countries. Linkages have not increased as expected and evidence coming from developing mining countries is far below what is showcased for the Australian economy (Arias et al 2014; Atienza et al, 2020; Atienza et al, 2021; Bravo-Ortega and Muñoz, 2020; Calzada Olvera, 2022; Navarro, 2018).

In this paper we discuss micro and meso-level factors that are opening new opportunities and preventing KIMS' entry into different types of mining supplier markets. We draw on ideas from innovation studies to explore this broad question. This perspective claims that the space of innovation opportunities changes with the historical moment and the prevalent technological paradigm (Freeman and Pérez, 1988). Based on this idea, opportunities have been identified emerging mainly from the need of solutions adapted to local specific natural conditions, the imperatives of green growth and the emergence of new technologies opened opportunities for innovation in the mining industry (Perez, 2020; Marin et al, 2015; Andersen et al, 2016). Domestic KIMS in developing countries could harness these opportunities in the last decades, though not massively (Urzúa, 2011; Morris et al 2012; Ramos, 1998; Kaplan, 2012; Stubrin 2017; Andersen, 2012; Petrobelli et al, 2018; Figueiredo and Piana 2016, 2018).

Macro, meso and micro-level factors have been broadly identified, and analysed in a separate fashion, as hindering newcomers to participate in the mining value chain (Pietrobelli et al, 2018; Tilton, 2014; Calzada Olvera, 2022; Stubrin, 2017; Kaplan, 2012;

Figueiredo & Piana, 2016). However, the interactions among such factors and the extent to which different entry barriers prevail across mining suppliers' markets are largely under-researched. In this paper we aim at shedding light on this issue by exploring how innovation opportunities vary across different types

of mining supplier markets, which types of micro-and meso-level entry barriers are counteracting such opportunities and what strategies can be implemented at firm and industry level to overcome such barriers. We explore these issues based on detailed empirical evidence from Argentina.

To do so we elaborated a taxonomy of supplier mining markets based on the type of product or service offered and the prevailing industrial organisation that characterise the market segment. This taxonomy is applied to understand the presence and absence of Argentine KIMS in different supplier markets of the metal value chain in the country, unravelling which are the prevailing micro and meso-level entry barriers that KIMS faced and the strategies they pursued to overcome such barriers. Data on Argentine KIMS is based on a fieldwork study carried out in 2019 (Marin et al, 2022).

We make two claims. First, mining supplier markets hold significant differences regarding their micro and meso- level dynamics, generating a very diverse set of opportunities and barriers for newcomers to participate and become established suppliers. Previous related literature as well as policy aiming at fostering mining linkages have tended to overlook such differences and their implications for policy. Second, micro and meso-level barriers for domestic KIMS to participate in mining supplier markets should be addressed in a combined manner. For instance, focusing just on addressing firms' level barriers, as it is more commonplace, is likely to make policies less effective. A mix of policies that address micro- and meso-level opportunities and barriers to entry, should be targeted for different mining supplier markets.

We believe that this paper is relevant to industrial policy in developing mining countries as it informs on the types of support that can be beneficial to new entrants in the mining value chain. In addition, our contribution is also helpful for governments to deliberately target the type of mining supplier markets in which opportunities for domestic companies to enter and participate can be maximised.

The paper is organised into 5 sections. The second section provides a literature review on the discussion about mining, linkages and innovation. The third section proposes a taxonomy of KIMS' supplier markets based on the type of product or service offered and the prevailing industrial organisation of different market segments. The fourth section focuses on the empirical analysis. In this section the case of the Argentine metal mining industry is presented, the methodological approach to study Argentine KIMS' suppliers is described and results of our empirical work are analysed. Finally, implications for industrial policy are discussed.

2. Natural resources, linkages and opportunities for innovation: what do we know about mining?

The prevailing view on the negative relationship between natural resource activities and economic development (Prebisch 1950; Singer 1950; Auty 1993, 1997; Sachs and Warner 1995, 1997; Gylfason, Herbertsson & Zoega, 1999; Nankani 1980) stood to a large extent on the poor capabilities of these type of activities to set up linkages with the rest of the economy and to be used to deliver products different from commodities. More recently, however, this view has been largely questioned in association with changes in demand, institutions and technology which have substantially increased innovation opportunities in all sectors, impacting also on natural resource activities (Pérez, 2010; Marin et al, 2015; Andersen et al, 2015, 2018). The development of innovative activities upstream and downstream natural resource activities in the last decades fostered increasing optimism about a positive relation among natural resources, innovation and development which even permeated the policy agenda (ECLAC 2018, Martinez-Ortiz 2014). The case of the mining industry is very illustrative of that shift.

The term enclave economy was used for long to characterise the behaviour of extractive sectors in mineral-rich developing countries pointing out their limited capability to connect to the local productive system, and almost exclusively set up linkages of fiscal type (given by the flow of income captured by the State in the form of taxes on this activity) (Heeks, 1998). The enclave thesis, however, was more recently questioned in association with the large changes that the mining sector has experienced in the last decades (Morris et al, 2012; Bloc and Owus 2012; Urzúa, 2011). A prominent one has been the change in its industrial organisation consisting of a de-verticalization of mining companies, which tended to increasingly concentrate on their core activities - operational and resource extraction - and relying more on specialised suppliers for inputs and services along the value chain. This de-verticalisation process, which began limited to mining operations in developed countries, has evolved into global outsourcing programmes enabling the opportunity for domestic suppliers to develop in all mineral-rich countries (Kaplinsky and Farooki, 2011; Urzúa, 2011; Wold Bank, 2002; Morris et al, 2012).

The emergence and global success of the Australian mining software supplier industry showed the potential of mining to spur domestic knowledge-intensive and innovative suppliers' sectors (MTSAA 2002, Scott-Kemis 2011, 2013, Austmine 2014). This case very much inspired developing mineral-rich countries to implement policies aiming at transforming mining into a platform for diversification, employment generation and growth (Morris et al., 2012; Morris & Fessehaie, 2014; IGF, 2018; Barcena, 2018; CAF, 2018). The Chilean Government, for example, set the goal of promoting the creation of 250 local suppliers to the mining sector by 2035, which were expected to generate

knowledge and technology intensive exports for around US\$ 10 billion (Comisión Minería y Desarrollo de Chile, 2014).

Even though the effective emergence of KIMS in many of developing mineral-rich countries such as South Africa, Peru, Brazil or Chile has started to be documented in the last decade (Urzúa 2011; Morris et al 2011; Kaplan 2012; Kuramoto and Sagasti, 2006, Bamber et al 2016; Benavente and Goya 2011; Figueredo and Piana 2016; Stubrin, 2017; Aaron and Molina, 2020), mining linkages in these regions remain limited, and overwhelmingly concentrated on low-tech inputs (Stilwell et al., 2000; Aroca 2001; Nchor & Konderla 2016; Phelps et al, 2015, Arias et al, 2014; Bravo-Ortega and Muñoz, 2021; Calzada, 2022), as the degree of 'enclavement' of the mining sector remains significant (Atienza et al., 2018; Castaño et al., 2019; Nchor & Konderla, 2016; Sadik-Zada et al., 2021).

The literature has pointed out several macro-, meso- and micro-level factors that attempt to explain the slow pace at which linkages have evolved, particularly those related to knowledge-intensive inputs. Macro-level factors being the type of governance of mining global value chains which tended not to favour newcomers' participation and upgrading within the chain (Fessehaie, 2012; Pietrobelli et al, 2018), commodity prices imposing a strong negative effect on mining linkage development as mining firms' higher profit margins discourage investments in innovative inputs (Tilton, 2014; Calzada Olvera, 2022; Morris et al, 2012) and territorial aspects of linkage formation which deter linkages (Atienza et al, 2020).

At meso-level, factors related to the industrial organisation of the mining value chain have been also highlighted. Mining has been characterised as a conservative industry, mining houses having high risk aversion to experiment and try new technological solutions (particularly when they are developed by newcomers). Failure when trying a new solution or halting production to try a new process could cause losses in the millions of dollars to mining companies. This risk reinforces conservative practices of mining houses and generates a sort of inertia in terms of their supplier practices, discouraging new entrants (Stubrin, 2017). Economies of scale can be also critical for newcomers to participate in certain supplier markets, such as heavy machinery, in which few large multinationals cater the mining worldwide market by enjoying economies of scale advantages, and enforcing market standards, prices and innovations paths (Kaplan, 2012).

Finally, at firm-level factors such as scarce domestic firms' technological capabilities to participate in international competitive markets, difficulties to access information regarding mining firms' needs and demands, and even lack of support for the entrepreneurial costs and risks involved in developing new solutions have been pointed out (Figueiredo & Piana, 2016; Stubrin 2017; Figueiredo and Piana, 2016; Molina, 2018; Kaplan, 2012).

In this paper we extend this literature by attempting to better understand micro- and meso- level factors that enable and deter domestic suppliers entry into different mining supplier markets.

3. A taxonomy of mining supplier markets

We draw on empirical literature on the mining industry and our own research to propose a taxonomy of KIMS' supplier markets based on the type of product or service offered and the prevailing industrial organisation of different market segments. We distinguish among three types of mining supplier markets: i) consolidated markets, ii) traditional taylor-made markets and iii) emerging markets (Table 1). We examine each of them below.

Table 1 - A taxonomy of mining supplier markets

Markets' main characteristics	Type I - Consolidated markets	Type II - Traditional taylor-made markets	Type III - Emerging markets
Type of product/service commercialised	Standard products and services	Taylor-made (standard products and services adapted to local conditions)	World-class innovations (products and services) based on new technologies
Size	Large	Small to medium	Potentially large
Type of suppliers	Large multinational companies	Medium and small-sized companies	Start-ups
Market structure	Oligopolistic	Market-niche	New markets
Other prevailing characteristics	-Scale-intensive -Established global brands -Long history of user-producer relationships -Demand driven	-Opportunities for economies of scope -Supply driven	-Supply driven

I. Consolidated markets

Consolidated markets (*Type I*) are characterised by scale-intensive standardised

critical inputs (i.e. such as pumps, trucks, drilling down the hole percussion hammers, diesel engines, explosives, reparations of heavy machinery) provided by large multinational companies in concentrated markets around the world. These supplier markets are mostly driven by the demand of critical day-to-day inputs by mining houses. An example of this type of market is that of haulers and trucks, in which few large multinational companies, such as Caterpillar, Komatsu and Liebherr, cater the mining worldwide market by enjoying economies of scale advantages, and enforcing market standards, prices and innovations paths. Mining firms' high levels of brand loyalty to incumbents based on trusting their proven technology and a long history of user-producer relationships tends to prevail.

II. Traditional taylor-made markets

Traditional taylor-made markets (*Type II*) are characterised by the provision of traditional inputs (products and services) customised or adapted to local conditions. Since no two mining sites are the same (each location has a unique combination of rock type, altitude, climatic condition, ore grade, etc.), the need to attain productivity gains in a context of declining ore grades has triggered the demand for site-specific solutions (Tilton 2014), promoting the creation of taylor-made market niches.

Innovation studies have documented how the need for "local specific knowledge", quite typical of natural resource exploitation, generated opportunities for the creation of small and medium-sized KIMS in developing countries that could take advantage of idiosyncratic knowledge and economies of scope to deliver adapted innovations (Marin et al, 2014; Andersen, 2012; Marin et al, 2018; Iizuka and Katz, 2015). For example, in the case of Chile, local KIMS developed engines adapted to the country's extreme weather conditions where mine sites are located, providing a more efficient alternative to standard engines that tend to under-perform by deteriorating early and consuming more fuel (Stubrin, 2017). Similar examples of the emergence of local KIMS taking advantage of possessing idiosyncratic knowledge to cater the mining market by offering innovative adapted solutions have been documented also for other mineral-rich countries (Scott-Kemis, 2013; Urzúa, 2011; Pietrobelli et al, 2018; Kaplan, 2012; Pogue, 2008).

III. Emerging markets

Emerging markets (*Type III*) can be created by start-ups companies to commercialise innovative solutions based on cutting-edge technology to attend prevailing or new problems of the mining industry. Mining faces today a significant demand for metals and minerals that will necessarily be met by developing new technological solutions to increase productivity in older deposits and facilitate the expansion of the activity to new sites in a sustainable way (World Bank, 2020). Productivity gains from the use of ever larger

equipment in large mines, as has been the case since the second industrial revolution, are beginning to show signs of exhaustion (Humphrey, 2019). Exploration discoveries are generally getting smaller and the cost of finding an economically recoverable unit of ore is increasing (Koch et al. 2015; Chender 2012). These challenges, coupled with sustainability imperatives, create a latent demand for new technologies in the mining sector.

In this scenario, developing countries with mineral resources have the opportunity to maximise the advantages of outsourcing from large companies in the sector by developing a KIMS sector that provides innovative solutions. In recent decades, it has been observed how the third industrial revolution has opened up opportunities for the opening of new supplier markets through the development of innovative goods and services for the mining activity based on Information and Communication Technologies (ICTs) (Humphrey 2019). The case of the Australian software supplier sector is a prominent example of an emerging supplier market (MTSAA 2002, Scott-Kemis 2011, 2013, Austmine 2014). KIMS in South American mining countries are timidly taking advantage of advances in new technologies to enter such new markets by means of innovation (Bamber et al. 2016, Stubrin 2017, Benavente and Goya, 2011, Figueredo and Piana 2018).

In the following section, we use the proposed taxonomy of mining supplier markets to understand the presence and absence of Argentine KIMS in the metal value chain in the country. We further investigate which are the prevailing meso- and micro-level entry barriers that KIMS faced in each type of supplier market, and the strategies they pursued to overcome such barriers, when they did so.

4. Empirical analysis

In this section we present the empirical results of the research. The section is divided into four subsections. First we present the Argentine case, outlining the main characteristics that the mining industry takes in Argentina and the prevailing view regarding its potential to trigger economic growth and diversification of the production matrix in that country. Second, we describe the methodological approach taken to collect data on Argentine KIMS. Third, we analyse the supplier markets in which Argentine KIMS participate and do not participate. Fourth, we use the proposed taxonomy on mining supplier sectors to understand in which types of supplier markets Argentine KIMS do participate, which are the micro- and meso-level barriers that these firms faced in each type of market, and which type of strategies they have deployed to overcome such barriers, if so.

4.1. Mining activity in Argentina

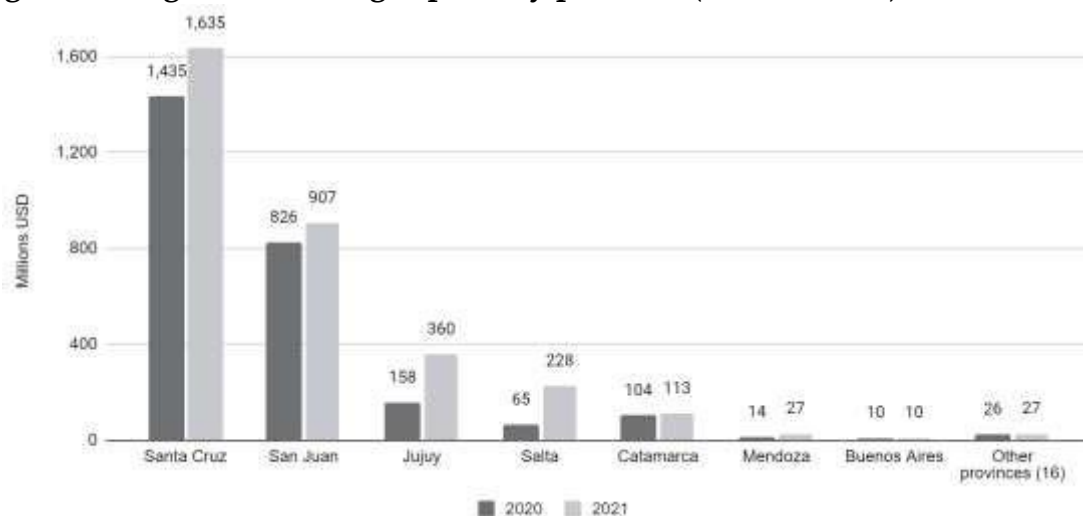
Argentina is a country with substantial mineral potential. It is ranked globally

6th among countries with the largest amount of mineral resources which include minerals necessary for the energy transition such as copper and lithium.¹ (Murguía and Bastida, 2022). The potential includes known world-class deposits such as the Pachón copper deposit (located in the San Juan province next to the Pelambres operation in Chile), and a significant amount of high mining potential under-explored areas.² It is estimated that if all 32 advanced copper, gold/silver, potash and lithium projects advanced into the production stage, annual mining exports could reach USD 18 million, i.e. multiply the 2021 mining exports by more than 5 times (Murguía, 2021).

Yet, such geological-mining potential has been scarcely developed. The metal mining sector currently accounts for 0.5 % of the country's GDP and around 4 % of the country's total country exports (USD 3300 million in 2021). A comparison with Latin American countries reveals the limited scale of the activity in Argentina: in terms of the size of mining activity relative to GDP, the sector in Argentina is one-tenth the average for Latin American countries (Marin et al, 2022).

The structure of the metal mining sector in Argentina is dominated and highly concentrated on global multinational firms (Barrick, Newmont, Yamana, AngloGold, etc.), chiefly Canadian companies targeting gold and silver mining operations (Barrick, Yamana, Fortuna Silver). Argentine private firms (IRSA, Mirgor) participate as associates in small projects and with very minor positions. Argentine state-owned companies, mainly provincial companies³, are often owners of the mineral resources and participate as minority partners sharing the economic rent of the projects operated by larger foreign companies. The activity is geographically concentrated on 5 out of 24 provinces, two of them (the provinces of Santa Cruz and San Juan) accounting for over 75 % of the country's mining exports (Figure 1).

Figure 1 - Argentine mining exports by province (million USD)



Source: Own elaboration based on the National Institute of Statistics and Censuses (INDEC) from Argentina.

In a global context of growing demand for minerals and a local context signed by an ongoing economic and financial crisis, national and provincial governments are raising the stakes in the metal mining sector. In recent years, the strategic interest in the mining sector has even been expressed out by the last two Presidents, which represent two highly different political visions:

"Mining can be a gigantic opportunity for us. It can be a generator of quality employment at the level of the countryside"... "This does not mean sacrificing anything, but opening doors to development. This is quality work for many Argentines. And it can be given with perfect care for the environment" (President Mauricio Macri (2015-2019) at the presentation of the Federal Mining Agreement at Casa Rosada, June 13, 2017).

"Mining is a great opportunity for a country that needs to produce, grow and export" (...) "For many years we neglected mining wealth, and that is why we lost a great opportunity. Thanks to technological progress, mining ceased to be a risk and became a great opportunity for a country that also needs to produce, grow and export. Mining has a relevant focus there because it exports much of what it produces, and the only way to take care of the obligations is by exporting" (...) "There are still many untapped mining resources in Argentina, as is the case in the provinces of San Juan, Catamarca, Santa Cruz, as well as in many other jurisdictions that are reluctant to this industry" (President Alberto Fernández (2019-2023) during the Mining Industry Sectorial Meeting in the Province of San Juan, December 22, 2020).

In early 2022 the national government launched the initiative "Argentina Productiva 2030" as the leading productive development plan consisting of ten key priority missions (Mazzucato, 2018). Two of them are related to mining development in the country: i) "Mission 7: Developing Argentina's mining potential with strict care for the environment", and ii) "Mission 9: Promote productive linkages from the primary sector (mining, agriculture, oil&gas, fishing and forestry) to generate more jobs and development"⁴. Mining development is, thus, expected to contribute to the country's foreign exchange earnings and diversification of the productive structure and job-creation. There are, however, no previous studies on how the mining supplier market is evolving in the country, and, in particular, how Argentine suppliers are participating in the mining value chain. In this paper we empirically mapped Argentine KIMS' participation in the metal value chain in the country, and use the mining suppliers' market taxonomy developed in Section 2, to understand firms' presence and absence, in different supplier markets.

4.2. Data and methodology

The study is based on multiple case study methodology. A fieldwork study was conducted over 10 months in Argentina (from November 2018 to September 2019). We collected quantitative and qualitative evidence through interviews with senior managers of 26 mining suppliers, 5 mining companies⁵, 7 government institutions⁶ and 5 mining business chambers⁷. Two critical elements of the fieldwork study were the identification of KIMS' MSMs of the metal mining value chain in Argentina, and those MSMs in which Argentine KIMS' participate. We define KIMS' MSMs as those supplier markets that require knowledge-based or specialised solutions. Thus, low-tech product markets such as that of cables, or generic services such as transport or catering were excluded from the study. Interviews with mining companies and business chambers were of utmost importance to identify KIMS' MSMs, to gather information on the entry and participation of domestic suppliers in the metal mining value chain in the country, to identify Argentine KIMS, to understand the nature and type of relationships between this type of suppliers and mining companies and to unravel the main activities of mining companies in the country.

Argentine KIMS are defined as those suppliers that are knowledge-based and provide specialised products or services to mining companies. As there is no official list or registry of domestic mining suppliers in Argentina, the process of identification of KIMS was dynamic. A first set of suppliers were identified through the review of documentation and consultations with mining companies, business and governmental institutions. Using the snowball method, often used in unknown populations such as KIMS in Argentina, a universe of 78 Argentine mining suppliers was identified. In a second stage, we interviewed 19 Argentine KIMS (Table x). These interviews focused on their productive and technological capabilities, the type of products/services they offered, the entry barriers they faced to enter MSMs, the strategies they pursue to overcome them and the type of relationship they forged with mining companies.

Table 2 - Argentine KIMS' interviewed: main characteristics

Argentine KIMS' name	Foundati on year	Firm Size(*)	Knowledge base (**)	Type of Supply	Market
Aminco	2015	Small	Geology, geotechnics, geophysics, topography and hydrogeology.	Services	Geological, geophysical & topographical services for mining exploration and production

DAMS	2015	Micro	Geophysics, Earth Sciences, Surveying, Civil Engineering	Services	Geological, geophysical & topographical services for mining exploration and production
Hidroar	1981	Small	Geology, hydrogeology, hydraulic engineering, civil engineering and biology.	Services	Hidrological, satellite images & environmental studies for mining exploration and production
Balderram o	1975	Small	Metalworking and electric engineering	Services	Heavy machinery maintenance & repair for exploration and production
Jaime	1989	Medium	Engineering	Services	Heavy machinery maintenance & repair for exploration and production
Indumet	1989	Medium	Metalworking capabilities in turnery	Services	Heavy machinery maintenance & repair for exploration and production
Perforacio nesSC	2012	Small	Geology, electromechanics, mining engineering	Services	Drilling, earthworks and core sampling
Ecominer a	1996	Large	Engineering	Services	Drilling, earthworks and core sampling

AGV Falcon Drilling	1992	Medium	Engineering	Services	Drilling, earthworks and core sampling
Hidrotec	2012	Medium	Engineering and geology	Services	Drilling, earthworks and core sampling
BTZ Minera	1992	Medium	Mining engineering	Services	Engineering & Construction
Di Bacco	1956	Medium	Engineering	Services	Engineering & Construction
MineTech	2010	Small	Electronic engineering	Services	Safety-related services
Inbelt	1996	Medium	Engineering and new materials	Products	Heavy machinery and equipment parts
Metalar	1949	Small	Engineering, machining and foundry	Products	Heavy machinery and equipment parts
Acerias 4c	1976	Small	Industrial engineering	Products	Heavy machinery and equipment's parts
Kousal	1955	Medium	Engineering	Products	Heavy machinery and equipment's parts
Saeta	2008	Micro	Engineering and machining	Products	Heavy machinery and equipment's parts
Indumet	1989	Medium	Metalworking capabilities in turnery	Products	Heavy machinery and equipment's parts

(*) To classify interviewed firms according to their size we followed the following criteria: micro (less than 10 employees), small (less than 50 employees), medium (less than 150 employees) and large (more than 150 employees).

(**) Self-declared by companies interviewed.

4.3. Mapping Argentinean KIMS: in which supplier markets do they (not) participate

The analysis is based on the identification of Argentinean KIMS that participate in mining supplier markets in the exploration, construction and production stages of the Argentinean metal mining value chain (Table 3). Results show that domestic KIMS participate in *Type I* and *Type II* supplier market-types. That is, Argentine KIMS have succeeded in starting to provide standardised products and services to consolidated markets and customised goods and services to local-specific mining conditions. We did not find Argentine KIMS that have taken advantage of new technologies to create new solutions to previously unresolved or new problems of the mining industry, as was found in other mining countries such as Australia, and to a lesser extent in Chile (Scott-Kemis 2013, Stubrin, 2017). Thus, we could not identify any domestic company supplying markets Type III.

Table 3 - Argentine KIMS' participation in mining supplier markets of the metal value chain in Argentina

Type of mining supplier markets	Type of Supply	Market	Do local KIMS cater to this MSM?	Argentine KIMS (* interviewed)
Type I	Services	Core Sample Analyses for mining exploration and production activities	No	
		Heavy machinery's maintenance & repair	Yes	Balderramo*, Indumet*, Jaime*, Acer, BS, Minoli, Talleres Dominguez, Zecin

	Products	Heavy machinery's and equipment's parts for exploration and production	Yes	Inbelt*, Metalar*, Acindar
		Chemical products for mining	No	
		Heavy machinery, topography and spectrometry equipment for exploration and production	No	
Type II	Services	Geological, geophysical, remote sensing & topographical services for mining exploration and production	Yes	AMINCO*, DAMS*, HytecAltoAmericas, Consultores GIS, Supraimagen, DronXplora
		Hidrological, satellite images & environmental studies for mining exploration and production	Yes	HidroAR*, Kgori Punku, Consultores GIS
		safety-related services	Yes	MineTech*, Tecin

		Drilling, earthworks and core sampling	Yes	Ecominera*, Perforaciones Santacruceñas*, Hidrotec*, AGV*, Andina Perforaciones
		Engineering & Construction	Yes	BTZ*, Di Bacco*, Techint, Benito Roggio, Panedle, CINTER, Burgwardt, Grupo IMPO, Cartellone, Milicic, Ruiz & Asoc, GeoPetrol
	Products	Heavy machinery and equipment's parts	Yes	Acerias 4c*, Kousal*, Saeta*, Indumet*
Type III	Services		No	
	Products		No	

Argentine KIMS caters to *Type I* supplier markets by providing parts and reparation and maintenance services for heavy machinery. Standardised maintenance services to heavy machinery are provided by around ten small and medium-sized companies with metal-working capabilities and a long history of supplying other sectors in the country. Some of them were founded in the 1950s, started as suppliers to other industries (agricultural machinery, oil&gas) and have recently diversified into mining. Much less Argentine companies, however, have been identified supplying equipments' parts. These are very specialised companies. For example, the firm *Inbelt*, which has a strong knowledge base on the use of rubber and steel working, supplies spare parts for mills, such as mill linings and wear plates. *Metalar* produces bushings for crushing mills, stone crushing mantles and parts for vacuum pumps. *Acindar* supplies mill balls.

It should be noticed, however, that Argentine KIMS are not present in all *Type I* markets, but in some of them. They do not participate in market segments such as "Core Sample Analysis services for mining exploration and production activities", "Heavy machinery and other mining equipment" and "Chemical products for mining", which are entirely provided by multinational companies.

The majority of Argentine KIMS participate, however, in *Type II* markets

supplying a wide range of services which require a great deal of idiosyncratic knowledge and heavy equipment's parts adapted to local conditions. Small specialised domestic KIMS have developed by offering knowledge-intensive services, such as geological, geophysical, topographical, hydrological and environmental studies services, to large mining houses and first-tier suppliers that lack these capabilities in-house within the country. The most developed company is *Hidroar*, a service provider specialised in hydrology, environmental impact and remediation services. This knowledge-based company was created in 1981 by researchers from the National University of La Plata. The company started supplying environmental and hydrogeological studies services to the mining sector. Their first work consisted of identifying water sources for the Cerro Vanguardia project, one of the most relevant mining sites in the country. Since then, it has specialised in the identification of water sources and the engineering to transfer the water to the mine particularly for the Patagonia region.

Some KIMS have also emerged providing safety-related services. The owner of one of such companies, *MineTech*, asserted how they took advantage to innovate in a tailor-made solution in this market: "We have built the first rescue capsule adapted to local conditions". Other Argentine KIMS in *Type II* markets offer drilling services. These KIMS tend to be medium to large companies that carry out R&D activity to adapt drilling equipment to local rock, climate and geographic characteristics of Argentine mine sites. These KIMS are knowledgeable of the mine sites' characteristics (high altitude, very low temperatures, types of rocks) and also socio-cultural practises. Usually drilling service providers adapt their equipment, bought from international suppliers, to work in the local extreme climate and conditions or at high altitudes. The company *Hidrotec*, which started providing drilling for water wells and then entered also the lithium value chain, illustrate this clearly:

"There is equipment that is standard. With the experience we have, instead of struggling with the standard equipment that was produced for somewhere else in the world but does not work well here, we adapt it to the local climatic conditions and to the operational and sociocultural level of the operators here. We modify everything so that it is more effective to use here and perform better. Many things are related to security requirements that are local. It can be something simple or more complex which is not required by security standards in India or Brazil. Here we elevate the standard of security. Even modifying a rig so that it drills with 25°C".

Another example of a domestic KIMS in tailor-made markets is *Eco Minera*, a comprehensive provider of drilling-related services and an industry leader founded in 1995 with 700 employees. The company provides drilling, earthmoving and mine construction services to mining sites in Argentina. It competes with both domestic and multinational firms by being able to adapt

the drilling service to the characteristics of the local terrain, also making changes in standard machinery. The company has even developed a metalworking department internally that takes care of equipment adaptation.

Other market segments where tailor-made products are developed are that of equipment for large machinery, where domestic KIMS with metalworking capabilities (Acerias 4c, Kousal, Saeta, Indumet), many of which started providing standardised services or parts, have started to develop adapted large machinery parts.

4.4. Argentine KIMS' strategies to overcome supplier markets' barriers: a discussion

In this section we discuss the meso and micro-level barriers that Argentine KIMS faced to enter mining supplier markets, and the strategies they pursue to overcome such barriers (if so). We use the proposed taxonomy of markets to structure the analyses.

We distinguish between market barriers and firm capabilities' barriers.

Market barriers refer to those factors that are external to the firm and affect its opportunities to entry and cater a mining supplier market. They encompass: inertia in mining firms' purchasing policies to acquire inputs from incumbents, mining firms' risk aversion to try new products/services or buy from previously unknown suppliers, mining firms's lack of long term contractual commitments with newcomers, asymmetric information regarding mining firms' demands and needs, economies of scale, long history of user-producer linkages and established standards, prices and innovation paths set up by incumbents.

Firm capabilities' barriers are of four types: investing in production capabilities (equipment, plants, testing benches), acquiring idiosyncratic knowledge about the local specificities that negatively affect the performance of mainstream supplies (i.e. reducing their efficiency), access to frontier knowledge by means of investing in R&D, and obtaining non-technological capabilities needed to enter the mining value chain such as developing managerial skills to negotiate more effectively with mining firms.

Based on research results we classified market and firms' capabilities barriers into high, medium and low. Barriers are considered to be high when domestic firms find enormous difficulties to meet the firm-level or industry-level requirements imposed to participate in the market. Barriers are considered to be medium when, even being significant, firms can more easily deploy strategies to overcome them. And low when they tend not to be significant (Table 4).

Table 4 - Argentine KIMS' market and firm capabilities barriers in different miningsupplier markets

Types of barriers	Supplier market Type I	Supplier marketTypeII	Supplier marketTypeIII
	Market barriers		
Inertia in mining firms' purchasing policies	<i>High</i>	<i>Medium</i>	<i>Low</i>
Mining firms' risk aversion	<i>High</i>	<i>Medium</i>	<i>High</i>
Mining firms' lack of long term contractual commitments with newcomers	<i>High</i>	<i>Medium</i>	<i>High</i>
Asymmetric information regarding mining firms' demands and needs	<i>Low</i>	<i>High</i>	<i>High</i>
Economies of scale	<i>High</i>	<i>Low</i>	<i>Low</i>
Long history of user-producer linkages	<i>High</i>	<i>Medium</i>	<i>Low</i>
Established standards, prices and innovation paths set up by incumbents	<i>High</i>	<i>Medium</i>	<i>Low</i>
	Firm capabilities' barriers		
Investment in production capabilities	<i>High</i>	<i>Medium</i>	<i>Medium</i>
Idiosyncratic knowledge capabilities	<i>Low</i>	<i>High</i>	<i>High</i>
Frontier knowledge	<i>Medium</i>	<i>Low</i>	<i>High</i>
Market-creation capabilities	<i>High</i>	<i>Medium</i>	<i>High</i>

We discuss market and firm level barriers that Argentine KIMS' faced that helped to understand their participation in the metal mining value chain.

Inertia in mining firms' purchasing policies and mining firms' risk aversion are key barriers that Argentine KIMS needed to overcome. As the literature has pointed out, mining is a conservative activity. Mining firms are usually reluctant to adopt or buy untested solutions, or innovations coming from new suppliers, as they prefer to avoid the possible cost of a failure. Firms interviewed deployed three types of strategies to address such barriers: acquire previous reputation, prove the effectiveness and quality of their solutions beforehand, and being flexible and able to respond rapidly to mining firms' demands.

Having catered other sector or another firm within the industry, has been a powerful factor for Argentine KIMS to reduce prevailing risk aversion. 15 out of 19 KIMS interviewed have participated in a wide range of related and unrelated sectors before entering the mining value chain, such as other extractive activities (such as oil & gas), the agricultural machinery sector (metalworking knowledge bases) and other traditional natural resource-based sectors (food, sugar cane, pulp and paper) (Table 5). This previous experience was a key enabler, for example, for Argentine KIMS to participate in tenders organised by mining houses.

Interestingly, the mining industry represents for firms that are already suppliers to other sectors, an opportunity for diversification. That is, Argentine KIMS have taken the opportunity to use their knowledge bases and productive capabilities to migrate to mining.

For example, all metalworking firms that provide services and parts for heavy machinery have previous experience in providing services and products to other sectors. For these firms, mining represented between 50% to 70% of their total revenues in 2019.

For some Argentine KIMS having provided inputs to first- or second-tier suppliers has also proven to be a useful strategy to gain both expertise and visibility within the value chain.

Comments from the engineering company *Di Bacco* illustrate this type of entry:

We started making attempts everywhere, until finally we started with the Chilean company Orica, a first-tier supplier in charge of making the explosives plant that was going to supply the mine. Based on our work, when an Australian official from the mining company saw what we had done, he gave us a very big vote of confidence: he called us to do an expansion of the mine. That was something completely atypical, to the point that we were audited by the owners of La Alumbrera, who were from Canada, Australia, and Switzerland (in the years 2001 and 2002). The reason was that he saw that there

was a technical capacity and he was able to overcome the prejudices that existed. As he said, 'if these people are capable of solving these problems, they have to be able to solve these others.' This was a very strong milestone that installed us in the mining world and opened doors to other operations. We were suppliers and accessed other parts of the company.

The metalworking company Balderramo, specialises in repairing engines for large machinery, reduced mining firms' risk aversion by complementing its previous proven experience in repairing engines for heavy equipment for agriculture and construction, with its own capabilities to test the effectiveness of their work in-house. It has developed its own testing bench, used to prove the effectiveness of the engines' reparation before putting them into operation in the mine.

Table 5 - Previous participation of Argentine KIMS interviewed in other industries and share of sales to the mining industry over total revenue

Type of mining supplier markets	Type of Supply	Market	Argentine KIMS' name	Other markets catered before entering into the mining value chain	Sales to the mining industry over total revenues (Year 2019)
Type I	Services	Heavy machinery's maintenance & repair	Balderramo	Building, Agricultural activity	> 50 %
			Jaime	Food industry	> 50 %
			Indumet	Food industry	> 50 %
	Products	Heavy machinery's and equipment's parts for exploration and production	Inbelt	Port industry	> 50 %
			Metalar	Sugar industry	<50%
Type II	Services	Geological, geophysical, remote sensing & topographica	Aminco		100%

		I			
		services for mining exploration and production	DAMS	Limestone mining	> 50 %
		Hidrological, satellite images & environmental studies for mining exploration and production	Hidroar	Oil & Gas, Environmental Impact Services	<50%
		Safety-related services	MineTech	Energy; Oil & Gas	> 70 %
		Drilling, earthworks and core sampling	Perforacione sSC		100%
			Ecominera		100%
			AGV Falcon Drilling	Quarries mining	> 50 %
			Hidrotec	Water service	> 50 %
		Engineering & Construction	BTZ Minera		<50%
			Di Bacco	Sugar industry, lemon sector	<50%

	Products	Heavy machinery and equipment's parts	Acerias 4c	Agricultural machinery, Oil & Gas, railway industry	<50%
			Kousal	Sugar cane, pulp & paper, fruit industry	<50%
			Saeta	Heavy machinery repairs for several industries	<50%
			Indumet	Food industry	> 50 %

High risk aversion was also overcome by Argentinean KIMS through taking advantage of being close, flexible, and able to provide a rapid response to mining firms' needs. The metalworking firm *Indumet*, which started as a supplier to Finning (Caterpillar's official parts provider), was for a long time unsuccessful in trying to supply directly to mining firms but managed to enter the value chain by taking advantage of two crisis situations. First, the mining company *Barrick Gold* had a technical problem that stopped the plant. *Indumet* managed to quickly and effectively fix the problem, and *Barrick Gold* noticed the company. Then, there was a major cyanide leak at the *Barrick Gold's* Veladero mine in San Juan province, and *Indumet* managed to quickly and effectively produce a set of tubes and connectors for a specific type of tank that stopped the leak. In doing so, *Indumet's* owner interacted (at the time unknowingly) with the head of maintenance of *Barrick Gold*, and the relationship changed drastically, and the volume of work *Indumet* did for *Barrick Gold* increased exponentially. *Indumet* has then become one of the few firms with a long-term maintenance contract with this mining company, having its own facilities at the mine. The contract with *Barrick Gold* had a key signalling effect for the supplier within the industry: other mining companies started hiring *Indumet* due to its good reputation in the industry.

The following statement from the owner of *Indumet* summarise the events:

“San Juan province is far from everything. That’s a big disadvantage, but it also creates opportunities for us who are here. The response to a broken machine is very slow if you have to go, for example, to the United States and come back. And we are here. And that’s what happened: at one point a machine broke down and the plant stopped. And as a matter of urgency they asked the head of general maintenance within the mine who could repair it. The head of general maintenance came. When he arrived, he saw the company and the components that we supplied to Finning. They didn’t know that we supplied *Finning*. He ended up asking us why we didn’t work with them. I replied that we would like to work with them, that we had gone a thousand times, and we couldn’t enter. When that happened, they made the decision to stop working with *Finning*, and hire us directly”.

Reducing asymmetric information was another relevant market barrier for Argentine KIMS, particularly in supplier markets Type II, in which domestic firms need to get to know which are the demands and needs of mining houses, so as to develop adapted solutions. This information is not easy to obtain for an outsider, and formal mining firms’ purchasing mechanisms, as tenders, tend not be an effective way to communicate such types of needs. Previous studies indicate that more relevant, but more difficult to access to, are informal mechanisms such as face-to-face interactions to mine operators (Stubrin, 2017). Special initiatives, such as World Class Supplier Program (WCSP) in Chile, which aim was to encourage the development of local KIMS, aimed at reducing this market barrier by enforcing an innovative mechanism to communicate mining firms’ needs (Korinek, 2013; Barnett and Bell, 2011).

In Argentina, the only antecedent of reducing such barrier-type through a formal mechanism was a hackathon organised by *Barrick Gold* in 2017. This event provided the firm DAMS, whose knowledge base is related to topography and geophysics, with a great opportunity to enter the mining value chain. Getting to know *Barrick Gold*’s problem of locating the surplus gold from the leach valley, the firm developed a geophysics method using thermal sensors and drones to determine sectors with gold in the valley. This case, however, is an exception. In the absence of more systematic and comprehensive programs or initiatives that connect mining firms’ problems with potential suppliers, Argentine KIMS had to deploy very proactive strategies to overcome this market barrier, attempting to set up meetings with mining companies.

In most cases Argentine KIMS got to know mining houses’ needs and demands once they became providers of *Type I* supplier markets. According to Argentine KIMS interviewed, being allowed to enter the mine site enriches their opportunities to find out about mining firms’ requirements and needs, which they can then attempt to fulfil. The metalworking company *Indumet*, for

example, first took advantage of being able to respond rapidly to a mining house problem to start providing standardised heavy machinery maintenance and repair services. Then, once already a supplier, through conversations with mining company's technical personnel, to obtain feedback and discuss technical matters, they moved to provide also a MSM Type II, by innovating in adapted machinery parts. To convince the mining house to take the risk to try the solution, the company pursued a creative strategy: "For *Barrick Gold* we developed a component for a machine, we modified it with respect to the original. We told them to pay us if the product lasted longer than the original one. And it lasted almost three times as long. Then they began to buy that product from us".

Even when Argentine KIMS have succeeded in entering *Type I* and *Type II* market supplier markets, there are several market barriers that still persist which ban entry and participation of further local suppliers in mining supplier markets.

Potential newcomers to consolidated markets (*Type I*) still strongly face market barriers associated with attaining economies of scale, mining firms' brand loyalty to incumbents associated with a long history of user-producer relations, and the enforcement of established standards, prices and innovation paths set up by incumbents. As shown in Table 3, there are three market segments of *Type I* which are not supplied by local KIMS: services for core sample analyses, provision of heavy machinery and specialised equipment for mining exploration and production and chemicals. These markets are entirely served by multinational companies. Core sample analysis is a knowledge-intensive key task during exploration as it provides reliable estimates of the size, quality and value of mineral deposits beneath the ground. Having an internationally certified sample analysis is key for a mining company's credibility to start an exploration project, e.g. to obtain financing in the stock market. Even if a domestic KIMS develops the capacity to prepare a high-quality sample analysis, the chief entry barrier lies in their international reputation. Mining and exploration companies rather not run the risk of relying on a new-comer to provide such critical input. In Argentina, laboratories performing such services are foreign, even though they do take advantage of local capabilities in laboratory analysis, as Argentina has strong capabilities in chemistry and biological sciences.

The heavy mining equipment and machinery market imposes to newcomers huge entry barriers associated with economies of scale and a high level of investment needed to compete in this sector, which are difficult to attain by local companies that could have the technological capabilities to participate. However, in the mining machinery's spare parts markets, which certainly demands low investment levels, and where some Argentine KIMS have succeeded in participating, incumbents enforce practices that prevent more new entrants. As argued by an employee of a mining company in Argentina, "a procurement manager of a large mining company never gets fired because of

buying Caterpillar, but if he decides to buy from local firms and something fails, he is responsible.” This sort of defensive behaviour generates an “inertia” that hinders the participation of domestic companies, even when they do have the capabilities to provide the mining machinery’s spare part market. Hence, in Argentina there are long-standing supplier sectors that provide heavy machinery (trucks, seeders, harvesters) and spare parts for agriculture⁸, the automotive and the oil&gas sectors that do have technological capabilities to also cater the mining industry (Marin et al, 2022).

Interestingly, policy has been helpful to reduce some of the above entry barriers for Argentine KIMS in standardised and consolidated supplier markets (*Type I*). Macroeconomic imbalances have triggered the Argentinean government to implement temporal restrictions to imports in the last two decades which, in turn, had impeded mining houses to have access to critical inputs from global suppliers. These situations have forced them to look for local alternatives, generating opportunities for domestic KIMS. Several metal-working companies producing machinery’s parts, such as *Di Bacco*, *Kousal*, *Metalar*, and *Saeta*, entered the mining industry through these policies. However, this initiative opened a window of opportunity for local companies to enter the mining value chain which is temporary by nature. This window drastically reduces when imports’ restrictions cease, and prevailing market entry barriers arise again. The owner of the metalworking *Saeta* described this situation clearly:

“We began by developing drill rotation heads for *Barrick Gold*. At the time, there was a lot of pressure to develop local products, which was when imports were limited. Then, there were monthly meetings with the National Ministry of Industry. At these meetings there were suppliers and there were buyers, like *Barrick Gold* which was asked to sign a commitment to buy locally. Then they gave us a previously imported product to develop. We spent 16 months doing that development. We worked with INTI [*National Institute of Industrial Technology*] and a local university. Beyond reverse engineering, we were able to make a modification to the product so that it did not break anymore. And we were able to sell five boxes of those. They also gave us a *Caterpillar* fan to replicate. We completed it in over six months. It was manufactured and also, we introduced some improvements to the original. All the fans that *Caterpillar* makes in the world are manufactured in the United Kingdom. It was the first time that one of those was manufactured elsewhere, and not by *Caterpillar*. It was successful, they tested it, it worked very well. We sold 18 in the last few years—essentially nothing—but mining products are like that. At that time, it was a good business for us. Today, our product would be more expensive than the one they can import”.

Our empirical findings suggest that contractual arrangements between mining houses and Argentinean KIMS also enforce a market barrier for the latter to participate in supplier markets. Short-term and instability of contracts with newcomers makes it difficult for local KIMS to plan investments to build productive and technological capabilities. For *Type I* supplier markets, local KIMS providing services typically become mining suppliers by winning tenders. The length of the contract can vary from weeks to several years. Renewal of the contract is, however, always uncertain, and being the potential new contract for a period radically different from that of the original one. The case of the metal fabricator *Jaime* illustrates this issue. The supplier signed a contract with the mining house *Barrick Gold* to repair blades at the Veladero project for three years. To provide the service, Jaime invested in three specially equipped trucks and hired personnel to be housed at the mine site to do the repairs in situ when needed. After the first three-year contract expired, the contract was renewed every 30–60 days at most. This situation generates a great deal of uncertainty for the local supplier, giving it the feeling of having “one foot inside and one foot out,” as the manager of the local company asserted.

Argentine KIMS supplying products in *Type I* and *Type II* supplier markets were offered purchase orders-contracts. Typically, these contract-types establish the maximum amount of a certain product that the mining firm would purchase from a supplier during a certain period. During the term of the contract, Argentine KIMS had to be able to deliver such an amount any time the mining firm required. To do so, local KIMS usually needed to make specific investments in machinery, purchase specialised inputs and even hire extra personnel. However, purchase orders are a very unbalanced type of contract because mining companies have the right to buy all, some, or none of the items specified in the contract. This type of arrangement can be highly problematic for small firms, which usually lack the financial resources and may lack the managerial skills to successfully deal with this type of contract. As the manager of a metalworking firm asserted, “I cannot invest 6 million Argentine pesos in new machinery if the mining firm does not guarantee to purchase.”

A third type of business arrangement has been used by mining companies when mining firms first approached a local supplier asking for a specific or tailor-made solution. The procedure has been typically the following: mining companies specified the problem or provided a blueprint of the product that aimed to be replicated or improved by the local supplier. After making explicit their demands, mining houses did not participate further in the development of solutions neither providing technical assistance or even financing the developments. Argentine KIMS made the necessary investments and used their own capabilities to develop the solutions, which were only purchased by the mining firms when they fulfilled the required standards of the industry and were cost-effective. This type of agreement was settled, for example, with the Argentine metalworking company *Saeta* between 2010 and 2014. This supplier

developed a range of 480 products of different levels of technical complexity. The agreement entailed that in the case that the quality, costs and time-to-market of products were accepted by the mining companies, *Saeta* would be prioritised as a supplier. However, this type of agreement entailed that Argentine KIMS incurred in investments and costs that could not then be recovered, as the mining houses only bought little units of these products.

Finally, potential newcomers to *Type III* mining supplier markets can certainly rely on their knowledge bases on emerging new technologies (biotechnology, ICT, robotics) as platforms to develop innovative products and services. However, firm level technological capabilities required to create this type of market are high, and so are the challenges associated with the discovery of a new solution and the resources involved in market creation. KIMS aiming at participating in *Type III* markets, are affected in a similar way than KIMS that target *Type I* market segments, by meso-level barriers such as mining firms' high risk aversion to try new solutions and lack of mining houses' commitment to long-term contracts with newcomers. Also, similarly to KIMS aiming at *Type II* markets, companies that intend to participate in *Type III* markets are faced by the difficulties of identifying mining industry's needs and demands. At firm level, firms' access to venture capital as well as having spaces of experimentation to transform prototypes into proven solutions to be commercialised are also especially acute barriers to develop world-class innovations by newcomers.

5. Implications for industrial policy and development

In this paper, using Argentine KIMS' empirical evidence, we analysed the meso- and micro-level factors that favour and also deter mining linkages. Special emphasis has been placed on understanding how such factors vary across mining supplier markets and what type of strategies can be deployed to overcome them. Our empirical results suggest important implications for industrial policy.

One very important lesson derived from our results is that policy efforts directed to support mining linkages need to address a combination of different firm- and industry-level challenges across supplier markets. We have distinguished three types of markets, each of them possessing a diverse set of entry barriers associated with firms' capabilities and market configuration. Our understanding is that, from the policy perspective, there is an overemphasis on providing support to firms' technological capabilities while specific market barriers are less attended. Our empirical results suggest, however, that these two types of barriers need to be distinguished and approached together when designing and implementing policies. Exclusive focus on technological and production capabilities, if specific market barriers are not attended, will make policies less effective.

Domestic KIMS which achieve the minimum threshold of firm level capabilities to attend *Type I* supplier markets, would need support to deal with limitations derived from the lack of scale economies. They might have production and technological capabilities and reputation, however with a small market to serve, they are not able to reach the efficiency required to be cost-competitive. Initiatives oriented to help these firms to gain scale through, for instance, cooperation between client firms are, therefore, crucial. Through cooperation between mining houses, the risk and costs associated with developing local suppliers can be shared. A complementary strategy can be to set up a strategy to help these firms take advantage of economies of scope (Kaplan, 2012). Domestic KIMS aiming to enter these types of markets need support also to be able to negotiate with mining houses, since in these types of markets resistance to change is particularly significant, given the huge risks of changing suppliers.

For newcomers to *Type II* markets, it seems crucial to work with the clients, so that their needs, demands and requirements are acknowledged. Policies should mostly be focused on facilitating first contacts and exchanges between the mining houses and the domestic firms. These kinds of initiatives have been implemented in Chile, but with limited results. (Korinek, 2013; Barret and Bell, 2011; Navarro, 2018). Our results suggest that collecting and sharing information about the existing and potential suppliers, in relation to their capabilities and trajectory in other industries, can help to develop trust among clients softening related barriers such as inertia in purchasing policies and high risk aversion of mining houses. Meso-level policies of these kinds should, however, be complemented with others that focus on firm level capabilities' barriers. Small and medium-sized companies that tend to harness opportunities to participate in *Type II* markets, need also support to develop not only technological capabilities but also managerial and organisational ones. The latter ones are especially crucial for firms to more easily expand and eventually internationalise within the mining value chain.

For newcomers to *Type III* markets, technological and innovative capabilities required are certainly high, and so are the challenges associated with the discovery of a new solution and the resources involved in market creation. Public investments in the development of scientific and technological knowledge in selected areas, such as artificial intelligence, biotechnology or robotics, are particularly relevant for the creation of emerging supplier markets. However, in this type of market policy emphasis should also be on other types of complementary and crucial barriers. At meso-level, for instance, generating mechanisms that induce mining companies to reveal their demands and needs is also key. Mining houses should also be encouraged to cooperate with local KIMS in providing support for the development of the new products and services, or, at least, make longer-term commitments with KIMS, as investments are particularly risky in this type of market segment. For instance, supporting the creation of experimentation facilities can be especially helpful for new

entrants to have the chance to test and experiment with the new solutions. In addition, firm level support to create non-technological capabilities needed to create new markets such as master regulations or property right issues are also paramount.

Finally, results suggest that policies oriented to foster the spring of KIMS, and mining suppliers more broadly, should be connected with overall industrial policy design. We envisage two ways. One is related to identifying opportunities for horizontal migration of knowledge, which, in turn, could contribute to a more diversified economy. As the Argentinean case points out, metalworking companies that have traditionally provided other sectors, such as food and oil&gas, could capitalise on their reputation and previous technological and productive capabilities to start supplying the mining sector. Industrial policy can focus on assessing the potential of firms' horizontal diversification, and address firm- and industry-level barriers that can be blocking such opportunities. A second, and complementary industrial strategy, is adopting a more dynamic approach to support mining linkages. That is identifying the areas of technological opportunity and the potential markets that can be created, and promoting the development of new technological capabilities for domestic firms to participate in supplier markets *Type II* and *Type III*.

Finally, our results suggest that to improve our comprehension of why mining linkages are not evolving at scale in a sustained way and identify policy opportunities for more effective interventions, further research that jointly analyses macro-, meso- and micro-level factors affecting mining linkages is needed.

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Notes

¹ Argentina ranks top three globally for lithium and 11th for copper and gold. Argentina's lithium brine deposits hold the world's second largest lithium resources base (after Bolivia) and the third largest reserve base (after Chile and Australia).

² It is estimated that 65 % of the areas with high mining potential have not yet been assigned mining rights for exploration

³ Provincial companies involve companies of recent creation to capture part of the economic rent (and with a small internal structure) such as JEMSE (Jujuy), REMSA (Salta), CAYMEM (Catamarca), etc. and older ones such as FOMICRUZ (Santa Cruz). National state-owned (fully or partially owned) ones are Yacimientos Carboníferos de Río Turbio and YMAD, a mix Company owned by the national state and provincial state.

⁴ <https://www.argentina.gob.ar/produccion/argentina-productiva-2030/misiones-argentina-productiva-2030/>

⁵ Mining companies interviewed were Barrick Gold (located in San Juan province), Goldcorp (located in Santa Cruz province), Minera Santa Cruz (located in Santa Cruz province), Fortuna Silver Mines (located in Salta province) and Aldebaran, a junior company (located in San Juan province).

⁶ National Mining Secretariat, San Juan Province Ministry of Mining, Santa Cruz Province Ministry of Mining, Salta Province Ministry of Mining, Federal Mining Council, Argentine Geological Mining Service (SEGEMAR) and Argentine Institute of Nivology, Glaciology and Environmental Sciences (IANIGLA).

⁷ Cámara Argentina de Servicios Mineros (CASEMI), Cámara de Proveedores Mineros de Santa Cruz (CAPROMISA) Cámara Minera de San Juan (CMSJ) and Asociación de Empresas Mineras Exploradoras de Argentina (GEMERA).

⁸ The Argentinean agricultural machinery sector is composed of 1202 companies, 98% of national capital which produce tractors, harvesters, seeders, sprayers and other machinery implements such as harvesting heads, hoppers, bagging machines and extractors. The sector caters both the domestic and foreign markets. Exports are concentrated on Latin American countries such as Brazil, Paraguay and Uruguay (IERAL, 2019).

How do global south firms engage in pharmaceutical innovation networks? Lessons from Brazil.

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Abstract:

Pharmaceutical innovation relies on dense networks for accessing external knowledge and complementary assets. Firms in the global south, like Brazil, engage in pharmaceutical activities using copying and incremental innovation strategies. However, they face global technological disparities, barriers to entry, and imbalanced power relations. This study analyses Brazilian firms' involvement in pharmaceutical innovation networks using Social Network Analysis (SNA) on a sample of 398 life science deals from 1974 to 2020, obtained from the Cortellis Deals Intelligence database. The analysis highlights three key features: (1) imbalanced international and domestic linkages, (2) incomplete domestic network reflecting challenges in building national capabilities, and (3) the impact of Brazilian public policies on network evolution. The paper proposes strategies for better engagement in pharmaceutical innovation networks from a global south perspective.

Keywords: Pharmaceutical; Innovation; Networks; Global South; Health; Brazil.

1. Contextualization

The academic literature on pharmaceutical innovation highlights the emergence of a complex global network that involves strategic alliances, equity operations, and contractual relations to access external knowledge and complementary assets. This network has shifted the locus of innovation from the individual firms to the network, where innovative labour is divided among participants (Malerba and Osenigo 2015; Arora and Gambardella 1995; Orsenigo et al. 2001; Gravaglia et al. 2006; Vornotas 2009; Malerba and Vonortas 2009; Powell and Grodal 2005). While networking plays a crucial role in supporting pharmaceutical research, development, and innovation (R,D&I) (Arora and Gambardella 1995; Gravaglia et al. 2006; Orsenigo et al. 2001; Malerba and Osenigo 2015; Malerba and Vonortas 2009), it is essential to avoid simplistic "the more, the merrier" assumptions (Dong and McCarthy 2019). Instead, understanding the agreement types and governance structures within pharmaceutical social networks is critical for comprehending knowledge dynamics and the inherent power imbalances in these networks (Malerba and Vonortas 2009; Rikap 2019), particularly from a global south perspective.

Innovation networks are often seen as a spontaneous outcome of firm-level decisions, leading to positive feedback and self-reinforcing dynamics (Malerba and Vonortas 2009; Arora and Gambardella 1995; Vornotas 2009; Kogut 2000). However, industry-specific factors such as barriers to entry and hierarchical relationships also shape network formation (Malerba and Vonortas 2009; Rikap 2019; Vornotas 2009). Historical trajectories of industries and dominant technological regimes shape networking and steer the direction of technological changes (Malerba and Vonortas, 2009).

In pharmaceuticals, coevolution and self-reinforcing dynamics have reshaped the industrial organisation of activities involving chemical and biotechnological routes (Malerba and Osenigo 2015). Numerous changes stem from the crisis in pharmaceutical innovation, amplified by a heavily financialised environment (Mazzucato and Li 2021; Montalban and Sakinç 2011). The average worldwide cost of R,D&I for developing new pharmaceutical compounds has notably risen from USD\$1.19 billion in 2010 to USD\$2.51 billion in 2020 (Deloitte 2022). Despite this increased R,D&I investment, the introduction of new molecular entities (NME) to global markets have not seen a proportional increase, prompting concerns about the long-term viability of the pharmaceutical business model (Malerba and Osenigo 2015; Schuhmacher et al. 2016).

Moreover, firm-level decisions are increasingly influenced by short-term financial strategies, focusing on maximising shareholder value and boosting company stock prices, often at the expense of productive and innovative

investments (Mazzucato and Li 2021; Montalban and Sakinç 2011). Consequently, large pharmaceutical companies are downsizing their in-house corporate R,D&I facilities and outsourcing different technological and manufacturing services to reduce R,D&I costs while enhancing profitability and flexibility (Mazzucato and Li 2021; Malerba and Osenigo 2015; Schuhmacher et al. 2016; Balconi and Lorenzi 2017; Zirulia 2009).

The rise in outsourcing deals (Balconi and Lorenzi 2017; Schuhmacher et al. 2016) and the emergence of pharmaceutical innovation networks (Malerba and Osenigo 2015; Arora and Gambardella 1995; Orsenigo et al. 2001; Rikap 2019) have coincided with the entry of new firms from emerging global south countries like Brazil, India, and China in pharmaceutical activities (Lavarello et al. 2021; Rezaie et al. 2012; Rezaie and Singer 2010; Paranhos et al. 2020). These companies from the global south primarily focus on generics and me-too drugs (Lavarello et al. 2021; Rezaie et al. 2012; Rezaie and Singer 2010) and offer technological and manufacturing services (Balconi and Lorenzi 2017; Schuhmacher et al. 2016) to global leading corporations (Rikap 2019; Montalban and Sakinç 2011; Mazzucato and Li 2021).

While research on pharmaceutical innovation networks has advanced (Arora and Gambardella 1995; Orsenigo et al. 2001; Powell et al. 1996; Depret and Hamdouch 2000; Pyka and Saviotti 2002; Puig 2004; Tijssen 2009; Okamura and Vonortas 2009) and their power dynamics have been explored (Rikap 2019; Vornotas 2009), there's still an academic void regarding the involvement of firms from global south nations in these networks. This article addresses this gap by examining the Brazilian perspective and offering potential insights that may apply to other global south countries.

The study analyses the engagement of Brazilian firms and institutions in pharmaceutical innovation networks, with a particular emphasis on comparing the structural characteristics between domestic and international networks and dynamic changes over time. Additionally, the research draws insights from the Brazilian context to reflect on pharmaceutical innovation networks from a global south standpoint.

The article follows a structured approach with six main sections. The first introduces the study's background. The second offers a thorough literature review. The third outlines data collection and methodologies. In the fourth, study findings are presented. The fifth provides an in-depth discussion of the results. Lastly, the sixth section explores implications for the global south, drawing lessons from the Brazilian experience.

2. Pharmaceutical innovation networks

In pharmaceuticals R,D&I, as with other knowledge-intensive endeavours, scientific and technological advancements occur rapidly. Knowledge-intensive

assets are scattered across different sources, and the knowledge base supporting R,D&I processes is ever-changing and encompasses multiple disciplines. Given this dynamic landscape, it is unlikely that individual firms possess the complete set of skills and resources required to excel in multiple application areas (Orsenigo et al. 2001; Arora and Gambardella 1995; Zirulia 2009)

The necessity to access external knowledge, financial resources, and complementary assets has led to the formation of a dense network connecting pharmaceutical companies, new biotechnology firms, universities, and public laboratories (Malerba and Osenigo 2015; Arora and Gambardella 1995; Gravaglia et al. 2006; Zirulia 2009). These pharmaceutical networks encompass links and governance arrangements, such as research collaborations, public-private partnerships, joint ventures, mergers and acquisitions (M&A), strategic alliances, and subcontracting deals. As a result, complex, cumulative, and collective learning processes take place within these networks (Malerba and Osenigo 2015; Balconi and Lorenzi 2017; Schuhmacher et al. 2016; Arora and Gambardella 1995; Malerba and Vonortas 2009). Pharmaceutical companies opt for specific schemes based on transaction costs, asset tradability, and their absorptive capacity to effectively select, transfer, appropriate, apply, and utilise the knowledge acquired from external sources (Arora and Gambardella 1995; Teece 2010).

Pharmaceutical networks are part of a global trend reorganising production and innovation across sectors. Companies outsource tasks to global south countries for cost advantages, while knowledge-intensive activities remain in global north countries, amplifying technological asymmetries and socioeconomic inequalities (Antonelli and Tubiana 2020). The disintegration of production and innovation requires knowledge exchanges and global coordination, leading to knowledge spillovers benefiting potential competitors (Durand and Milberg 2019). The tradability of intangible assets depends on knowledge modularity and appropriability, potentially leading to global monopolies (Pagano 2014; Durand and Milberg 2019). Managing knowledge flows in the pharmaceutical industry is crucial, given the impact of global trends on pharmaceutical innovation.

Knowledge monopolies are crucial in explaining how certain global pharmaceutical corporations consistently lead innovation races (Rikap 2019; Pagano 2014). By reinvesting in R,D&I, these firms establish knowledge monopolies due to the cumulative nature of knowledge and their dynamic capabilities in accessing and leveraging external knowledge assets (Rikap 2019; Antonelli and Tubiana 2020; Teece 2010; Zirulia 2009). This reinforces barriers to entry and strengthens their ability to profit from innovation rent, whether efforts are conducted internally or externally (Rikap 2019).

Leading pharmaceutical companies strategically form innovation circuits to access external knowledge and resources, outsourcing specific tasks to various entities like Contract Research Organizations (CROs), Contract Manufacturing Organizations (CMOs), universities, and research institutions. However, they retain a dominant share of innovation benefits due to existing technological and financial asymmetries. Despite the leading firms' guidance, subordinate companies and institutions maintain some autonomy in shaping their strategies and conduct within the circuits (Rikap 2019). This dynamic interplay influences the overall trajectory of pharmaceutical innovation.

Innovation networks consist of multiple circuits that divide innovative labour into modular knowledge building blocks and specific technological tasks outsourced to companies and institutions across different geographic locations. These networks operate on a transnational scale, involving cooperative and competitive dynamics. The cooperation between pharmaceutical leaders and subordinate companies within the network is characterised by hierarchical governance and imbalanced power relations (Rikap 2019). Socialising the innovation process within the network involves sharing risks and costs among all participants (Mazzucato and Li 2021; Arora and Gambardella 1995).

In pharmaceutical innovation networks, universities, public laboratories, university hospitals, and smaller companies subordinate themselves to the strategies of leading firms (Rikap 2019). Universities play a crucial role in generating fundamental knowledge for pharmaceuticals R,D&I but face challenges in appropriating innovation rents (Rikap 2019). Public organisations often fund academic research, and socialising innovation risks, while private companies retain most benefits and rents (Rikap 2019; Mazzucato and Roy 2019; Mazzucato and Li 2021).

The innovation process involves both geographical distribution and the coevolution of national and sectoral innovation systems with innovation networks (Lundvall 1988; Lundvall 2011; Malerba 2002; Malerba and Vonortas 2009; Malerba and Osenigo 2015). Domestic firms' opportunities to engage in global pharmaceutical innovation networks are shaped by various factors, including national industrial capacity, science and technology structures, public policies, and cultural characteristics (Rikap 2019; Chaminade et al. 2009; Vornotas 2009).

Public policies that foster pharmaceutical innovation must consider the hierarchical positions, international technological asymmetries, and power relations within global pharmaceutical networks (Rikap 2019). When the State takes a leading role in innovation networks, there may be more significant potential to socialise innovation rents and benefits (Rikap 2019; Mazzucato and Roy 2019). However, public funding often supports the production of critical knowledge, which is then appropriated privately in the final stages of

pharmaceutical corporate R,D&I (Rikap 2019; Mazzucato and Li 2021).

2.1 Pharmaceuticals in the global south: generics and me-too drugs strategies.

The emergence of pharmaceutical networks has led to the participation of firms from global south-emerging countries like Brazil, India, China, Argentina, Mexico, and South Korea (Lavarello et al. 2021; Niosi 2017; Rezaie et al. 2012; Rezaie and Singer 2010; Ortiz-Prado et al. 2020). These firms focus on low-cost manufacturing and imitation and adaptation strategies to provide quality products at affordable prices, catering to the health needs of middle and low-income countries (Niosi 2017; Lavarello et al. 2021; Rezaie et al. 2012). By creating less financially and technically demanding products, these firms build technological capabilities, sales revenues, and financial sustainability before undertaking riskier and more complex R,D&I activities (Rezaie et al. 2012; Rezaie and Singer 2010; Teece 2010; Paranhos et al. 2022).

Global South countries mainly specialise in producing generic and me-too drugs (Rezaie et al. 2012; Niosi 2017; Malerba and Osenigo 2015; Mazzucato and Li 2021). The imitation strategy, particularly in biological and second-generation drugs, requires significant prior knowledge of chemical and biotechnological routes and incremental innovation efforts, as the knowledge needed to copy biological drugs is not perfectly codified in patent documents (Lavarello et al. 2021; Niosi 2017; Guimarães et al. 2021).

Over the past few decades, many companies in emerging markets have harnessed innovation processes and built manufacturing capabilities, thereby reducing production costs and strengthening national industries (Rezaie et al. 2012; Rezaie and Singer 2010; Malerba and Osenigo 2015). The imitation strategy has also allowed them to create the technological and financial conditions to engage in more radical R,D&I activities, particularly in neglected diseases, non-communicable chronic diseases, diagnosis, and specific therapeutic areas (Paranhos et al. 2020; Lavarello et al. 2021).

Since the 1990s, the rise of generic markets has put significant competitive pressure on established global pharmaceutical leaders, leading firms from global north countries to enter these markets (Montalban and Sakinç 2011; Niosi 2017; Ortiz-Prado et al. 2020). The pharmaceutical oligopolistic core has historically focused on developing and marketing blockbuster products (Malerba and Osenigo 2015; Gravaglia et al. 2006; Montalban and Sakinç, 2011). However, when a blockbuster drug loses its patent protection, drug prices and sales revenues drop significantly (Montalban and Sakinç 2011). Therefore, pharmaceutical companies heavily rely on marketing and distribution competencies to extend the product life cycle and patent protection, ensuring long-term profitability (Montalban and Sakinç 2011; Gravaglia et al. 2006).

Additionally, barriers to entry in pharmaceutical activities are considerable,

including sunk costs, scale and network economies, regulatory and sanitary standards, lengthy and costly clinical trials, and increased R,D&I requirements (Montalban and Sakinç 2011; Balconi and Lorenzi 2017; Gravaglia et al. 2006). These factors make it challenging for new players to enter the pharmaceutical market and compete with established companies.

In this context, only a few companies from global south emerging countries possess the necessary skills and capabilities for developing and introducing novel drugs to global markets. Promising companies from these regions tend to focus their innovative efforts on specific drug niches, operating in domestic and global south markets or providing technological and manufacturing services to leading global pharmaceutical firms (Lavarello et al. 2021; Rezaie et al. 2012; Balconi and Lorenzi 2017).

Indeed, companies from global south emerging countries operate within specific contexts and local networks influenced by various characteristics of national and sectoral emerging innovation systems (Lundvall 2011; Malerba 2002). These characteristics encompass industrial capacity, qualified labour availability, support from public policies, regulatory frameworks, science and technology infrastructure, funding conditions, and other country-specific factors (Lavarello et al. 2021; Rezaie et al. 2012; Balconi and Lorenzi 2017; Malerba and Osenigo 2015).

Building national capabilities in drugs and vaccines and participating in global pharmaceutical networks depend on these systemic features at both country and sector levels. They are crucial in shaping companies' dynamic capabilities and networking skills (Chaminade et al. 2009; Lundvall 2011; Teece 2010; Malerba and Vonortas 2009). The interplay between firm-level capabilities and the external context is vital for successful engagement in pharmaceutical innovation networks.

3. Methodology

3.1 Case Selection and Discussion

Brazil was chosen as a case study to assess its involvement in pharmaceutical innovation networks due to the unique features of its innovation system and their influence on network formation (Chaminade et al. 2009; Lundvall 2011).

The Brazilian domestic pharmaceutical market is the largest in Latin America and the seventh largest globally, generating US\$15 billion in 2020 and representing 2% of the global pharmaceutical market. Brazilian capital stakeholders own almost 80% of the 441 pharmaceutical firms operating in the country (Sindusfarma 2021). Despite global technological disparities¹ in the pharmaceutical sector, Brazil ranks among the top ten non- OECD countries and regions regarding patent families in pharmaceutical technology domains

between 2005 and 2019 (Oecd 2023). This indicates relatively solid national technological capabilities in the pharmaceutical field.

Health is recognised as a social right in Brazil under the 1988 Federal Constitution. The country has a Public Unified Health System that positions the State as a coordinator of public health demands and responsible for designing and implementing related policies (Guimarães et al. 2021; Gadelha et al. 2021).

Brazil's production of medicines and vaccines dates back to the early 20th century when the State established the first public laboratories to address national health needs (Guimarães et al. 2021). However, the country's pharmaceutical companies historically had limited R,D&I efforts due to late industrial development patterns, firms' risk aversion, and orthodox macroeconomic policies focused on inflation control, which hampered productive and innovative investments (Paranhos et al. 2020; Szapiro et al. 2016).

A significant turning point occurred with implementing the Generics Law, Law nº 9789/1999, bolstering Brazil's national production of drugs and vaccines. Since 1999, Brazilian pharmaceutical companies have developed critical productive and technological capabilities, particularly in chemical routes and later in the biological me-too drugs segment (Paranhos et al. 2020; Guimarães et al. 2021). Their market share in the national pharmaceutical market has increased from 32% in 2003 to 58% in 2020 (Sindusfarma 2021). Recent years have seen a shift in investment patterns, with increased R,D&I expenditure and a focus on more complex, sophisticated, innovative efforts (Paranhos et al. 2020).

Continuous public policy efforts aided pharmaceutical R,D&I advancements in Brazil (Szapiro et al. 2016). Since the 2000s, Brazil's government has implemented three industrial policies, eight health policies, and three science, technology, and innovation (S,T&I) policies², partially coordinated to support pharmaceutical industrial and innovative development (Paranhos et al. 2022; Szapiro et al. 2016; Guimarães et al. 2021). However, the results of these policies were hindered by overlapping efforts and unclear direction in policy acts (Paranhos et al. 2022; Szapiro et al. 2016).

More recently, especially during the 2010-2018 period, the Partnership Policy for Productive Development (PDPs) has been implemented by the Ministry of Health (MoH) to promote technology transfers between public laboratories and private pharmaceutical companies, fostering local production of essential goods to meet Brazilian health needs (Paranhos et al. 2022; Guimarães et al. 2021). The PDPs incorporates a public procurement for innovation instrument and involve complex multilevel coordination within the Executive Group of the Health Industrial Complex (Gecis)³. This initiative generated significant cost savings, estimated at around USD\$ 850 million, in providing medicines and vaccines for public health needs from 2008 to 2016 (Guimarães et al. 2021). Strengthening the

Brazilian Public Laboratories through the PDP policy also proved crucial during the Covid-19 pandemic from 2020 onwards (Gadelha Et Al. 2021; Alves 2022).

3.2 Question and Contributions

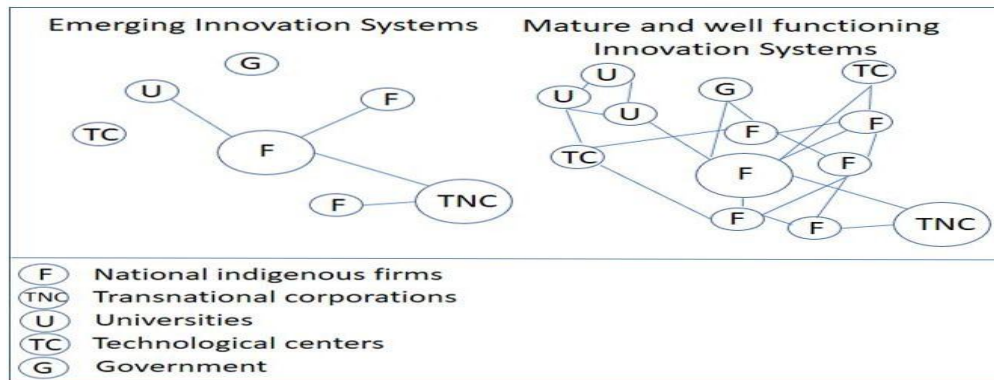
The paper's main objective addresses the following question: How do Brazilian companies and institutions engage in pharmaceutical innovation networks? By examining network formation and dynamic evolution in a global south emerging country, the study adds to the existing literature on the subject. The research focuses on a country actively involved in public initiatives to develop national capabilities in knowledge-intensive pharmaceutical activities.

Pharmaceutical innovation networks involve diverse participants in various relationships, including exchange, competition, and command. These connections can be both market-based and non-market-based and may include collaborations, collusion, and hybrid governance arrangements (Malerba and Vonortas 2009; Montalban and Sakinç 2011; Schuhmacher et al. 2016; Zirulia 2009). The networks facilitate scientific and knowledge exchanges and technological partnerships, such as joint ventures, formal alliances, and licensing agreements (Malerba and Vonortas 2009; Zirulia 2009). These interactions occur among firms and between firms and non-firm entities, such as government agencies, universities, hospitals, and other institutions (Malerba and Vonortas 2009; Arora and Gambardella 1995; Orsenigo et al. 2001).

The significance of linkages in accessing knowledge and assets for pharmaceutical innovation is well-established (Malerba and Osenigo 2015; Arora and Gambardella 1995; Orsenigo et al. 2001). However, the types and governance of these linkages require further attention, particularly from a global south perspective. Understanding the differences between domestic and international relations is crucial for evaluating systemic development and engagement patterns in innovation networks (Chaminade et al. 2009), especially given the presence of global knowledge monopolies and the dominant role of transnational corporations in coordinating R,D&I efforts (Rikap 2019; Montalban and Sakinç 2011).

Interactive learning skills and networking capabilities are vital in producing and exploiting knowledge-intensive assets, shaping the evolution of industries and innovation systems (Lundvall 2011; Zirulia 2009). However, from a global south perspective, innovation systems face limitations due to inadequate firm-level capabilities and incomplete innovation networks, lacking essential nodes and ties (Chaminade et al. 2009). Figure 1 illustrates the differences between developed and emerging systemic networks.

Figure 1. A Comparison of Emerging and Mature Innovation Systems'



Networks

Elaborated by the authors based on Chaminade et al. (2009)

Emerging innovation networks in global south countries face significant constraints due to limited local capabilities and fragmented domestic networks (Chaminade et al. 2009). This often leads to dependent hierarchical relationships with transnational corporations and foreign firms (Rikap 2019). To overcome these challenges, building local capabilities and strengthening domestic networks, including user-producer, inter-firm, inter-sectoral, and university-industry linkages, becomes crucial for leveraging knowledge spillovers (Chaminade et al. 2009). Otherwise, transnational corporations may prioritise routine operations or exploit indigenous R,D&I efforts without sufficient knowledge exchange (Chaminade et al. 2009; Lundvall 2011).

Departing from this framework, this study investigates pharmaceutical networks involved in R,D&I activities for drugs, medicines, and vaccines in Brazil. It examines and maps domestic and international linkages to understand how Brazilian firms and institutions engage in global pharmaceutical networks. Additionally, the study identifies key players in the Brazilian pharmaceutical innovation networks as central nodes for coordinating knowledge and resource flows and enhancing network density (Vornotas 2009; Powell and Grodal 2005). By analysing these networks, the research offers valuable insights into the participation of global south countries in global pharmaceutical networks.

3.3 Data collection and analytical approach

This article's analysis is based on a sample of 398 deals related to pharmaceutical activities, spanning from 1974 to 2020. The data was obtained from Clarivate Analytics' Cortellis Deals Intelligence database on three different dates: November 11, 2019, October 15, 2020, and July 13, 2021. To ensure accuracy, double-counted deals were excluded from the sample. The selection criteria required either the Principal Company or the Partner Company to have their headquarters in Brazil, ensuring that all sampled deals involved at least

one Brazilian firm or institution. The Principal Company is the leading company in the deal, serving as the licensor, service provider, or asset seller. At the same time, the Partner Company acts as the licensee, receiver, or purchaser of the assets and services.

The sample comprises sixteen agreement types related to pharmaceutical activities, covering various drug development and commercialisation aspects. These agreement types include drug discovery & design, drug screening & evaluation, drug early research & development (R&D), technology delivery & formulation, drug commercialisation license, drug development & commercialisation license, drug manufacturing & supply, drug development services, drug asset divestment, technology asset divestments, drug funding, technology other proprietary, exclusive patent rights, patent litigation settlement, company joint venture, and company M&A (in whole or part).

The diversity of agreement types presents methodological challenges due to data heterogeneity, but it is essential for evaluating how Brazilian firms and institutions engage in pharmaceutical innovation networks. To complement the analysis qualitatively, each deal's summary was individually examined, containing detailed information about the interaction. This comprehensive approach allows for a deeper understanding of the dynamics and complexities within the Brazilian pharmaceutical innovation landscape.

The study employed Social Network Analysis (SNA) methods to map the Brazilian pharmaceutical innovation networks and a descriptive analysis of the sampled data based on different agreement types. SNA represents a graphical representation of interconnected nodes linked by specific social relations (Wasserman and Faust 1994; Vornotas 2009). The structure of the networks is determined by patterns and regularities within the ties, influenced by social, political, and economic factors (Wasserman and Faust 1994). The position of a firm within the networks influences its behaviour and performance, as it affects access to valuable resources and capabilities (Vornotas 2009).

The study established links between firms and institutions based on sixteen agreement types. Due to agreement types heterogeneity, the networks are undirected. In domestic networks, both principal and partner companies are located in Brazil, while in transnational networks, at least one company or institution is in Brazil. Additional edges were established to link the MoH to the Federal Government and the public laboratories Biomanguinhos and Farmanguinhos to Oswaldo Cruz Foundation (FIOCRUZ).

Analysing social networks requires different indicators from traditional statistical approaches (Wasserman and Faust 1994). Each linkage represents a communication channel between autonomous units. The characteristics of these linkages, such as frequency, type, and direction, determine the network's capacity to transfer knowledge and resources between nodes (Powell and

Grodal 2005; Vornotas 2009; Kogut 2000). Structural variables evaluate patterns and regularities within the network (Wasserman and Faust 1994).

The network maps in this study are primarily focused on constructing and analysing subgraphs based on headquarters' locations and deals' start and end dates. Graph dispersion was achieved using the Force Atlas Two algorithm in Gephi Open Software, with no overlap and label adjustment. Node sizes were standardised according to degree indexes (ranging from one to four), and node colours were normalised based on betweenness centrality indexes (ranging from red to black). Detailed graphs and subgraph statistics can be found in the supplementary online material. The Social Network Analysis (SNA) primarily

The centrality of a node in the network is determined by its ability to establish ties with other nodes, reflecting its embeddedness in the network structure (Wasserman and Faust 1994; Vornotas 2009; Powell and Grodal 2005). Degree centrality indicates the number of direct connections a node has with other nodes, making it a focal point of relational information and coordination (Wasserman and Faust 1994).

Betweenness centrality measures how a node acts as a bridge between other nodes, facilitating communication and knowledge flow within the network (Wasserman and Faust 1994). Indeed, ties between adjacent nodes in a network can be influenced by other nodes located along the shortest path between them, known as the geodesic distance. Nodes along this path can exert control or relational influence over the adjacent nodes (Wasserman and Faust 1994). Nodes with a higher betweenness centrality, intermediate nodes, tend to have more control or power over the network dynamics (Vornotas 2009; Wasserman and Faust 1994).

Network density is essential for grasping network structures. It represents the ratio of actual links to the maximum possible connections in a graph, where the total number of nodes determines the maximum (Wasserman and Faust 1994). High-density Dense networks with redundant ties are valuable in uncertain environments like innovation driven by bounded rationality. They encourage experimentation, learning, and information flow among nodes (Vornotas 2009). Density is a relative measure. So, when the number of nodes and edges increases significantly, density might stay the same or decrease. This can happen if the potential maximum edges grow more than expected.

4. Pharmaceutical Innovation Networks: Findings and Analysis

The results in Table 1 include a sample of 398 deals categorised by agreement types, comprising domestic and transnational deals.

The initial R,D&I stages account for 16% of the total deals, which consist of drug early R&D (52), discovery and design (6), screening and evaluation (1), and

technology delivery and formulation (5). Although the number of initial R,D&I deals is limited, these ties are critical in fostering learning processes and supporting Brazil's dynamic pharmaceutical innovation core.

In the sample, drug manufacturing & supply (19%) and commercialisation licenses (13%) are the most frequent deals, occurring in the latter stages of the R,D&I chain. Drug development & commercialisation licenses and development services also constitute significant portions, accounting for 13% of the deals. These licenses involve technological orders and transfers to build local capabilities for complex drugs and vaccines. On the other hand, marketing and distribution deals are characterised by low-intensity technological efforts, focusing on product adaptation to local regulatory requirements. Global leading companies use commercialisation licenses to access the Brazilian pharmaceutical market, generating significant revenues for Brazilian firms but involving reduced knowledge-intensive activities conducted locally. Overall, production stages are highly intensive in tacit knowledge and problem-solving skills, serving as crucial sources of innovation. Marketing and distribution activities also contribute to innovation by facilitating information feedback between users and producers.

Equity operations, including M&A, divestments, and joint ventures, make up nearly 18% of the deals. However, to comprehend the engagement patterns in pharmaceutical innovation networks, it is essential to assess domestic and transnational linkages carefully.

Table 1. National and transnational deals

Agreement types	Total		National deals			Transnational deals		
	N	%	N.	deals	BR/TotalN.	N.	%	EX/Total
Company joint venture	19	5%	11	17%	58%	8	2%	42%
Company M&A (in whole or part)	48	12%	11	17%	23%	37	11%	77%
Drug asset divestment	5	1%	2	3%	40%	3	1%	60%
Drug commercialisation license	53	13%	0	0%	0%	53	16%	100%
Drug development services	6	2%	0	0%	0%	6	2%	100%
Drug development & commercialisation license	45	11%	6	10%	13%	39	12%	87%
Drug discovery & design	6	2%	2	3%	33%	4	1%	67%
Drug early R&D	52	13%	14	22%	27%	38	11%	73%
Drug funding	14	4%	4	6%	29%	10	3%	71%
Drug manufacturing & supply	77	19%	8	13%	10%	69	21%	90%
Drug screening & evaluation	1	0%	0	0%	0%	1	0%	100%

Patent exclusive rights	3	1%	2	3%	67%	1	0%	33%
Patent litigation settlement	1	0%	0	0%	0%	1	0%	100%
Technology asset	1	0%	0	0%	0%	1	0%	100%
divestments								
Technology delivery & formulation	5	1%	0	0%	0%	5	2%	100%
Technology other proprietary	62	16%	3	5%	5%	59	18%	95%
Total	398	100%	63	100%	16%	335	100%	84%

Source: elaborated by the authors based on Cortellis Deals Intelligence (2021).

4.1 National Linkages in Pharmaceutical Innovation Networks

Limited domestic linkages represent only 16% of the sample, with sixty-three deals. The data collection process, possibly conducted by a global north company, might have underreported Brazilian domestic agreements. However, the small number of national deals suggests a foreign-oriented focus of ties, supporting the idea of a subordinate position in pharmaceutical networks and a significant technological dependence in Brazil.

National joint ventures and M&A deals primarily reflect the realignment strategies of Brazilian companies' dynamic capabilities and core competencies.

The formation of joint ventures is closely linked to the impacts of the PDPs, with many deals involving creating two major biopharmaceutical Brazilian companies, Bionovis and Orygen⁴. These ventures aim to capitalise on opportunities in me-too biological drugs made possible by the public procurement instrument within the PDPs. National joint ventures are generally established to collaborate on R,D&I activities in biological and high-complexity drugs.

On the other hand, M&A deals focus on integrating or disintegrating R,D&I and manufacturing activities in specific market niches. For example, the Brazilian pharmaceutical company Aché acquired Melcon, Nortis, and Tiaraju Pharmaceuticals to realign capabilities and increase market share in hormonal drugs, antibiotics, and prescription-free medicines. Blanver acquired CYG Biotec to internalise the production of Active Pharmaceutical Ingredients. Hypermarcas acquired Mantecorp and Neo Química, dedicated to generics, dermatological, and prescription-free medications, among other deals.

The results highlight the significance of domestic linkages in the early R,D&I stages, constituting 22% of the national deals. This indicates the relevance of local networks in supporting innovation processes within Brazil. Mainly, deals related to drug discovery & design, early R&D, funding, and exclusive patent rights show a considerable proportion in the national context. Furthermore, domestic commercialisation licenses involve local development activity,

reinforcing the role of the domestic network in supporting knowledge-intensive R,D&I efforts in the pharmaceutical sector. These findings underscore the importance of fostering and strengthening domestic collaborations and capabilities to drive pharmaceutical innovation in the country.

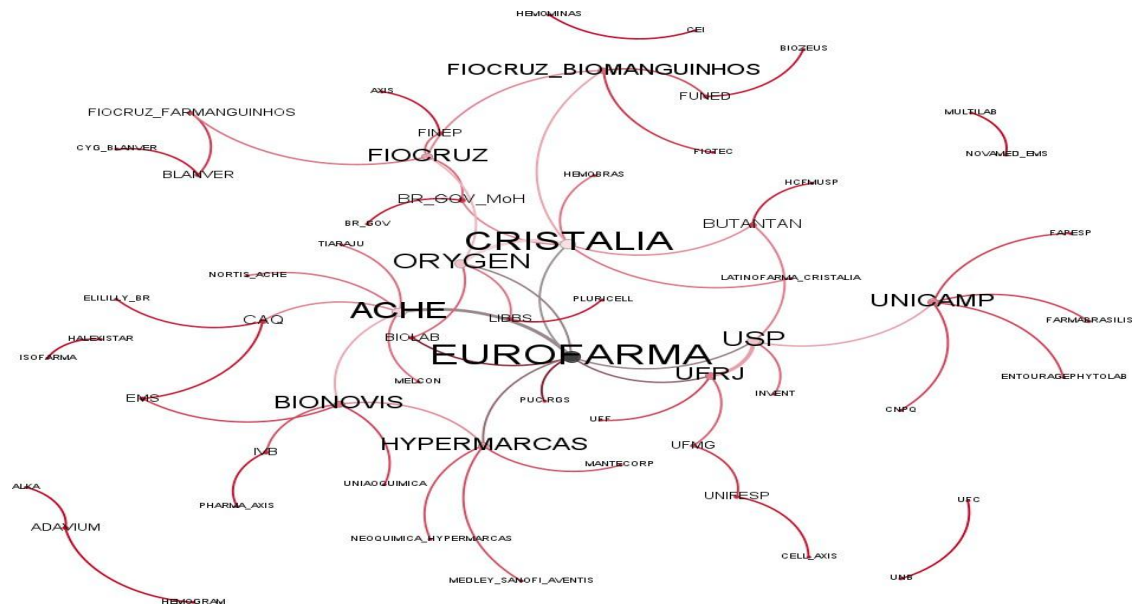
The analysis of national deals does not reveal a clear and consistent pattern over time. However, a significant deal increase was observed in 2012, which coincides with the establishment of the Orygen and Bionovis joint ventures, driven by the implementation of the PDPs. This policy stimulus led to a general rise in deals from 2010 onwards. Additionally, the outbreak of the COVID-19 pandemic in 2020 further increased the volume and diversification of deals.

Figure 2 illustrates the national pharmaceutical network comprising 61 nodes, 63 edges and six weakly connected components. Figure 3 shows the giant component of the network. As measured by overall graph indicators, the network's complexity appears limited.

In the national pharmaceutical network, certain key players emerge as central hubs. These include pharmaceutical companies Eurofarma and Cristália, the joint ventures Bionovis and Orygen, and the universities USP, UNICAMP, and UFRJ. The public laboratories Butantan Institute, Biomanguinhos, and Farmanguinhos also play significant roles as network hubs. The Brazilian Federal Government, particularly the MoH, holds a central position in the network due to its role in providing essential drugs to meet public health needs and coordinating the PDPs.

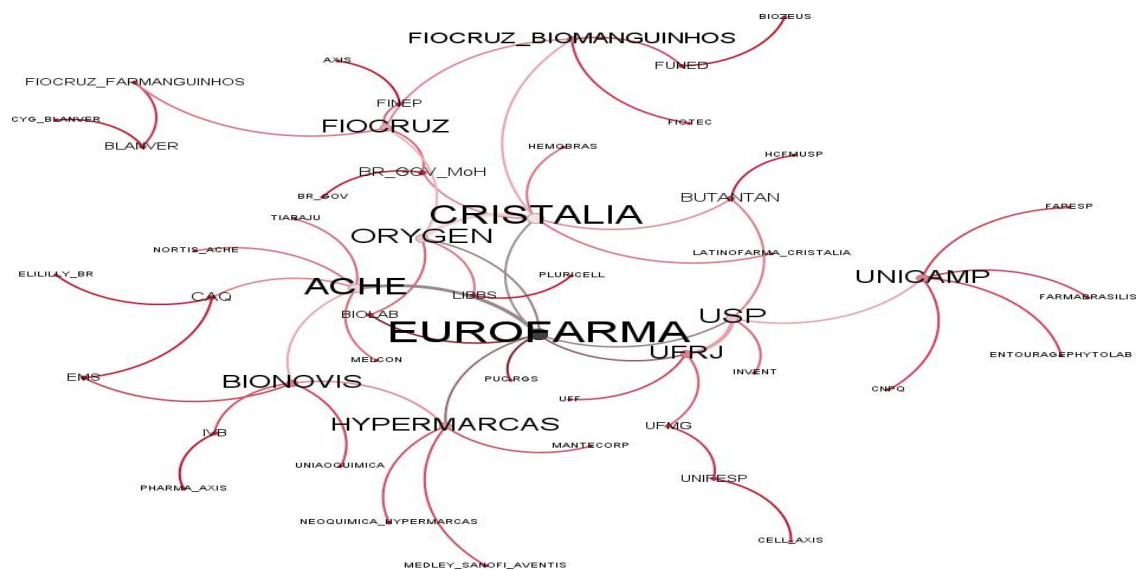
Eurofarma, Cristália, USP, and FIOCRUZ are notable central nodes due to their high betweenness centrality. These nodes play a crucial role in coordinating activities within the network. Their strategic positions make them well-suited to promote the growth of the network and facilitate exchanges of both tangible and intangible assets in the country. As central players, they have the potential to integrate new nodes and establish new connections in the future, further strengthening the national pharmaceutical innovation network.

Figure 2. National Pharmaceutical Network



Source: elaborated by the authors based on Cortellis Deals Intelligence (2021).

Figure 3. Network Giant Component



Source: elaborated by the authors based on Cortellis Deals Intelligence (2021).

4.2. Transnational Linkages in Pharmaceutical Innovation Networks

Transnational deals dominate the pharmaceutical innovation network, making up 84% of the linkages. These international deals are more prevalent in most agreement types, except for joint ventures and patent-exclusive rights. In these

two categories, the proportion of national deals is higher. This indicates that joint ventures and patent-exclusive rights agreements focus more on domestic collaborations, while most other deals involve interactions with foreign or transnational entities. The predominance of transnational deals highlights the significance of global connections and partnerships in the Brazilian pharmaceutical industry.

Transnational joint ventures in the pharmaceutical industry differ from national joint ventures. About 64% of these ventures were established for marketing and distribution activities in Brazil, allowing global companies to enter the Brazilian market. On the other hand, only 36% of the joint ventures were focused on conducting R,D&I activities in Brazil. Most firms involved in these joint ventures were from the United States (US), India, Germany, and Canada. This highlights the foreign companies' interest in leveraging the Brazilian market for distribution purposes, while a smaller proportion engages in collaborative research and development within the country.

Transnational deals dominate commercialisation licenses that do not require local productive and innovative efforts, accounting for 100% of such arrangements. For licensing deals involving local development and commercialisation, transnational deals represent 87% of the share, manufacturing and supply deals represent 90%, and development services deals represent 100%. These deals often involve technological orders and transfers, including those associated with the PDPs.

The transnational companies involved in these licensing deals mainly originate from the United States (US), Switzerland, South Korea, Italy, India, China, Israel, France, and the United Kingdom (UK). These findings indicate that transnational companies play a significant role in licensing activities in Brazil, both for local development and commercialisation purposes and for direct import and distribution arrangements.

Transnational linkages in early R,D&I activities show a slightly lower share in total deals, indicating the importance of national links in these stages. However, transnational deals still constitute a significant portion, accounting for 73% of early R&D, 67% of discovery and design, 100% of delivery and formulation, and 100% of screening and evaluation. These findings highlight Brazil's high transnational technological dependence and vulnerability in pharmaceutical innovation core activities. Deals involving transactions of patent-exclusive rights (33%) are an exception. However, this exception is related to knowledge monopolies and challenges in transferring technological control and intellectual property rights to global south firms. Most deals involve the US, Switzerland, the UK, France, China, and Canadian firms.

Transnational M&A accounts for 77% of all M&A deals. The data reflects the significance of the Latin American region as a source and destination for deals.

Brazilian firms acquired assets from various countries, including the US, France, and India, but primarily from neighbouring South American countries like Chile, Uruguay, and Argentina. Additionally, the results align with the geographic distribution of global leaders' headquarters, as the acquirers of Brazilian assets were mainly from the US, France, and Switzerland.

Knowledge-intensive entrepreneurship comprises 30% of international M&A deals, with most acquired firms being Brazilian academic spinoffs. These spinoffs have historically received support from public policies in Brazil and were funded by public resources. Section five discusses concerns arising from the potential loss of local innovative capabilities and the risk- reward balance associated with these deals.

Brazilian pharmaceutical companies' internationalisation strategies comprised 24% of transnational M&A deals, primarily targeting global south countries. Transnational companies acquiring Brazilian assets to access the national market account for 22% of the deals. Acquisitions of technological assets, such as brands and pipelines, constitute 8% of the total. A few deals were not directly related to drugs and vaccines but involved firms dedicated to other health products.

From 2007 onwards, there was a notable increase and diversification in the volume of transnational deals. The impact of the COVID-19 pandemic also led to a surge in the volume and variety of links in 2020.

Figure 4 displays the transnational network, consisting of 415 nodes and 323 edges. Figure 5 shows the network's giant component, excluding its 107 weakly connected nodes. The global network exhibits a remarkable complexity – regarding the number of nodes, edges and weighted average degree – compared to the national one. Interestingly, node centrality shows similarities between the national and transnational networks.

The Brazilian pharmaceutical company Eurofarma stands out in the transnational network due to its high degree and betweenness centrality. Brazilian pharmaceutical firms like Cristália, EMS, Biolab, Aché, and Libbs also hold central positions in the network structure based on degree indicators. ReceptaBio, a successful knowledge-intensive entrepreneurship focused on developing novel oncology drugs, emerges as a prominent node in R,D&I deals with foreign firms, universities, and research institutes.

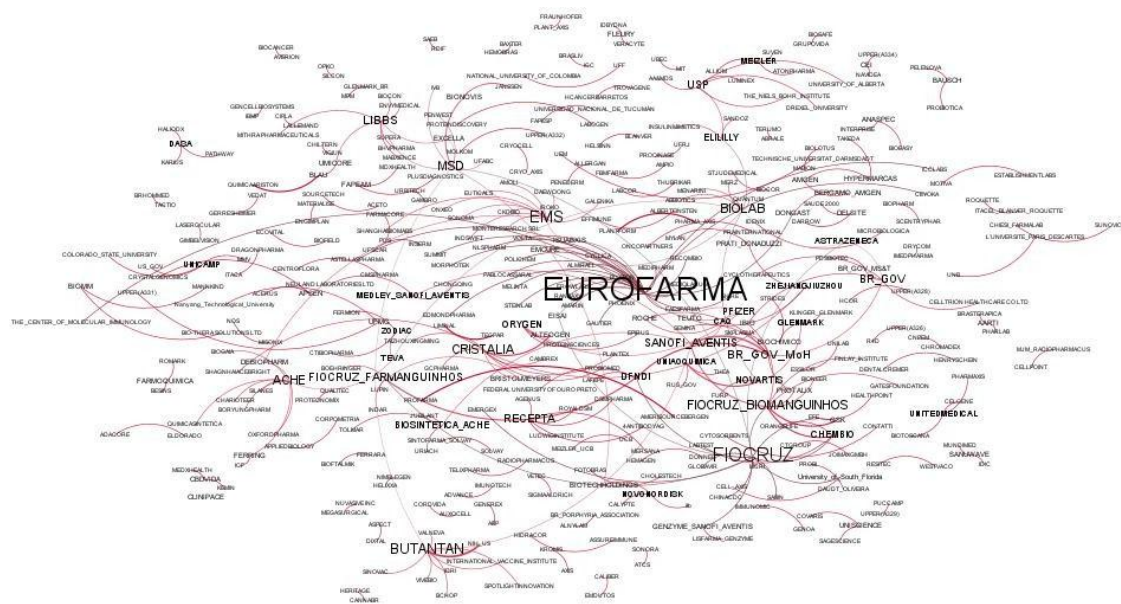
The public laboratories Biomanguinhos, Farmanguinhos, and Butantan Institute also exhibit a significant degree and betweenness centrality in the transnational network. These public laboratories are crucial in using knowledge-intensive deals and technology transfer agreements to develop and produce highly complex drugs and vaccines locally. They are essential coordinators of asset flows within national and transnational networks.

The Brazilian Federal Government and the MoH hold relatively important positions in the transnational network based on the degree of centrality. Their roles involve providing essential goods and services to meet public health needs in Brazil and, to some extent, coordinating the PDPs.

In contrast to the national network, the University of São Paulo (USP) is the only Brazilian university with central relevance in transnational deals. The relative importance of Brazilian universities is a notable difference between the national and transnational networks. While foreign universities and research centres are present in sampled deals, their linkages are diffused and not structurally significant. Additionally, the data source used is not specialised in academic engagement.

Finally, leading global pharmaceutical companies such as Merk Sharp Dohme (MSD), Sanofi- Aventis, Novartis, Chembio, Pfizer, Eli Lilly, and AstraZeneca are also prominent nodes in the transnational network. Given their importance in global pharmaceutical activities, these companies' presence and relative degree position within the international network are expected. It is worth noting that many of these companies have established subsidiaries in Brazil.

Figure 4. Transnational Pharmaceutical Network

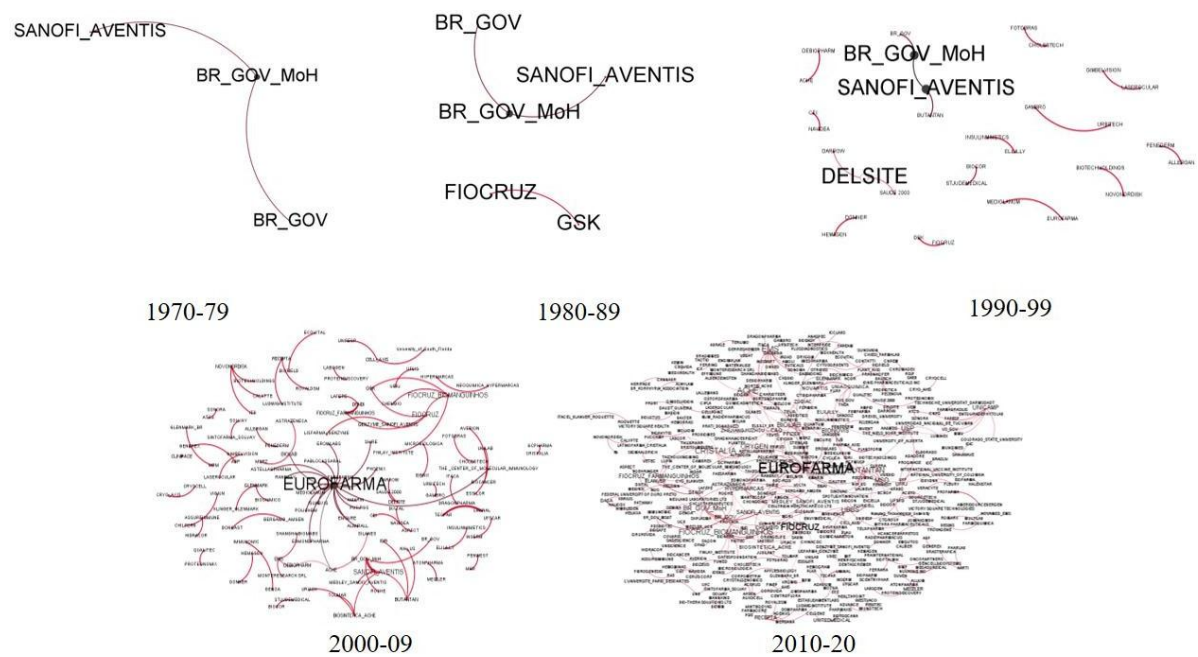


Source: elaborated by the authors based on Cortellis Deals Intelligence (2021)

includes numerous other Brazilian pharmaceutical companies.

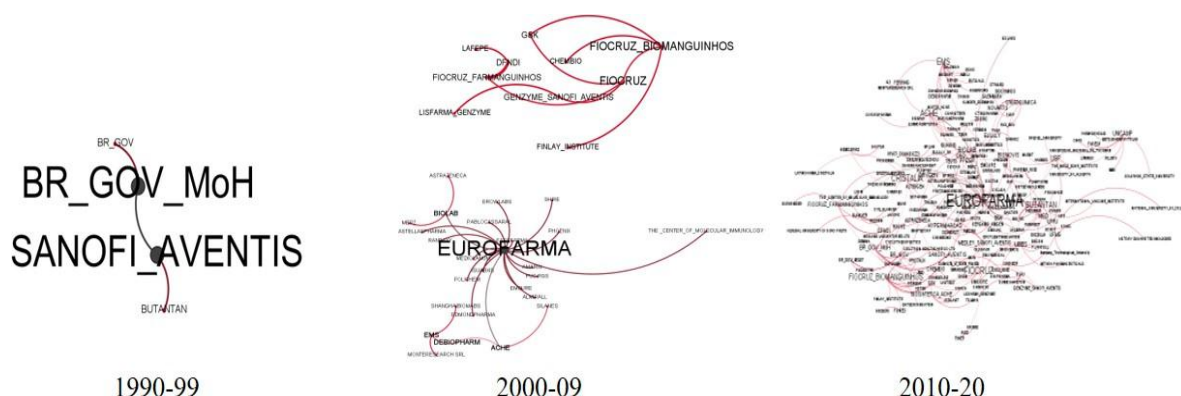
The 2010s witnessed further network diversification involving national and international pharmaceutical companies, knowledge-intensive entrepreneurship, CROs, CMOs, universities, academic hospitals, and public laboratories. The network dynamic has been convoluted with implementing policy instruments like the PDPs and the enhanced convergence between Brazil's health, industrial and S,T&I policy efforts. Agreement types included early R,D&I stages, suggesting a positive relationship between national firm-level capabilities-building processes and network linkages. The growth and increasing complexity of the network during the 2010s indicate the progress made by the country in developing its pharmaceutical innovation system and the global trend towards increasing outsourcing on a worldwide scale. Brazil's pharmaceutical innovation network progressed from a sparse and loosely connected structure to a more complex and interconnected network involving domestic and transnational participants. The previous fragmented giant components developed into a larger and more intricate unified structure.

Figure 6. Pharmaceutical Innovation Networks' Dynamic Evolution in Brazil



Source: elaborated by the authors based on Cortellis Deals Intelligence (2021)

Figure 7. Networks' Giant Components Evolution



Source: elaborated by the authors based on Cortellis Deals Intelligence (2021)

5. Discussion

The results presented in the previous sections strongly suggest that Brazilian firms and institutions are subordinated in global pharmaceutical networks, particularly when considering the differences in node volume and network weighted average degree between national and international networks. The data source might have contributed to the underreporting of Brazilian deals. The significant presence of leading global pharmaceutical companies, such as MSD, Sanofi Aventis, Novartis, Chembio, Pfizer, Eli Lilly, and AstraZeneca, further supports the argument of subordinate insertion.

The dominance of transnational ties in almost all agreement types, including early R,D&I activities, highlights the challenges, technological dependence, and vulnerabilities Brazilian pharmaceutical firms and public laboratories face in their interactions with the global pharmaceutical industry. This highlights the importance of enhancing domestic capabilities and better positioning Brazilian firms and institutions in global pharmaceutical innovation networks.

The distinguished centrality of certain Brazilian companies, such as Eurofarma and Cristália, along with public laboratories like Biomanguinhos, Farmanguinhos, and Butantan Institute, indicates potential opportunities for a more favourable and less dependent engagement in global pharmaceutical innovation networks.

The sampled data shows a correlation between centrality positions in national and transnational networks, although causality relations are challenging to define. Strengthening national scientific and technological capabilities in pharmaceuticals may increase the number of nodes in national networks. This, in turn, could promote leading Brazilian firms and institutions to central and

more advantageous structural positions in transnational pharmaceutical networks. The importance of central nodes lies in their ability to coordinate and facilitate flows within each network structure and their potential to incorporate new players and stakeholders.

To gain a more in-depth understanding, further qualitative studies at the firm level are recommended to evaluate this conjecture. A thorough investigation of science and technology indicators for nodes, including patent data, scientific publications, R&D expenditures, and qualified personnel employed, can also yield more precise and comprehensive insights. Nevertheless, the evidence points towards a correlation between building technological capabilities and the centrality of specific nodes in national and international networks.

The central position of public laboratories indicates the significant role of the State in Brazil's pharmaceutical innovation system. The Brazilian Federal Government, mainly through the MoH, is also central in national and transnational networks. This reflects the State's role as a policy maker, coordinator of the Unified Health System, and essential supplier of drugs and vaccines through public laboratories.

The data suggests a correlation between network linkages and public policies, especially implementing the PDPs and the technology transfers to address the covid-19 pandemic. The broad scope of action of the Brazilian State in policy design and implementation, including demand-side and supply-side incentives, appears critical in pursuing a positive agenda in engaging with global pharmaceutical networks and advancing pharmaceutical and health technologies. Further research on network dynamics and their correlation with public policies in Brazil is needed to understand how policy decisions influence network structures and contribute to the country's progress in the pharmaceutical and health sectors, promoting sovereignty in these critical areas.

Brazilian universities, particularly USP and UFRJ, have a central role in the national network, facilitating knowledge spillovers nationally. Building national scientific capabilities in pharmaceutical-related areas and fostering university-industry linkages are crucial for drug and vaccine development. The data show that academic institutions, both national and foreign, are more involved in early R,D&I activities. However, the data source is not specialised in academic engagement. USP stands out as a gatekeeper of knowledge in the transnational network. Since academic research is often publicly funded in Brazil, risk-reward concerns must be addressed in university-industry linkages. Further research is recommended to explore these dynamics in greater detail.

Indeed, socialising innovation risks and rewards is a significant concern in equity operations like M&A. While such deals can lead to expansion, reorganisation, or internationalisation for Brazilian pharmaceutical companies, foreign acquisition of knowledge-intensive entrepreneurship supported by

public resources raises significant issues. These ventures often have limited capabilities, qualified employees, and physical structures. As a result, acquisitions may lead to companies leaving the country or being extinguished, causing Brazil to lose critical scientific and technological capabilities built through public efforts. Innovation risks and costs are shared in these cases, but private and foreign stakeholders may reap innovation rents and rewards. This situation requires careful consideration and policy measures to safeguard national capabilities and interests.

Indeed, encouraging strategic alliances between Brazilian pharmaceutical companies and domestic knowledge-intensive entrepreneurship could be a promising approach to retaining critical, innovative capabilities in the country. Strengthening the density of the domestic network and fostering linkages between these entities could enhance the utilisation of external knowledge and financial resources at local levels. However, it is essential to note that some Brazilian pharmaceutical companies have successfully acquired foreign knowledge-intensive entrepreneurship while exploring technological opportunities abroad. Future studies should delve deeper into this topic to gain valuable insights and inform policy decisions.

Transnational linkages in the pharmaceutical industry predominantly involved firms from the US, Europe, and emerging countries of BRICS, notably India and China. Deals with global north firms align with the presence of leading global pharmaceutical companies in those regions. These agreements may include significant technological transfers and learning opportunities for Brazilian entities, alongside low technological intensity licenses to access the Brazilian pharmaceutical market. Conversely, deals with BRICS and other global south companies tend to be more associated with indigenous innovation and expanding trajectories of Brazilian firms and public laboratories.

The dynamic evolution of the network is aligned with the strengthening of national capabilities in pharmaceutical activities since the implementation of the Generic Law in Brazil. The increasing complexity of the network may also reflect the global trend of pharmaceutical outsourcing and networking. However, the significant impact of Brazilian public policies in fostering industrial and technological capabilities suggests an alternative approach to promote a more autonomous and less subordinate engagement of Brazilian firms and public laboratories in global pharmaceutical networks.

6. Implications for global south countries.

This study offers valuable insights for global south countries considering a virtuous approach to pharmaceutical and health activities. Despite the prevalent trends of outsourcing, financialisation, and knowledge monopolies, the findings based on the Brazilian experience suggest that engaging in pharmaceutical innovation networks is a challenging but not a hopeless path for

global south countries.

Firstly, building strong local and national productive and technological capabilities and fostering domestic knowledge-intensive linkages can enhance the centrality of national firms and institutions in both national and transnational network structures. A higher degree and betweenness centrality positions enable these entities to better coordinate, monitor, access, and leverage knowledge-intensive asset flows, thereby capitalising on international knowledge spillovers and technological opportunities.

Secondly, The State's active role in shaping and guiding local innovation circuits can enhance national firms' and institutions' coordinating capacity in global innovation networks. A comprehensive approach to public policy is necessary to build a virtuous agenda in pharmaceutical linkages and networks. This approach should include a mix of instruments, addressing both supply-side and demand-side incentives, to foster national industrial and innovative capabilities aligned with long-term social and economic development goals. Providing medium and long-term funding and financing options to national firms is also critical to mitigate short-term financial pressures and ensure the sustainability of investments in intangible and tangible assets required for developing productive and technological capabilities at the local and national levels.

Thirdly, universities are pivotal in pharmaceutical innovation networks in global south countries. Strengthening university-industry linkages at the national level can facilitate knowledge transfers and spillovers, essential for building local R,D&I capabilities in pharmaceutical-related knowledge domains. Establishing relationships with foreign universities and research centres is crucial for generating international knowledge spillovers. However, addressing the risk-reward nexus is essential, given that academic research is often publicly funded. The same consideration applies to academic spin-offs and knowledge-intensive entrepreneurship supported by public resources. Sharing innovation benefits and rents, as well as its risks and costs, and guaranteeing access conditions to be new or improved drugs and vaccines at affordable prices, is vital for national development and welfare, especially from a global south perspective and in health-related domains.

Fourthly, while not the primary focus of this study, the literature reviewed highlights the significance of developing treatments for tropical and neglected diseases in the global south.

This represents a critical opportunity for companies from these regions to overcome barriers of entry and engage in riskier and more complex radical pharmaceutical innovation processes. Additionally, addressing these diseases is essential for increasing social welfare and meeting the health needs of global south countries and regions, particularly in the context of significant economic

and social inequalities.

Fifthly, it is essential to recognise the significant role that transnational corporations and global pharmaceutical leading companies play in the global south's industrial activities, employment, and provision of health products. Acknowledging their economic importance is crucial. However, there is a need for reflection on alternative policies and incentives to encourage these firms to increase their local R,D&I expenditures, knowledge-intensive linkages, and overall innovation efforts in global south regions. Such initiatives can foster national development, stimulate interactive learning processes, and promote effective technology transfers between the global north and south countries.

Further research on pharmaceutical networks in global South nations such as India, China, Russia, and South Africa is advised. This will help comprehend their distinctive challenges and opportunities, guiding policy-making and fostering inclusive and sustainable development in health and pharmaceutical activities from a global South standpoint.

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Notes

¹ Global North OECD countries hold 89% of patent families in pharmaceutical technology domains, indicating a concentration of pharmaceutical technological capabilities in those regions (Oecd 2023).

² Brazil has implemented several key policies to support industrial, technological, and trade development, such as the Política Industrial, Tecnológica e de Comércio Exterior; Política de Desenvolvimento Produtivo; and Plano Brasil Maior. In the healthcare sector, four editions of Plano Nacional de Saúde; Política Nacional de Ciência, Tecnologia e Inovação em Saúde; Pacto pela Saúde, Mais Saúde, and Política Nacional de Inovação Tecnológica na Saúde have been implemented. Additionally, initiatives like Programa de Aceleração do Crescimento de Ciência e Tecnologia and two editions of Estratégias Nacionais de Ciência, Tecnologia e Inovação have been part of Brazil's efforts (Paranhos et al. 2022).

³ Dissolved in 2019 and reestablished in 2023 (Guimarães et al. 2021; Brasil 2023).

⁴ For a comprehensive discussion on the PDPs and the establishment of the joint ventures Bionovis and Orygen, readers can refer to the work of Alves (2022).

Survival of Innovative and Non-innovative Industrial Firms in Brazil: an analysis of the 2000-2018 period

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As evidenced in recent studies, innovation has become a major element of business survival strategies. Accordingly, the objective here is to analyse the survival of innovative and non-innovative industrial firms in Brazil in the 2000s. To meet this objective, an unprecedented empirical study was developed based on data from firms that had participated in all editions of the Survey of Innovation (PINTEC) (2000, 2003, 2005, 2008, 2011, and 2014), which were taken from special tables provided by the Brazilian Institute of Geography and Statistics (IBGE), and cross-referencing between the PINTEC and the Central Register of Enterprises (CEMPRE) databases. The study examines a period of 18 years, and survival rates are identified through the year 2018. The empirical analysis also considers breakdowns by size and sector (technological intensity). Among the main results, innovative firms were found to have higher survival rates than non-innovative ones. The second main result is that survival rates are directly related to size for both innovative and non-innovative firms. Regarding the sectors of activity, broken down by technological intensity, firms that engaged in some type of innovation presented the highest survival rates, regardless of the sector of operations. The breakdown shows that innovative firms in sectors with a medium-high technological intensity presented the highest survival rates, whereas non-innovative firms in sectors with a high technological intensity exhibited the lowest survival curve.

Keywords: Survival; Innovative firms; Non-innovative firms; Industry; Brazil.

Introduction

The dynamics of productive structures, according to the Neo-Schumpeterian approach, are determined by firms' permanent search for innovations. This process occurs through the entry and exit of firms that seek to survive, grow, and gain profits with innovation in a constantly changing environment (Nelson; Winter 1982). Recent research in this field of knowledge shows that business survival and growth are the result of a set of determinants, but the most common phenomenon is early mortality, as reported in studies from several developed and developing countries. Mortality rates are generally high among young, small firms.

However, the relationship between size and survival becomes less direct and more complex as different socioeconomic environments are considered and other variables are factored into the analysis. The following explanatory variables are often investigated: age of business (Anyadike-Danes and Hart 2018; Coad et al. 2018); economic cycles (Cefis and Marsili 2006); innovative activities, such as research and development (R&D) and other expenditures (Cefis and Marsili 2006; Boyer and Blazy 2014); sector of activity, usually considering the level of technological intensity (Audretsch 1991; Cefis and Marsili 2011; Cefis et al. 2020); government support in the form of fiscal or financial incentives (Conceição et al. 2018; Ehrl 2021); export activities and entry into international trade (Wagner 2011); and even the entrepreneurs' personal characteristics, such as age, sex, past experiences, sense of opportunity, financial independence, among other aspects commonly listed under the label of entrepreneurship (Cowling et al. 2018; Ortega-Argiles and Moreno 2007).

Accordingly, the main objective here is to analyse how innovation influences the survival of Brazilian industrial firms. To this end, a set of unpublished data derived from special tables prepared by the Brazilian Institute of Geography and Statistics (IBGE) was examined. The data were obtained by cross-referencing the Survey of Innovation (PINTEC) and the Central Register of Firms (CEMPRE) databases and by referring to the 2000s, more specifically to innovative and non-innovative companies found in the 2000, 2003, 2005, 2008, 2011, and 2014 editions of PINTEC, whose survival rates are identified through the year 2018. In each of these editions, between 10,234 (PINTEC 2000) and 14,211 firms (PINTEC 2008) are placed in the appropriate stratum and classified as innovative and non-innovative. In addition to the general data, breakdowns by size (small, medium, and large) and sector (classified by technological intensity) are also examined.

This period was marked by intense changes in the Brazilian economy which deepened the deindustrialisation process underway since the 1990s (Morceiro and Guilhoto 2019, 2020; Nassif et al. 2015). Simultaneously, the discussion on innovation and how essential it is to increasing the

competitiveness of Brazilian firms greatly advanced during this period, laying the groundwork for a set of public policies intended to stimulate the innovative activities of businesses (Abdi 2015; Laplane and Laplane 2017).

Based on the literature, the following hypotheses were made:

- H1: Innovative firms have higher survival rates than non-innovative ones (Buddelmeyer et al. 2010).
- H2: Survival is directly related to size; in other words, larger firms have higher survival rates (Rosembusch et al. 2011).
- H3: Survival rates differ based on the sector's technological intensity and are lower in sectors classified as high technology, given the higher risk and uncertainty related to investments in innovation in frontier technology sectors (Ugur et al. 2015; Cefis et al. 2020).

The article is organised into three sections, aside from the Introduction and Final Considerations. The second section presents a review of the literature; the third describes the methodology, and the fourth section analyses the results.

Literature review

Several empirical studies that observe business survival in developed and developing countries point to innovation's crucial role in reducing the mortality rate. Regarding innovative effort, expenditures on R&D are the main innovation indicators analysed. As for innovative results, product innovation is the most common indicator. These studies usually contemplate contexts based on company size and industrial sector, generally considered from the perspective of technological intensity.

In a study of Dutch companies, Cefis and Marsili (2019) aimed to identify whether companies that invest in R&D presented better survival indicators after the 2008 economic crisis. The authors found that product innovation was essential to survival during and after the crisis, whereas other innovation types did not present the same results. In the case of product innovations, a major conclusion is that innovative capabilities act as adaptive capabilities in the post-crisis period.

Pérez and Castillejo (2008) also analysed the relationship between R&D activities and the survival of Spanish manufacturing companies. The study showed that companies that conduct R&D have a lower mortality rate than those that do not conduct or purchase R&D, regardless of the industry's innovative intensity. However, only in sectors with a high technological intensity, the survival rate of companies that conduct R&D is higher than that of companies that only purchase R&D.

Buddelmeyer et al. (2010) examined the relationship between innovation and business survival in Australia. They developed an empirical study based on data from 300,000 Australian companies during the 1997-2003 period. One of the main aspects highlighted by the authors refers to the strong presence of uncertainty in the companies' decision to innovate. According to the authors, the results of most international studies point to a positive relationship between innovation and survival. In the case of the authors' study, they investigated the relationship between survival and more radical investments in innovation, such as patent applications. Among the results, a negative relationship was detected between this type of investment in innovation with its high degree of uncertainty and the probability of business survival.

Ugur and Vivarelli (2020) investigated the relationship between R&D/innovation and business survival and productivity. The authors analysed studies and found evidence of innovation's positive effect on survival and productivity. They also identified theoretical and methodological advances in the articles published on the subject. However, they highlighted some problem areas that require further research, such as evidence of a large degree of heterogeneity in the results of empirical research given the proliferation of innovation variables, which hinders a comparative analysis between the studies.

One of the most important aspects analysed in the debate over innovation and survival is business size (small, medium, and large). Rosembusch et al. (2011) conducted an important study that analyses this relationship empirically. The authors investigated the intensity and direction of the relationship between innovation and the survival of small and medium-sized firms (SMEs). To this end, they developed an empirical analysis by means of a meta-analysis technique including 42 empirical studies involving about 21,270 companies. The results revealed the following: a) a positive effect between innovation and the performance of SMEs;

b) a greater volume of resources in R&D activities points to greater chances of business survival; c) innovation has a positive, more pronounced impact on young firms than on more established SMEs; and d) contrary to most international studies, innovation projects developed with outside partnerships (networks) do not have a significant effect on business survival.

Considering the context based on size, Ortega-Argiles and Moreno (2007) performed an empirical study to observe the relationship between managerial competitive strategies and business survival. Using semi-parametric and parametric techniques, the empirical study includes a sample of Spanish industrial firms for the 1990-2001 period. The authors found that the competitive strategies adopted varied based on the size of the enterprise. One of the main results indicates that adopting product differentiation strategies, such as R&D

expenditures and investments in advertising, reduces the mortality risk, considering the total sample and small- sized companies.

Another notable dimension of analysis in the international debate concerns the role of innovation in business survival, noting the technological intensity of the industrial sectors of the companies under study. Fontana and Nesta (2007) scrutinised the relationship between product innovation and business survival for a sample of 121 companies in sectors with a high technological intensity. The evidence indicated that companies close to frontier technology are more likely to be acquired than not to survive. For the authors, the results demonstrated that the positioning of the innovative product is a marker of the company's quality and that a stock of knowledge (intangible capital) increases the probability of survival.

To observe the relationship between innovation and survival in Chinese high-tech companies, Zhang et al. (2018) conducted an empirical study of 14,065 Chinese high-tech start- up companies from 2007 to 2013. The authors believed that the relationship between innovation and survival was still inconclusive based on the existing literature, especially in the case of a rapidly growing emerging economy such as that of China. The results suggested that innovation measured by patents, innovation efficiency, and the companies' import and export activities can increase the survival rate of Chinese high-tech companies.

Ugur et al. (2015) investigated the relationship between innovation and survival using the sector classification proposed by K. Pavitt. The authors constructed an empirical study with an unbalanced panel analysis consisting of 39,705 firms from the United Kingdom for the 1997-2012 period. The results revealed the presence of an inverted U-shaped relationship for different types of R&D expenditures and funding sources. As the intensity of R&D increases from a low initial level, survival rates also increase. After the inflection point, high expenditures in R&D may reduce survival rates. The authors also reported that the intensity of R&D is more likely to increase survival when firms are in more concentrated industries and are classified into sectors known as 'specialist suppliers' and 'scale-intensive industries'.

Still considering the sectoral context by technological intensity, in a study of Dutch firms that left the market in 2018, Cefis et al. (2020) found two patterns: 'revolving door' and 'gale of creative destruction'. The former pattern was found mostly in the less innovative sectors, and in this case, young, small firms did not survive. However, in the most innovative sectors, both young and mature firms did not survive, and the latter were driven out by incoming innovative firms in a process of creative destruction.

Velucchi and Viviani (2007) explored the relationship between innovation and survival in Italian firms using the Organization for Economic Co-operation and Development's (OECD) sector classification by technological intensity. The

empirical analysis included a sample of firms in the Tuscany region of Italy operating in the manufacturing industry and services sector for the 2000-2005 period. The companies' predominant characteristics were their small size and low technological intensity. The following results were noteworthy: a) survival rates for large firms were significantly higher than those of smaller firms; b) firms in the services sector had a higher probability of survival than firms in the manufacturing industry as the risks of the activity are lower; c) business size represented an advantage in increasing the probability of survival in mature, traditional industrial sectors (such as leather and clothing), but not in high-tech and emerging industrial sectors (such as biotechnology).

Although most studies have reported this positive result between R&D activities and survival, as evidenced by Rosembusch et al. (2011), Boyer and Blazy (2014) identified a distinct result for French firms. A comparison of innovative and non-innovative firms pointed to a negative relationship between innovation and survival, which is more closely linked to human capital (entrepreneurs' individual characteristics, such as sex, age, previous experience, and access to financial resources).

In Brazil, studies on this subject are very scarce. Although the relationship between size and survival is thoroughly documented in surveys of business entities (SEBRAE 2016), studies with larger databases and longer periods are rare. Conceição et al. (2018) addressed the issue of longevity by specifically focusing on the effects of the tax system. The authors analysed Brazil's Simplified Tax Regime (*Simples Nacional*) to understand the effect of this regime on the longevity of micro-industrial organisations in the country between the years 2007 and 2013. They concluded that organisations formed in 2007 that adhered to the Simplified Tax Regime presented a lower mortality rate than non-adhering companies by 30%. Furthermore, results revealed a trend towards a greater effect of the Simplified Regime on the survival of less technologically intensive sectors.

Resende et al. (2016) used the Annual Report of Social Information (RAIS) database to examine the survival of small Brazilian firms in the 1995-2005 period. The main results, which corroborate studies from developed countries, pointed to the positive effects of business size and industry size and growth and the negative effects of the minimum production scale, industrial concentration, and minimum efficient scale on survival rates. Another crucial result indicated that regional inequalities were a source of variation in survival rates.

Ehrl (2021) also used the RAIS database to explore the effect of loans from the Brazilian Development Bank (BNDES) in the 2003-2014 period. The author concluded that these loans, which offer lower interest rates and longer terms than those commonly practised in the market, helped reduce firms'

chances of leaving the market and were thus important public policies.

In a recent article, Botelho et al. (2022) discussed factors that determined the survival of small Brazilian industrial companies in the 1996-2016 period. With microdata from the Annual Industrial Research Company (PIA-Empresa) and CEMPRE, the study applied nonparametric (Kaplan-Meier risk function) and semiparametric (Cox proportional hazards model) survival analysis models to examine survival rate by the company's size, region, and technological intensity. The main results demonstrated a higher survival rate for small companies classified as having a moderate technological intensity and those located in the Northeast region of Brazil. Furthermore, firms that enter less concentrated markets and have higher growth rates are at a lower risk of terminating their activities.

In short, the studies analysed herein confirm the conclusions made by Cefis et al. (2022). Their analysis of a set of 142 articles showed that companies' exit from the market should be seen as a *heterogeneous event* that was determined by both micro- and macroeconomic factors. At the microeconomic level, '... there exists an innovation premium in terms of survival that is larger for young and small firms' (p. 430).

Materials and methods

The data for this study were derived from special tables provided by the Brazilian Institute of Geography and Statistics (IBGE) by cross-referencing the PINTEC and CEMPRE databases. PINTEC adopts the methodology established in the Oslo Manual.

The main objective was to obtain a set of data to compare the performance of innovative and non-innovative firms in terms of survival. Firms which declare not having made innovations in the PINTEC survey are not asked the same set of questions as those that declare themselves innovative. Therefore, little is known about this business universe that corresponds to about two-thirds of the total sample on average in the editions of the PINTEC survey.

Given this main objective, the two databases were cross-referenced, covering the industrial companies found in all editions of the PINTEC survey (2000, 2003, 2005, 2008, 2011, and 2014), whose survival rates are identified for the subsequent periods, 2005, 2010, 2015, and 2018¹. Based on this methodological procedure, the largest possible survival interval was determined to be 18 years for companies that participated in the first edition of the PINTEC survey.

After cross-referencing the PINTEC and CEMPRE databases, the sample of innovative and non-innovative industrial companies, which corresponds to the appropriate stratum for research, was obtained for this study, as shown in

Table 1.

Table 1. Number of innovative and non-innovative industrial companies – PINTEC 2000, 2003, 2005, 2008, 2011 and 2014

Firms	INTEC 2000	INTEC 2003	INTEC 2005	INTEC 2008	INTEC 2011	INTEC 2014
Innovative	4.958	4.522	6.055	6.563	5.813	5.876
Non-innovative	5.276	6.049	6.180	7.648	6.836	5.846
Total	10.234	10.571	12.235	14.211	12.649	11.722

Source: Elaborated by the authors based on microdata from Brazil (2022).

In addition to the general survival data throughout the period, breakdowns by size (small, medium, and large) and sector (classified by technological intensity) were also verified. Regarding size, the industrial firms were divided into three groups: micro and small firms (0 to 99 employees), medium-sized firms (100 to 499 employees), and large firms (500 or more employees), following the classification adopted by the Brazilian Micro and Small Enterprise Support Service (SEBRAE) (2013). Relative to the breakdown by sector, we used the OECD classification (2005), which divides the sectors into four levels: low, medium-low, medium- high, and high technological intensity.

Results and discussion

One of the elements repeatedly given to explain the current weak state of Brazilian industry is the firms' low innovative capacity. Among the general characteristics evidenced in the various editions of the PINTEC survey, the low rate of innovation in relation to that of developed countries and little spending on research and development (R&D) are notable. Innovative activities are concentrated essentially in the acquisition of machinery and equipment. Breakdowns by sector demonstrate that even sectors classified as high technology spend little on R&D in comparison to their international counterparts.

Considering this general diagnosis, this section illustrates the survival scenario of innovative and non-innovative industrial firms in Brazil based on information from the 2000, 2003, 2005, 2008, 2011, and 2014 editions of the PINTEC survey, which was cross-referenced with data from CEMPRE for the selected years (2005/2018). Figure 1² comprises seven graphs (one for each edition of the PINTEC survey) and demonstrates the survival rate of innovative

and non-innovative firms in Brazil. The graphs show the percentage of firms that are still active and that participated in the Survey of Innovation, classified as innovative and non-innovative.

In general, the survival curve for innovative firms is higher than the curve for non-innovative firms in all editions of the PINTEC survey analysed in the study. In other words, companies that did not innovate were more likely to terminate their activities than companies that carried out some type of innovation.

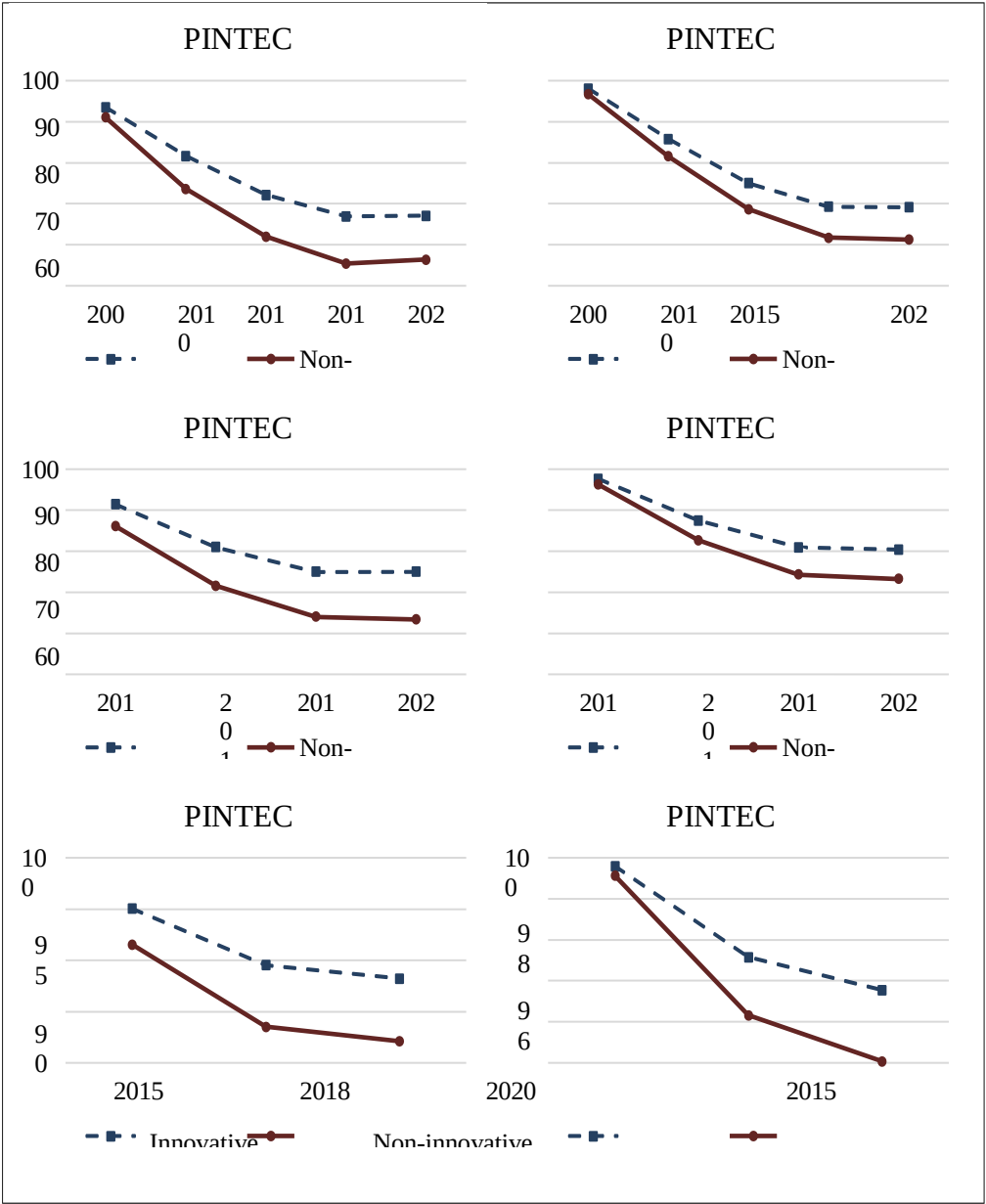
In the 2000 edition of the PINTEC survey, from the total number of companies that made innovations and were active in 2000, 93.51% were still active in 2005. This percentage decreases in the following years, and 81.63% of the innovative companies were active in 2010. The survival rate was 72.13% in 2015, and 66.92% of the active innovative companies in 2000 were active in the last year analysed (2018).

As for the companies that did not make innovations in the 1998-2000 period, the percentage of non-innovative companies that remained active over the years is lower than the percentage verified for innovative companies. Of the total number of companies that participated in the 2000 edition of the PINTEC survey and declared to be non-innovative, only 55.42% continued in activity in 2018, corresponding to 11.50 percentage points (p.p.) below the survival percentage verified for innovative companies (66.92%).

Similar results were found for the other editions of the PINTEC survey (2003, 2005, 2008, 2011, and 2014), as depicted in Figure 1. Based on the 2003 edition of the PINTEC survey, innovative firms presented a survival rate of 98.10% in 2005, whereas non-innovative firms registered a rate of 96.73% (2005). Both presented a drop in the survival rate throughout the period under study. In 2018, 69.28% of the innovative firms were still active, while this percentage was 61.71% for non-innovative firms.

The 2005 edition of the PINTEC survey also portrays what had been observed in the previous editions. Firms that did not make innovations in the 2003-2005 period registered a higher percentage of terminations in their activities than the industrial organisation that made some type of innovation. Accordingly, 8.59% of the innovative firms had terminated their activities in 2010, while this percentage was 13.90% for non-innovative firms.

Figure 1. The survival rate of innovative and non-innovative firms in Brazil – PINTEC 2000, 2003, 2005, 2008, 2011 and 2014 (%)



Source: Elaborated by the authors based on microdata from Brazil (2022).

From the 2006-2008 survey (PINTEC 2008), 80.92% of the innovative firms remained in business in 2018, while this percentage was 6.65 p.p. lower for non-innovative companies (74.27%) (Figure 1).

Based on the 2011 edition of the PINTEC survey, 95.03% of the companies that made innovations were still active in 2015. This rate declined in the following years as the percentage of active innovative firms was 88.54% in 2018. Regarding the non-innovative companies that participated in this edition

of the PINTEC survey, their survival rate was lower than that of the innovative companies for all the years under study. In the last year of the series, 16.47% of the non-innovative companies had terminated their activities.

Information from the 2014 edition of the PINTEC survey points to the same results demonstrated in the previous editions: innovative firms had higher survival curves than non-innovative firms in all the years analysed. These results are similar to those reported in studies from other countries, such as research by Ugur and Vivarelli (2020), Cefis and Marsili (2019), and Pérez and Castillejo (2008), and confirm the first hypothesis that innovative firms have higher survival rates.

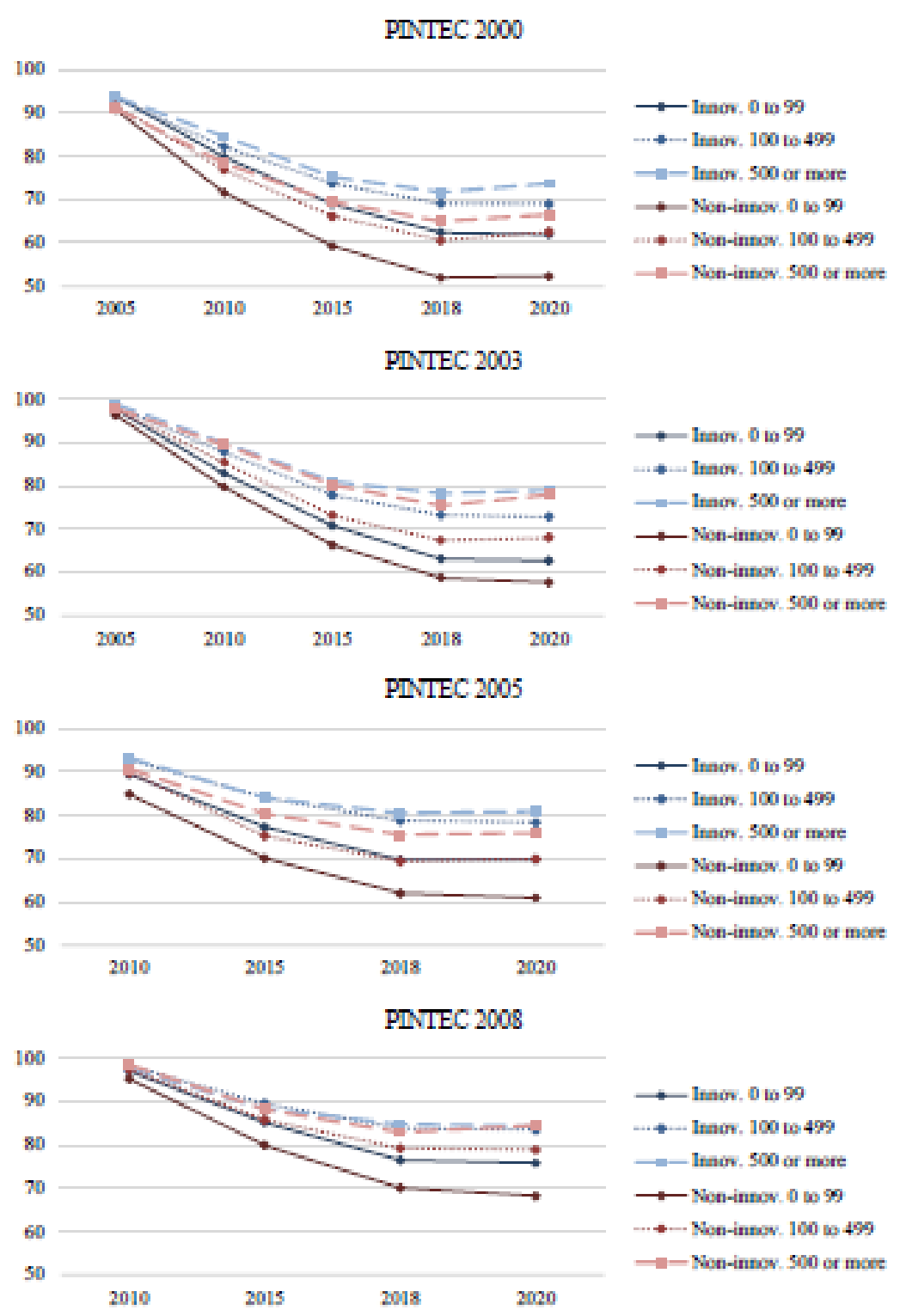
Survival among innovative and non-innovative firms by size

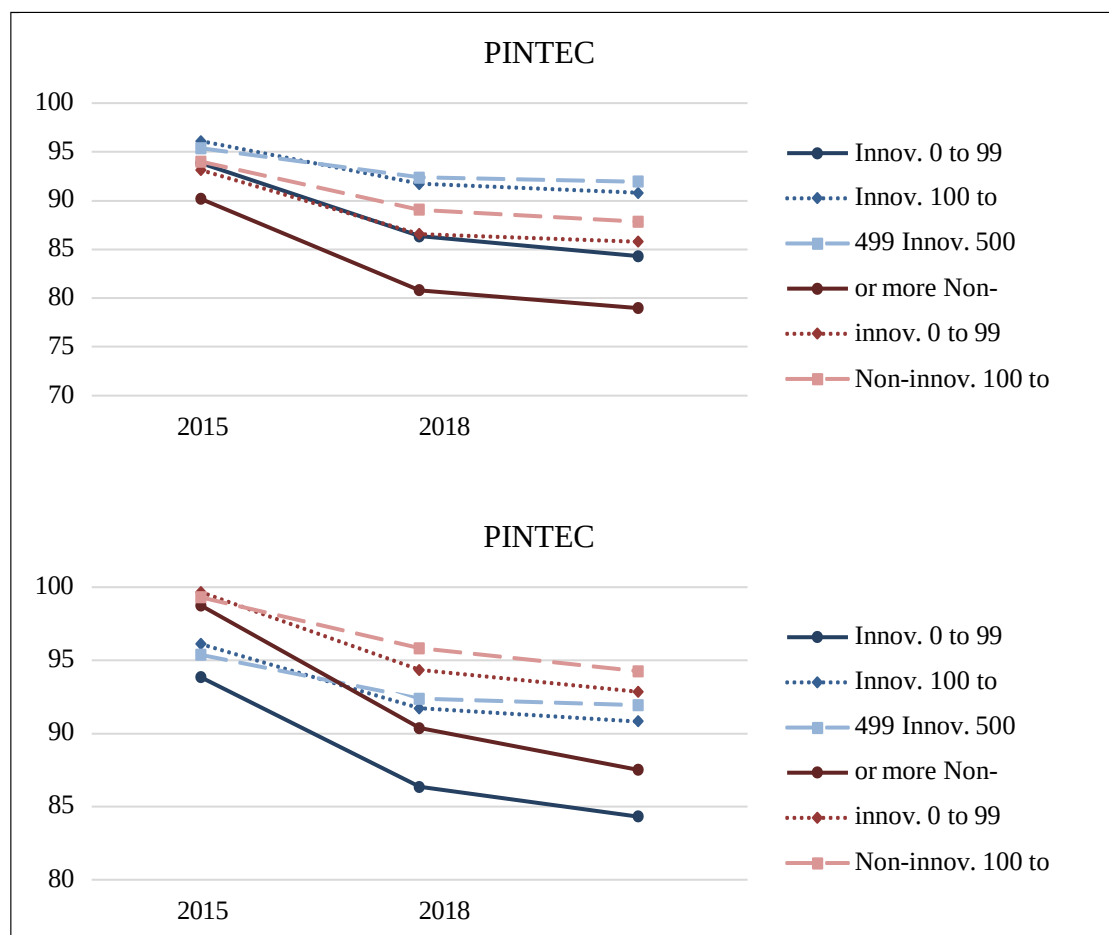
The next analysis refers to the breakdown of data by business size, and the criterion for defining sizes was based on the number of staff employed in the organisations, according to the SEBRAE (2013) classification. Thus, the industrial firms were divided into three sizes: micro and small firms (0 to 99 employees), medium-sized firms (100 to 499 employees), and large firms (500 or more employees).

The set of graphs in Figure 2³ shows the survival rate of innovative and non-innovative firms by size and for all the editions of the PINTEC survey selected in this study. However, the analysis will focus on the 2000, 2008, and 2014 editions of the PINTEC survey since the results of the other surveys are similar.

Based on information from the 2000 edition of the PINTEC survey, for micro and small firms, 62.35% of those that made innovations in the 1998-2000 period remained in operation 18 years later, while this percentage was lower for non-innovative firms at 51.90%. With respect to medium-sized firms, 69.02% of the innovative firms were active in 2018, whereas only 60.56% of the non-innovative firms remained active in the same year. As for large firms with over 500 employees, the innovative firms' survival rate was 71.67% and the non-innovative firms' rate was 64.93% after 18 years (Figure 2).

Figure 2. The survival rate of innovative and non-innovative firms in Brazil, by size – PINTEC 2000, 2003, 2005, 2008, 2011 and 2014 (%)





Source: Elaborated by the authors based on microdata from Brazil (2022).

In the 2018 edition of the PINTEC survey, the results revealed that from the total number of small companies that were active in 2008 and that made some type of innovation in the 2006-2008 period, 97.04% were active in the year 2010; however, this percentage dropped to 76.46% in 2018. This drop in the survival rate was greater for micro and small non-innovative firms. In 2010, 95.28% were still active, and by 2018, this figure was 70.05%. Medium-sized and large firms, on the other hand, had higher survival rates than firms with up to 99 employees, applying to both innovative and non-innovative firms. Over the course of 10 years, innovative firms with 100 to 499 employees presented a survival rate of 83.86%, while the rate for non-innovative firms of the same size was 79.21%. Large innovative firms exhibited a survival rate of 84.84%, and

non-innovative firms had a survival rate of 82.89% in 2018.

Therefore, with respect to the same size, firms that engaged in innovation presented higher survival curves than non-innovative firms. For example, for companies with 0 to 99 employees, it appears that innovative companies had a higher percentage of survival than non-innovative organisations of the same size (micro and small firms). This is also valid for the other business sizes. However, this result was not verified in the 2014 edition of the PINTEC survey.

In the analysis conducted in the 2012-2014 period, medium-size and large non-innovative firms presented higher survival rates than those of innovative organisations, regardless of their size. As shown in Figure 2, large firms with over 500 employees and non-innovative firms presented a survival percentage of 99.30% in 2015 and 95.83% in 2018. The survival rates of medium-sized non-innovative firms were 99.66% in 2015 and 94.34% in 2018. These figures were higher than those verified for innovative firms: large firms' survival rates were 95.38% (2015) and 92.37% (2018); medium-sized firms' survival rates were 96.11%

(2015) and 91.72% (2018); and micro and small firms' rates were 93.84% (2015) and 86.34%

(2018).

For all size ranges, the percentage of active firms, both innovative and non-innovative, decreased, occurring in all editions of the PINTEC survey analysed herein (considering the 2018 result in comparison to the first year of the series of PINTEC surveys). This reduction was more intense for firms with up to 99 employees, especially for organisations that did not engage in innovation. Conversely, firms with more than 500 employees had the highest survival rates, and in second place, medium-sized firms (100 to 499 employees) had the highest survival percentages.

Finally, a comparison of the survival curves between sizes and the division between innovative and non-innovative companies unveils an interesting fact: non-innovative firms classified as large (over 500 employees) had a higher survival curve than that of small innovative companies (0 to 99 employees), except in the years 2005 and 2010 in relation to the 2000 edition of PINTEC. Moreover, in the last year analysed for the 2008 and 2011 editions of PINTEC and in all the years of the 2014 edition, medium-sized non-innovative firms also had a higher survival rate than that of small innovative organisations.

In sum, in the 2000, 2003, 2005, 2008, and 2011 editions of PINTEC, the highest survival rates were registered as follows: 1) large innovative firms, 2)

medium-sized innovative firms, and 3) large non-innovative firms. The lowest survival curve was verified for small non-innovative firms. In the 2014 edition of PINTEC, medium-sized and large non-innovative organisations had the highest survival rates, along with the innovative firms of the same sizes. Finally, in the last edition of the PINTEC survey, the survival curves of medium-sized innovative and non-innovative firms presented close trajectories and were the highest survival curves, in addition to the curve of large non-innovative firms.

Regarding these results, the importance of innovation for business survival does not depend on business size. Throughout most of the period, innovative companies survived more often than non-innovative companies. Furthermore, the data point to changes in the year 2014, when medium-sized and large non-innovative companies demonstrate higher survival rates. In this period, the crisis in the Brazilian economy deepened, and policies were dismantled to support business innovation, which certainly influenced innovative activities requiring a more stable environment due to the high degree of uncertainty and high costs involved.

Given these caveats, the results confirm the second hypothesis that larger companies have higher survival rates. Additionally, the data show that the role of innovation in business survival is more pronounced for small businesses, which confirms the existence of an innovation premium for this segment of firms (Cefis et al. 2022).

Survival among innovative and non-innovative firms based on the sector's technological intensity

Considering the firms' sectors of operations classified by technological intensity, the results from the editions of the PINTEC survey analysed herein evidence a greater probability of survival for innovative firms operating in sectors with a medium-high technological intensity. The survival curves of companies in this segment were higher than the other curves, regardless of sector classification and segmentation into innovative or non-innovative activities.

Based on the 2000 edition of the PINTEC survey, Figure 3⁴ illustrates that innovative firms in sectors classified as having a medium-high technological intensity had the highest survival rate, 70.18%, in 18 years. Meanwhile, the percentage of innovative firms in sectors classified as having medium-low technological intensity which remained active in 2018 was 68.76%, and the survival rate was 64.62% for innovative firms in sectors with low technological intensity that were still active in the last year and had made innovations in the 1998-2000 period. Organisations operating in sectors with a high technological intensity exhibited the lowest percentages of survival in 2018 at 62.23%.

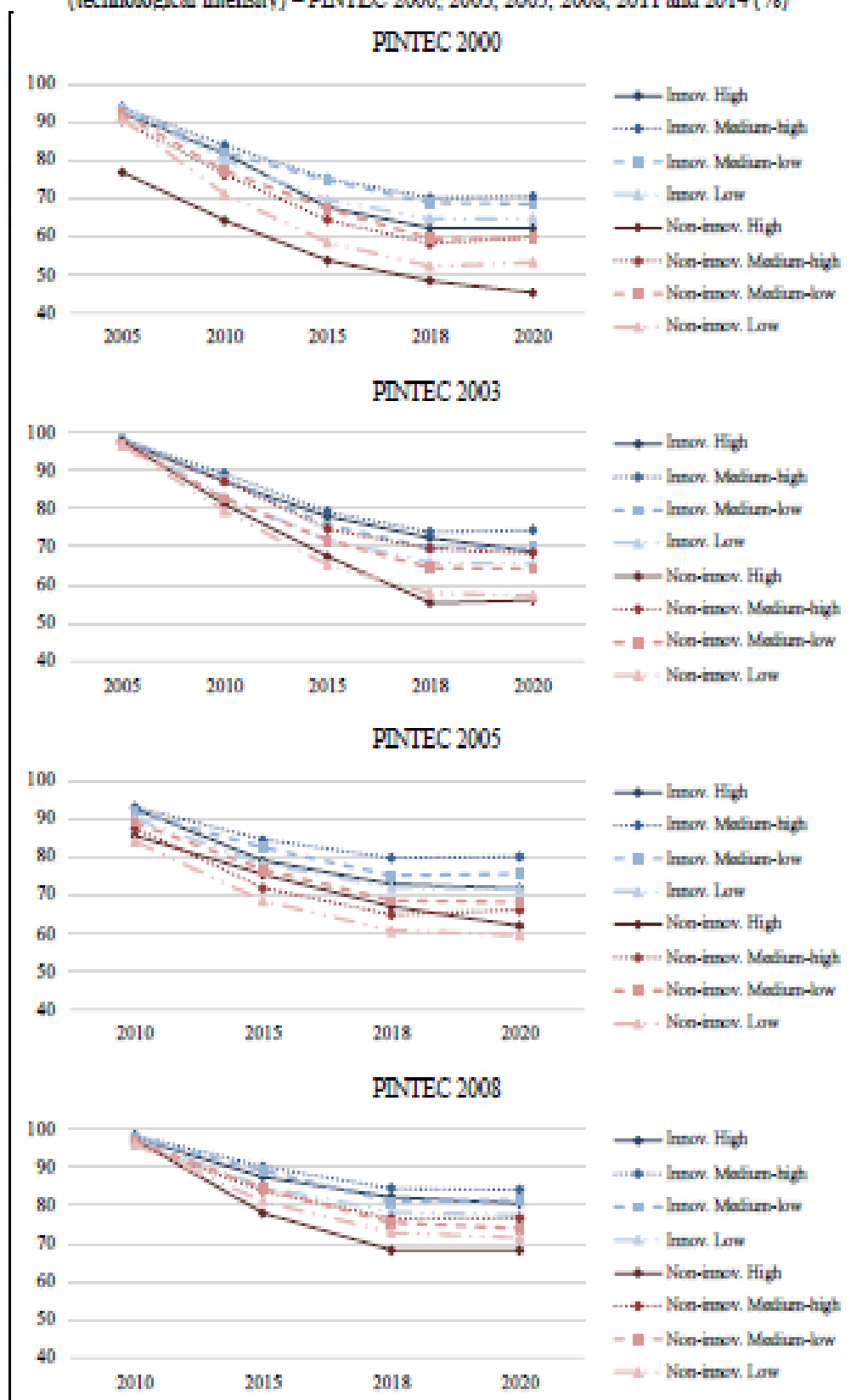
A similar process was observed in the 2008 edition of PINTEC. Innovative companies in sectors with a medium-high technological intensity had the highest survival rates. In 10 years, only 15.54% of the innovative firms operating in medium-high technology sectors had terminated their activities, while this percentage was higher for innovative firms operating in sectors with low technological intensity, at 21.67%.

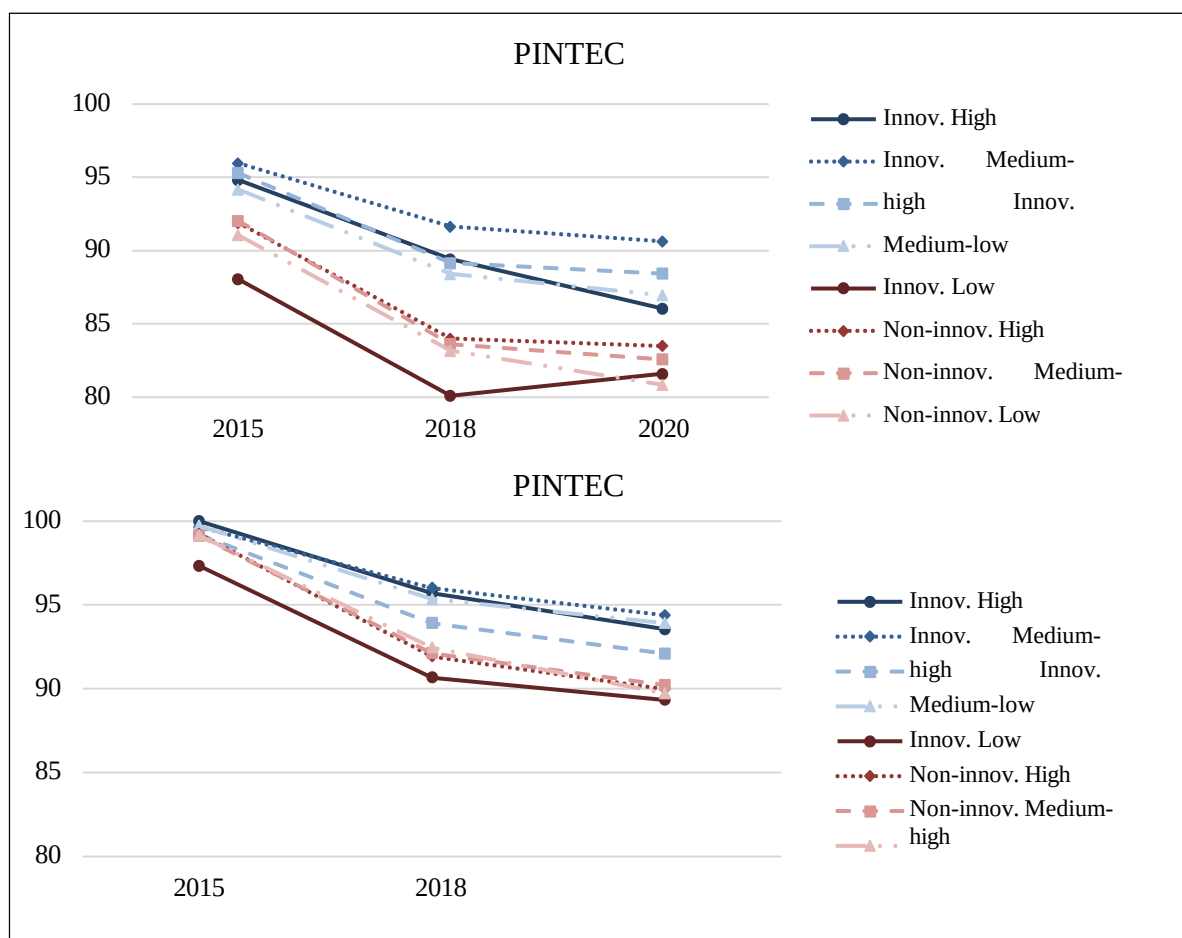
In the 2014 edition of PINTEC, the survival curve of innovative companies operating in sectors with a medium-high technological intensity was also higher than the other curves. The innovative organisations in medium-high technology sectors registered a rate of 96.01% in 2018. This result corroborates international studies conducted by Zhang et al. (2018), Ugur et al. (2015), Velucchi and Viviani (2007), and Fontana and Nesta (2007), who, for different samples of companies and countries, found that companies operating in more technologically intensive sectors have higher survival rates. However, in the case of Brazil, the highest rates are found in sectors classified as medium-high, not in sectors of high technological intensity. This certainly reflects Brazil's productive structure, which presents little participation from these sectors and low competitiveness from the respective companies.

In relation to the non-innovative companies, which had lower survival rates than the innovative companies, regardless of sector, the lowest survival rate was noted for firms in sectors with a high technological intensity (in the 2000 edition of PINTEC, as well as in the 2008 and 2014 editions). A small difference was verified in the 2003 and 2005 editions of PINTEC. In these editions, a lower survival curve was recorded for non-innovative companies operating in sectors with low technological intensity.

Based on the data for non-innovative firms from the 2000 edition of PINTEC and CEMPRE, 51.48% of the non-innovative firms operating in sectors with a high technological intensity terminated activities after 18 years. This percentage was lower for non-innovative companies operating in sectors of medium-high technological intensity and medium-low technological intensity

Figure 3. The survival rate of innovative and non-innovative firms in Brazil, by sector (technological intensity) – PINTEC 2000, 2003, 2005, 2008, 2011 and 2014 (%)





Source: Elaborated by the authors based on microdata from Brazil (2022).

Regarding the 2008 edition of PINTEC, non-innovative companies operating in sectors of high technological intensity also presented the lowest percentages of survival. Only 68.27% of the non-innovative organisations in high technology sectors were still active in 2020, while non-innovative firms in the other sectors presented survival rates above 70%. A similar result was identified in the 2014 edition of PINTEC: non-innovative firms operating in sectors with a high technological intensity also presented the lowest survival rates, while the highest curves were verified for companies operating in sectors with a medium-low and medium-high technological intensity.

The lowest percentage of survival was noted for non-innovative companies in the high technology sector in five of the seven editions of the PINTEC survey analysed herein, which demonstrates how difficult it is to remain in sectors with a high technological intensity without implementing innovations. In the other editions (2005 and 2011), the lowest survival rates were verified for non-innovative companies in sectors with low technological intensity. These companies represent the largest share of the Brazilian

productive structure, while the sectors present few barriers for entry and high entry and exit rates.

This result partially confirms the third hypothesis that survival rates differ according to technological intensity and that they would be higher in sectors classified as high technology. In fact, there were major differences in survival rates according to technological intensity. However, the sectors that present the lowest survival rates present some variation between innovative and non-innovative companies, as well as between the editions of PINTEC.

In short, the highest survival curves, according to the 2000, 2008, and 2014 editions of PINTEC, were verified for companies that engaged in some type of innovation, regardless of sector. A breakdown of the data showed that innovative firms in sectors of medium-high technological intensity had the highest survival rates, whereas non-innovative organisations in sectors of high technological intensity had the lowest survival curve.

Regarding sectors with medium-high technological intensity, they also exhibited the highest survival rates in Botelho et al. (2022). This study used microdata from the Annual Industrial Research Company (PIA-Empresa) for the 1996-2016 period. Therefore, with another database and methodology for analysis, the importance of these sectors for the Brazilian economy is also highlighted.

Conclusions

This unprecedented empirical study contributes to the debate over which factors determine business survival by providing data on the innovation and survival of Brazilian industrial companies over an 18-year period. Among the findings, innovative companies present higher survival rates than non-innovative companies, thus corroborating the first hypothesis of the study. This result is particularly vital given the importance that innovative activities present for business survival in Brazil, even with the focus on the acquisition of machinery and equipment.

As for the relationship between survival rate and business size, the results confirm the evidence presented in other empirical studies: survival rates are directly related to size, both for innovative and non-innovative companies. In sum, larger companies have higher survival rates. However, innovative companies always present higher survival rates, and this relationship does not depend on size.

Regarding the behaviour of survival rates according to the sector's technological intensity, companies that engaged in some type of innovation exhibited the highest survival rates, based on the 2000, 2008, and 2014 editions of PINTEC, regardless of the sector of operations. A breakdown of the results

shows that the highest survival rates were presented by innovative firms operating in sectors of medium-high technological intensity, while the lowest survival curve was demonstrated by non-innovative organisations operating in sectors of high technological intensity.

Given the results found herein, it is possible to infer the significance of implementing public policies to support innovation since innovation plays a fundamental role in the survival of Brazilian companies. Based on the data, increasing the number of innovative companies would have positive implications for reducing business mortality and would play a central role in the country's reindustrialisation process. It is also worth emphasizing the need to design policy instruments that consider the specificities presented by the context based on size and the sector's technological intensity.

Finally, there is ample room for future studies, such as research applying data from companies after 2018 to identify the effects of the COVID-19 pandemic on the rate of innovation and on the survival rate by size and industry sector. Another dimension of analysis is to identify macroeconomic factors that influence business survival and distinct effects between innovative and non-innovative firms.

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Appendix

Table 1A. The survival rate of innovative and non-innovative firms in Brazil – PINTEC 2000, 2003, 2005, 2008, 2011 and 2014 (%)

Edition of the PINTEC	Firms	2005	2010	2015	2018
PINTEC 2000	Innovative	93,51	81,63	72,13	66,92
	Non-innovative	91,03	73,64	62,02	55,42
PINTEC 2003	Innovative	98,10	85,78	75,01	69,28
	Non-innovative	96,73	81,58	68,71	61,71
PINTEC 2005	Innovative	-	91,41	81,01	74,98
	Non-innovative	-	86,10	71,55	64,03
PINTEC 2008	Innovative	-	97,65	87,48	80,92
	Non-innovative	-	96,30	82,65	74,27
PINTEC 2011	Innovative	-	-	95,03	89,54
	Non-innovative	-	-	91,53	83,53
PINTEC 2014	Innovative	-	-	99,59	95,15
	Non-innovative	-	-	99,13	92,32

Source: Elaborated by the authors based on microdata from Brazil (2022).

Table 2A. The survival rate of innovative and non-innovative firms in Brazil, by size – PINTEC 2000, 2003, 2005, 2008, 2011 and 2014 (%)

Edition of the PINTEC	Firms	Size	2005	2010	2015	2018
PINTEC 2000	Innovative	0 to 99	93,79	79,74	68,88	62,35
		100 to 499	93,16	82,14	73,72	69,02
		500 or more	93,73	84,43	75,25	71,67
	Non-innovative	0 to 99	90,72	71,56	59,22	51,90
		100 to 499	91,62	76,81	66,13	60,56
		500 or more	91,04	78,36	69,40	64,93
PINTEC 2003	Innovative	0 to 99	97,69	82,81	70,75	63,08
		100 to 499	98,25	87,77	77,80	73,14
		500 or more	98,83	89,82	80,91	78,15
	Non-innovative	0 to 99	96,33	79,67	66,29	58,71
		100 to 499	97,68	85,36	73,12	67,35
		500 or more	97,73	89,52	80,17	75,35
PINTEC 2005	Innovative	0 to 99	-	89,54	77,30	69,71
		100 to 499	-	92,84	84,13	78,77
		500 or more	-	93,21	84,04	80,48
	Non-innovative	0 to 99	-	84,86	70,08	61,97
		100 to 499	-	89,92	75,25	69,41
		500 or more	-	-	-	-

PINTEC 2008	Innovative	500 or more	-	90,69	80,34	75,52
		0 to 99	-	97,04	85,18	76,46
		100 to 499	-	98,30	89,54	83,86
	Non-innovative	500 or more	-	97,68	88,32	84,84
		0 to 99	-	95,28	79,93	70,05
		100 to 499	-	97,47	85,82	79,21
PINTEC 2011	Innovative	500 or more	-	98,56	88,25	82,89
		0 to 99	-	-	93,84	86,34
		100 to 499	-	-	96,11	91,72
	Non-innovative	500 or more	-	-	95,38	92,37
		0 to 99	-	-	90,17	80,80
		100 to 499	-	-	93,13	86,57
PINTEC 2014	Innovative	500 or more	-	-	94,00	89,08
		0 to 99	-	-	93,84	86,34
		100 to 499	-	-	96,11	91,72
	Non-innovative	500 or more	-	-	95,38	92,37
		0 to 99	-	-	98,74	90,37
		100 to 499	-	-	99,66	94,34
		500 or more	-	-	99,30	95,83

Source: Elaborated by the authors based on microdata from Brazil (2022).

Table 3A. The survival rate of innovative and non-innovative firms in Brazil, by sector (technological intensity) – PINTEC 2000, 2003, 2005, 2008, 2011 and 2014 (%)

Edition of the PINTEC	Empresas	Technological intensity	2005	2010	2015	2018
PINTEC 2000	Innovative	High	92,45	81,65	67,63	62,23
		Medium-high	93,91	83,90	75,12	70,18
		Medium-low	93,54	82,06	74,73	68,76
		Low	93,38	79,91	69,56	64,62
	Non-innovative	High	76,84	64,21	53,68	48,42
		Medium-high	90,41	76,21	64,38	58,16
		Medium-low	92,22	77,20	67,39	59,38
		Low	90,78	71,09	58,46	52,23
PINTEC 2003	Innovative	High	97,99	87,15	77,91	72,29
		Medium-high	97,95	89,13	79,11	73,80
		Medium-low	98,48	87,40	75,68	69,60
		Low	98,00	83,03	71,82	65,87
	Non-innovative	High	97,73	81,06	67,42	55,30
		Medium-high	96,94	87,05	74,62	69,42
		Medium-low	96,68	82,51	71,73	64,47
		Low	96,57	79,27	65,16	57,80
PINTEC 2005	Innovative	High	-	92,71	79,03	72,95
		Medium-high	-	93,06	84,54	79,75
		Medium-low	-	91,71	82,53	75,12
		Low	-	90,01	78,10	72,00
	Non-innovative	High	-	85,59	75,42	66,95
		Medium-high	-	87,54	71,84	64,87
		Medium-low	-	89,05	76,75	68,55
		Low	-	84,11	68,47	60,67
PINTEC 2008	Innovative	High	-	97,61	87,42	82,21
		Medium-high	-	98,30	90,15	84,46
		Medium-low	-	97,66	89,09	80,97
		Low	-	97,28	84,81	78,33
	Non-innovative	High	-	97,19	77,91	68,27
		Medium-high	-	95,95	83,80	76,62
		Medium-low	-	96,80	84,40	75,44
		Low	-	95,98	80,99	72,86
PINTEC 2011	Innovative	High	-	-	94,83	89,41
		Medium-high	-	-	95,98	91,64
		Medium-low	-	-	95,30	89,15
		Low	-	-	94,18	88,41
		High	-	-	88,06	80,10

PINTEC 2014	Non-innovative	Medium-high	-	-	91,91	84,00
		Medium-low	-	-	92,05	83,62
		Low	-	-	91,06	83,17
	Innovative	High	-	-	100,00	95,71
		Medium-high	-	-	99,66	96,01
		Medium-low	-	-	99,20	93,91
		Low	-	-	99,71	95,35
	Non-innovative	High	-	-	97,33	90,67
		Medium-high	-	-	99,24	91,94
		Medium-low	-	-	99,13	92,13
		Low	-	-	99,15	92,46

Source: Elaborated by the authors based on microdata from Brazil (2022).

Notes

¹ A change in methodology related to the selection criteria of active units was implemented at CEMPRE in 2019, which inhibits the use of this register for a survival analysis after the year 2018. Thus, it was not possible to use the 2017 edition of the PINTEC survey 2017 in this study. For more details, see <https://biblioteca.ibge.gov.br/visualizacao/livros/liv101832.pdf>. Accessed on Oct. 25, 2022.

² The corresponding table is found in the Appendix (Table 1A).

³ The corresponding table is found in the Appendix (Table 2A).

⁴ The corresponding table is found in the Appendix (Table 3A).

The infrastructural conditions of (de-)growth: The case of the internet

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Abstract

Infrastructure studies are an area that remains largely underexplored by degrowth scholars. It is paradoxical as infrastructures are a prerequisite for much of the human wellbeing degrowthers argue should be more evenly distributed, yet their consumption of resources and energy can be significant. The internet offers an instructive case study of such tendencies, at its best it forges human connections and is productive of considerable societal value. Yet, the resource implications of the often-overlooked physical layer of data-centres and submarine cables needs to be acknowledged. Furthermore, the ways in which assumptions of perpetual growth are built into this global infrastructure via the logic layer of internet protocols and other governing mechanisms such as finance and network design need to be examined if we are to determine the extent to which such infrastructures are inherently growth dependent. In making these two arguments, we draw upon the work of both science and technology studies and urban scholarship on the inherent problems of large infrastructures which have thus far seen little engagement with questions of degrowth to review the case of the internet and suggest a number of scenarios that illustrate potential roles for such infrastructures in any planned reduction of economic activity.

Introduction

Postgrowth and degrowth scholarship has, with increasing force, made the case that present levels of consumption are incompatible with environmental and social sustainability. Yet, within these arguments, the role of infrastructure remains relatively underexplored or theorised. This omission is problematic. The majority of degrowth scholars argue that high levels of societal wellbeing can be maintained in a non-growing economy, but only if current consumption/production arrangements are radically reconfigured to this end. Infrastructure is often a prerequisite for achieving the levels of material wellbeing degrowth scholars argue all are entitled to; reliable clean energy, fresh water and sanitation as well as opportunities for sustainable mobility and the chance to communicate with each other. Yet infrastructure systems also underpin and facilitate 'hypermobility' (Adams, 2001) and enable resource intensive lifestyles. Infrastructure networks represent considerable sunk resources and embodied carbon (Krausmann et al., 2017). The promise of new infrastructure holds political decision makers in its thrall to the point that any realistic appraisal of its ultimate costs are banished (Flyvbjerg et al., 2003; Frick, 2008) and, their continued expansion often appears predicated on maintaining growth at the global national and local scale (Kirkpatrick & Smith, 2011; Woetzel et al., 2016) to the point that the logic of growth appears written into the structures themselves.

As possibly the biggest infrastructure built by humanity (Blum, 2001), nothing appears to embody these tensions more than the internet. This assemblage of different networks and technologies (Morozov, 2015) has rapidly become integral to our lives and relationships, fundamental to social processes and productive of considerable societal value (Frischmann, 2005). There are also clearly negative elements to the impact the internet has had on society although a full appraisal of these beyond the scope or intention of this article. Here we, by and large, seek to avoid discussion of the content of the internet. We acknowledge its impact on wellbeing is mixed. On the one hand, it can raise awareness of environmental issues and facilitate activism but it can also reduce life satisfaction (Zhang et al., 2020). On the other, we accept that a significant proportion of the content of the internet is advertising, intended to reduce satisfaction and drive individual consumption, and that regulation of such content is integral to any attempts to foster wellbeing (Kozinets et al., 2017). The same is true of content with a negative impact on democracy and respect for others (Morozov, 2015). However, we restrict ourselves here to a discussion of the material elements of the internet. Its resource and energy implications.

Thus far discussion on energy consumption within the internet has tended to focus more on the demands of specific applications, such as blockchain and the

new generation of artificial intelligence (Naughton, 2023; Stoll et al., 2019). A more holistic approach, where the materiality of the internet infrastructure is considered as a whole rather than focusing on specific applications, is thus missing. In this regard, the internet has evolved into a global mega-infrastructure whose construction, maintenance and use demand immense flows of energy and resources. Foregrounding this material perspective is important to counter the widespread perception of the internet as a largely immaterial entity, which often leads to the erroneous assumption that growth of internet-based solutions involves a dematerialisation of the economy. At the same time, we take the view that a critical understanding of the internet's materiality cannot be reduced to a mere quantification of energy-matter flows without considering the political and social structures in which the latter are embedded. This conceptual move is necessary to address a second misconception in the literature, whereby infrastructural arrangements are treated as a purely technical domain devoid of political and ideological mechanisms.

In the following sections, we consider the extent to which the politics of growth are built into infrastructural artefacts. First, drawing on insights from science and technology studies (STS), we call for the foregrounding of global infrastructure networks within degrowth debates. This, we argue, raises questions about current conceptions of technology within the degrowth literature and the questions of scale which we explore in turn. Framed by key questions from STS on the relationship between infrastructures, the sociotechnical systems they constitute and their potential for change we introduce a case study of the material elements of the internet. This is divided into a physical and a logical layer, the latter governing the extent to which the technology is shaped in the expectation of perpetual growth. We conclude with two points for discussion and further research. First is a discussion of the implications of the voluntary restraint degrowth implies for the governance and materiality of the internet, specifically of what a more 'sober' internet might look like with an acceptance of the limits of existing infrastructure combined with greater efficiency of its use and some restrictions on the more damaging content. Second, we return to our call for degrowth to engage more with large scale infrastructure and the need for further research in this area.

Growthism in infrastructure

In his seminal essay "Do artefacts have politics?" Langdon Winner (1980) paints a compelling picture of the capability of infrastructures to limit social possibilities and crystallise power relations within society. Winner relates the history of the construction of overpasses in Long Island by Robert Moses, the public official responsible for much of New York's infrastructural growth from the 1920s to the 1970s. He claims Moses' overpasses were designed in a way such that public buses could not pass underneath, preventing the users of such

transport, working class and non-white New Yorkers, from accessing the public parks and beaches frequented by the rich. Thus building his own prejudices into the physical infrastructure with the intention of maintaining this status quo long after he had gone. “Doing politics” by other means (in this case through urban technology and infrastructure) is central to the way STS examines the mutual constitution of technology and society. Winner’s case of Long Island bridges has been the subject of fierce debate and criticism in the intervening decades over the extent to which intentions built into infrastructure actually shape the way it functions as human and non-human actors interact with it (Joerges, 1999; Rowland & Passoth, 2015). Nevertheless, within STS there is ample consensus about the capacity of urban infrastructures to enable or disable social possibilities. We argue such insights raise important questions about the extent to which other prejudices or intentions such as assumptions of perpetual growth are written into infrastructural systems.

Degrowth scholars have effectively problematised the concept of growth as a political project based on the lack of evidence it can be sufficiently and permanently ‘decoupled’ from resource consumption and greenhouse gas emissions (Parrique et al., 2019; Vadén et al., 2020). Simplistic conceptions of transitions from fossil fuel based to renewable energy infrastructural systems of the type reflected in pervasive narratives of ‘green growth’ have likewise, been challenged on the basis that they also fail to sufficiently decouple growth from its consequences (Hickel & Kallis, 2019). Yet any project of democratic downscaling of the economy (at least in the Global North) has to contend with the elevated position of technological utopianism within growth-driven societies. Growth-oriented institutions project technological futures onto and into the sociotechnical imaginaries that shape and justify the production of infrastructure (Jasanoff & Kim, 2015; Kerschner et al., 2018).

If this is correct, it means that unmaking imaginaries or changing people’s values, as many degrowth advocates (Feola, 2019; Latouche, 2009), might not in itself be sufficient to enable planned degrowth. Growth may be locked-in to the material underpinning of contemporary societies. Following Shove & Trentmann (2018), we agree that pylons, highways, pipes, satellite and communication networks, wires, electric charging points, sewage systems or electric grids can constitute physically imposing sights and conspicuous icons associated with the infrastructures of growth. Their workings are, however, typically invisible in current postgrowth accounts of technology, innovation and social-transformation which tend to focus on particular forms of technology and action at the local level. Therefore, alongside this imaginative shift there is a need to understand two key elements of degrowth that have remained under-researched and that are relevant to our relationships with infrastructure, the relationship to technology and the question of scale.

The relationship to Technology

An important influence on contemporary degrowth scholars in this area has been the work of Ivan Illich whose work draws on an established distinction between democratic and authoritarian infrastructures (Samerski, 2018). His calls for greater autonomy – or freedom from large techno-infrastructures and the centralised bureaucratic institutions, public or private, that manage them – require what he calls convivial tools or technology to free humans from large hierarchical non-democratic techno-structures (Illich, 1973). Recently, scholars have sought to engage in a more nuanced way with Illich's critique and the 'love/hate' relationship between degrowth and technology (Kerschner et al., 2018). Two relevant strands include calls for and examples of the democratisation of technology (Bradley, 2018; Rommel et al., 2018) alongside shifts in its governance and appraisal methods (Vetter, 2018). The former still relies, for empirical evidence, upon 'nowtopias' or small scale, real world experiments (Demaria et al., 2019). These have the advantage of providing some empirical insight into what a degrowth world of democratic technologies might look like. Nevertheless, they remain as marginal experiments, both within their own societies and as a share of the infrastructural systems used by a significant proportion of the planet. They may generate evidence that alternatives are theoretically possible, but, beyond that, the ability of these experiments to replace established systems remains unproven.

STS again adds to the discussion here in bridging the gap between technology and infrastructure without losing sight of the co-productive relationship both have with society. STS has a long heritage of studies into what are known as large socio technical systems such as electricity grids (Hughes, 1993). Alongside more recent STS influenced authors (Geels, 2002, 2005), this is a body of knowledge that offers insights into the network of social relations, material factors, human and non-human actors that govern the transition from small scale technology to large scale infrastructure and crucially for debates on how a switch to less carbon intensive infrastructure might be achieved. Key amongst these insights is a challenge to simplistic technological-determinism and technological-optimism showing that technical change, far from being a neutral and apolitical process, usually reflects the values, ideologies and worldviews of the society in which it emerges (Pansera & Owen, 2018). In this view, a certain path of technological change is enabled by specific socio-economic conditions, convergences of interests and historical circumstances that might or might not materialise (Bijker, 1995; Callon, 1991). Furthermore, multiple paths of technological change are possible and often coexist, although over time one might become hegemonic (Leach et al., 2012). Once a certain technological path becomes dominant, it goes through a process of naturalisation that creates the illusion that this is the only possible way of doing things, an inevitable progress of human ingenuity. However, what looks like an inexorable evolution is often the result of convergent interests, asymmetric power relationships and in many

cases systems of domination and violence (Harding, 2011). In a nutshell, over the last four decades, STS scholarship has provided robust evidence that the innovation process - the core of technical change - is socially, culturally and politically constructed.

This perspective is particularly valuable given the way degrowth literature largely overlooks existing infrastructural networks and the extent to which these are shaped by a growth-dependent political economy. These constitute the material foundation of our world and contain the embedded legacies of a very different set of relationships between and within states, and crucially towards the natural world (Serres, 1995). We argue that it is essential for degrowth to engage with this reality if it is to get beyond activities at the margins and to counter criticisms that it is in some way anti-modern or anti-technology and technological innovation. Indeed, it should not be assumed that all technologies envisaged under degrowth scenarios are inherently small scale. Moves towards a circular economy (Bauwens et al., 2020) and big shifts towards renewables are seen as compatible with and even central to this top-down reshaping of the economy (Mastini et al., 2021). There are productive avenues emerging exploring which sectors should expand or contract and engage with the questions posed by degrowth at the scale of national economies (Hardt et al., 2021). But the question of science, technology and innovation (STI) and the way they combine to create macro conglomerates of infrastructures, remains a critical one. Particularly, the type of STI possible under degrowth scenarios remains an underexplored area for degrowth-minded scholars, having received very limited reflection thus far (Pansera & Fressoli, 2021). Indeed, much of the degrowth approach to STI remains critical of the way they currently function as drivers of capitalist accumulation and of technical fixes (Kallis et al., 2018; Kerschner et al., 2018). Whilst not seeking to reject the critical perspective we argue it remains important to explore the extent to which such intentions and uses can be disentangled from the process of innovation. This is essential if we are to conceive of what innovation and infrastructure, particularly large scale infrastructure, might look like without the growth imperative.

The question of scale

The inherent difficulties in engaging with the larger than local scale have been acknowledged by some degrowth scholars who challenge the way early influences like Latouche uncritically accept the distinction between local, national and global (Kallis & March, 2015; Lloveras et al., 2021). Much discussion on technology within degrowth is informed by this simplistic interpretation of scale, where the "local" dimension is not only taken for granted, but also idealised as an optimal scale for degrowth-minded transformations (Lloveras et al., 2021). A fetishization of the local can, they argue, be seen in the emphasis on small scale technologies (Kallis and March, 2015). Yet there are emerging pathways out of this focus only on the small scale

or local level. One such pathway is replication as an alternative to growth which Pansera and Fressoli (2021) point to as a means of avoiding both the tendency toward oligopoly in large aggregations and as a means of maintaining internal democracy. Echoes of this strategy can be seen reflected in Ebenezer Howard's (1965) polycentric model for urban development based on an ideal sized community with new settlements established once a certain size was reached. This approach can be seen reflected in recent calls for the application of degrowth principles to urban planning through developing the concept of autonomy at a regional scale (Savini, 2019).

Variations on this theme are picked up in the work on degrowth and innovation with both Vetter (2018), and Pansera and Fressoli (2021) identifying modularity as an approach to growth that distinguishes conviviality from non-growth oriented technologies and organisations. Certainly, calls for a more modular approach within mainstream critiques of the problems of large scale infrastructures have something in common with similar approaches to convivial technologies (Ansar & Flyvbjerg, 2016). The main difference is that, whereas in this literature modularity is usually designed for upscaling, from a degrowth perspective this modularity should also offer the possibility of downscaling (Vetter, 2018).

Another possible pathway is the open source movement identified as a model for technological development that operates effectively at scale in a distributed manner whilst maintaining many of the features of openness. Despite problems in implementation and inclusion due to heavy gender imbalances (Vetter, 2018) open source technologies like Wikipedia or Linux offer examples of up to date technologies operating at scale on a collaborative basis. This final point is critical to how degrowth approaches to technology begins to engage more productively with the question of scale. It provides contemporary examples to support a body of evidence that questions the assumption that the management of complex infrastructures is inherently hierarchical and only achievable at the large scale (Graeber & Wengrow, 2021).

If a degrowth imaginary has any chance to succeed, it is necessary to understand how a planned contraction of the economy might work in practice at the scale inhabited by infrastructures such as the internet. This draws the question of infrastructure into sharp relief. As we have already suggested, posing the question at the local scale fails to go beyond the comfort zone of degrowth and risks sustaining false assumptions about the nature of democratic governance as something that can only be achieved at such scales. Moving from the local to the urban scale engages with valuable real world examples of the introduction and reintroduction of both commons and public governance of infrastructure (Becker et al., 2017; Hall et al., 2019). Yet it still cedes too much space to the large scale state and market led projects, the imaginaries (Jasanoff & Kim, 2015) and elites that support them (Menga, 2018)

and their reliance upon state support. This is particularly relevant to contexts where the state is either weak or captured by a global infrastructure industry (Kenney- Lazar & Ishikawa, 2019). It risks skirting around the power that now 'resides in infrastructure' (The Invisible Committee, 2017) and multi-trillion dollar programmes being called for to plug global 'infrastructure gaps'. These are programmes intended to equip infrastructure systems to keep pace with projected economic growth - an embedded growth mechanism - often requiring further funding if sustainable development goals are added on top (see for example the Global Infrastructure Hub Update - June 2018, n.d.).

There is already an established critique of mega-infrastructure albeit one largely framed in the type of cost- benefit terms more appropriate to a growth paradigm. Here the ever escalating cost of mega-projects, their inability to meet deadlines or to deliver the levels of performance that were originally claimed for them is widely known (Flyvbjerg, 2014; Flyvbjerg et al., 2003). This still acknowledges the dangers of locking policy making into attempts to chase investments sunk into large infrastructure projects (Cantarelli et al., 2010). As technologies and reflections of modernity, such practices are often aided by the grip endeavours of such scale and sophistication appear to exert over policy makers (Frick, 2008). Whilst the mega-project literature serves as a valuable cautionary note of the risks of hubris and optimism bias, the dangers of politically driven lock in, and the allure of technology, it focuses largely on the relationships between state and market. In contrast, the internet is a large socio-technical system for which the physical infrastructure is largely in the hands of private actors (Blum, 2001). This may alter the makeup of the web actors and technologies yet the basic insights from STS remain; i) technological change and innovation occur in complex socio- technical systems that are underpinned by specific interests, values and social relations; ii) socio-technical systems, and thus infrastructures, are arranged in ways that enable or disable certain social practices; iii) on the one hand, an implication of the above is that socio-technical systems are path-dependent, meaning that they tend to lock-patterns and generate inertia; iv) yet on the other, socio-technical systems (including infrastructures) are never totally stable. They can be contested and renegotiated in interaction with users, as well as other stakeholders who seek to endow them with different values

A case study: Internet Backbones as a Planetary infrastructure

The complex mesh of cables, machines, companies and software that constitutes the internet represents an ideal case to explore the limits to degrowth a mega-infrastructure. With its planetary network of submarine cables, its data centres spread across continents, and satellite communication links, the internet represents a truly global infrastructure (Blum, 2012). Somewhat paradoxically, it is also the most invisible one. Most of its five billion users worldwide mainly interact with terminal devices such as laptops or mobile phones while ignoring

the complex hardware infrastructure that make possible streaming, gaming or uploading holiday pictures to the cloud. Far from being an immaterial utopia, the internet emerges from and depends on a very concrete and vast materiality. What Bratton (2016) has called 'the stack' does not only involve software and hardware but also immense flows of material and energy resources, geographical territories in their traditional sense and the biosphere. Unlike other infrastructures of our industrial society, an interesting feature of this megastructure is that it is not the result of a coordinated master plan, although some of its key fundamental parts did emerge through planned and coordinated scientific efforts. Instead, its layered technologies converge in an emergent order that is largely the result of technical and social interactions at different scales and as part of different histories; interactions that are unmanaged and unplanned.

The internet has been instrumental to the current form of neoliberal globalisation. Born as a military project, then a scientific experiment, the network has been crucial to revolutionising global supply chains, *de facto* enabling an unprecedented acceleration not only of international trade but also the creation of complex planetary networks of production and consumption (Harvey, 1989). In this sense, the megastructure of the internet can be also thought of as a platform, a mix of standards-based technical and social systems with distributed interfaces that enable remote coordination of information and action (Wark, 2021). As a platform infrastructure, the internet enabled the emergence of neoliberal globalisation but it can and could also enable non-market forms like Common Based Peer Production, open source movements and endless possibilities for self-organisation and autonomy.

The Internet mega-infrastructure is then a critical element in understanding economic growth in the last 30 years since it has been instrumental in the expansion of digital technology which represents the fastest growing sector in the world economy (N. Jones, 2018a). But is this planetary infrastructure inherently designed to scale up indefinitely or, more appropriately, is the stack materially and/or institutionally locked- in a growth-dependent path? Reflecting on these questions is the first step to understanding to what extent a degrowth imaginary is compatible with planetary mega-structures or to think strategically of mechanisms to degrow mega-projects like the internet. In order to engage with these questions, it is useful to consider two analytical levels of the internet drawn upon the work of Frischmann (2005). The physical layer, includes the hardware and software infrastructures, and the logical layer, which consists of the different levels of the internet governance (Frischmann, 2005).

The physical layer

The physical layer of the internet consists primarily of submarine cables and data centres, landlines, radio links and satellites. This also includes the physical networks of terminals like computers, mobile phone networks controlled by human users. The materiality of the stack also includes the software layers, that are all the algorithms and code that allow computation, routing and management of the different hardware layers. More recently, there has been an increase of non-human users like sensors, 'smart' appliances, bots and others. It's estimated that humans represent only 36% of all internet traffic (Chinnasamy, 2022). The rest 64% is automated traffic including bots and hacking tools. For the sake of simplicity we will focus only on the major elements of the physical layer: submarine cables and data centres.

Most people wrongly assume that satellites in space are what enables internet connection between different parts of the world. In reality, ninety nine per cent of the data travels between continents through a global maze of undersea, transoceanic cables (Starosielski, 2015). Built upon the telegraph cables infrastructure at the end of the 19th century, submarine cables wrap the entire globe (see fig 1). Within this context, two general trends are worth discussing. First, since 2016 demand for cable capacity has been doubling every 2 years (TeleGeography, 2023), fueling a constant demand for more cables. Second, there has been a significant shift in cable ownership during the last 7 years. Traditionally, submarine cables had been funded by consortia of big carriers that include private companies and state agencies. These projects typically cost hundreds of millions of dollars to build. Carriers then sell broadband capacity to their customers, usually internet providers - who act as intermediaries between the large carriers and the end users. More recently, a new privately funded model has emerged where companies would fund an entire cable project and then lease capacity on the cable wholesale to carriers. Content providers like Google, Facebook, Amazon and others are directly funding submarine cable infrastructures with the intention to increase their bandwidth capacity and gain direct control over their traffic. This means that their hunger for big data will drive bandwidth growth. The Dunant cable, for example, that was launched in 2020 has the capacity to transmit the entire digitised Library of the USA Congress three times every second. Google was the first of the big four US-based hyperscale cloud platforms to start investing in this model based on content providers sidestepping carriers and directly building their own private submarine cables. The group, which also includes Facebook, Microsoft, and Amazon Web Services, to date has invested around \$20 billion in new cables all over the world (Sverdlik, 2021).

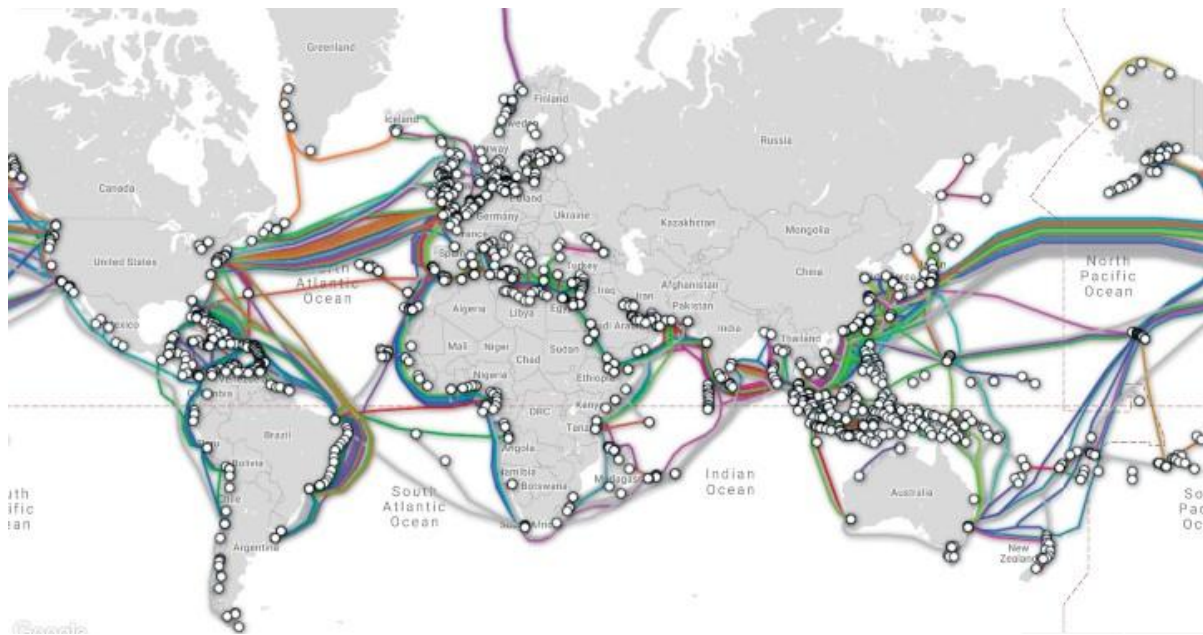


Figure 1 Global Submarine Network database. Source: <https://www.submarinecablemap.com/>

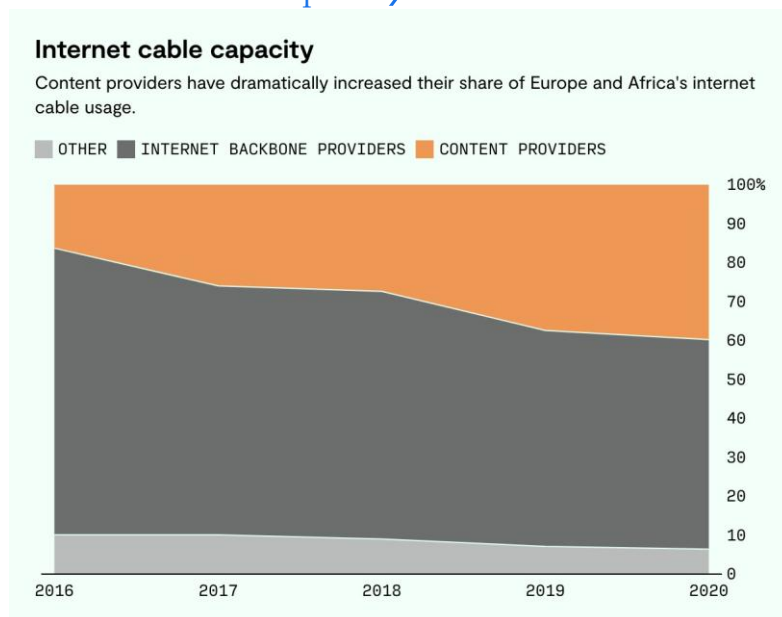


Figure 2 Internet Cable Capacity Source: <https://www2.telegeography.com/>

The network of submarine cables is intentionally designed to be resilient. In order to cope with multiple sources of disruption (e.g. submarine landslides and earthquakes, large vessels anchoring and other human or natural activities). Furthermore, intercontinental submarine connections are equipped with backup lines (Blum, 2012). Additionally, cable bandwidth capacity is always overdimensioned, meaning they are conceived in a way that they can physically carry more data than needed. This is because these infrastructures are not designed to serve present demand but rather to be able to scale up if demand for traffic increases (Blum, 2012). In this sense, it is useful to distinguish between the lit capacity and the potential capacity of cable. The first indicates the capacity a cable is currently equipped to handle, whereas the latter is the theoretical maximum capacity that a cable can support if additional capital was invested to fully equip the cable (Blum, 2012). Most of the major transatlantic links, for instance, use less than thirty percent of their potential capacity (TeleGeography, 2023). Although since 2018 we can observe an increase in the lit share of potential capacity, many companies prefer laying out newer cables because they are far more technologically advanced and their unit cost is cheaper than old cables whose lit capacity is increased. In other words, new cables have better economies of scale (TeleGeography, 2023). This mechanism drives growth in bandwidth availability that in turn feeds an ever increasing demand for traffic.

Besides the submarine cables, Another crucial element of the physical layer of the stack is the data centres. These are the physical infrastructures that store, process and transfer information and by far are the elements of the mega-infrastructure that consumes more energy (Jones, 2018b).

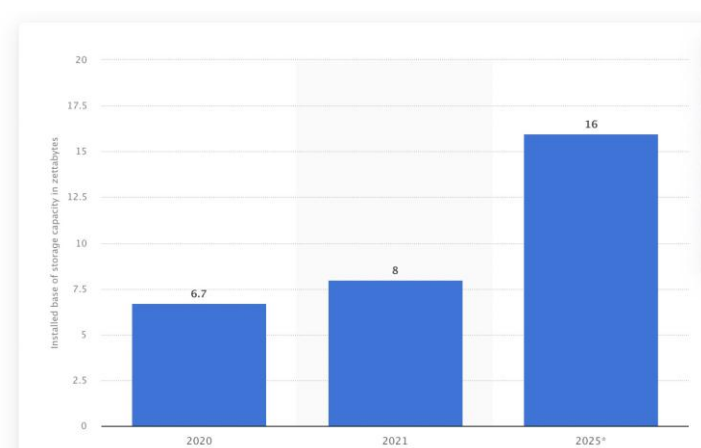


Figure 3 Data storage capacity in the global datasphere. Source: (Sandvine, 2022)

Data centres are the real engine of the stack and are also a highly concentrated business. One of the reasons big data corporations are heavily investing in submarine cables is that they are also the largest owners and managers of data centres. Google, Facebook, Apple, Amazon, Microsoft, and Netflix together generate almost 57% of all worldwide broadband traffic (Gartenberg, 2020). These companies are interested in connecting their data centres around the world in such a way as to be independent of internet providers and to have the capability to decide where to land the cables (McGeachy, 2022). Data centres are usually located where large users' numbers are. If they control the cables, internet companies could effectively dictate internet policy, even if apparently that is not their explicit intent. In order to increase flexibility and resilience, data centres also implement backup and redundancy mechanisms. Youtube, for example, stores most of its data in Google Modular Data Centers. A modular data centre is a portable structure that can be replicated and placed wherever the data storage capacity is required (Jones et al., 2013). Data in these centres are constantly transferred and updated on the basis of the users' demand. To maximise the efficiency of the systems and to minimise the latency in the network, most of the time content providers store different backup copies of the same content. This, combined with an ever increasing demand for traffic, partially explains the exponential growth of data centre capacity (Fig.3). The growth of demand forced companies like Twitter to redesign their original network structure as their traffic grows faster than the company can re-architect an entire data center. As a consequence, they started implementing a highly scalable architecture that allows adding capacity incrementally to cope with the increasing demand for data storage (Hashemi, 2017). The apparently infinite capacity to absorb data by the stack allows big actors like Google or Facebook to store content and users' data virtually forever, which in turn expands the energy demanded by these data centres, as we show below. According to Youtube policy, videos are deleted only when an account is blocked or cancelled or when youtube ceases its operation. Historically, Google has retained user data indefinitely, including very sensitive personal data and georeferenced data about users' positions. In 2019, however, the company rolled out a way to automatically delete data points after three months or 18 months, depending on the chosen setting (Google, 2023). Nevertheless, serious concerns can be raised about the transparency of data storage policy where no clear regulation is still in place. It appears reasonable to assume governments can store data indefinitely for security reasons. Considering also the fact that more and more companies such as Amazon profit through their data storage services, it makes sense to accumulate data instead of erasing and deleting it.

Data are not immaterial, they require energy and material to be processed and stored. If data increases, so do energy and material consumption. This inevitably requires and demands more growth. According to

Freitag et al., (2021) the internet produces around 3.7% of global CO2 emissions and unlike other sectors of the economy, its energy intensity is increasing 4% per year. Belkhir & Elmeligi (2018) have calculated that the whole ICT's relative contribution will exceed 14% of the 2016-level worldwide GHGE by 2040 with data centres being the largest culprit (45%) followed by communication networks (24%). These figures do not take into account the development of the 'Internet of Things' and the cryptocurrency explosion (The shift project, 2018). Madlener et al., (2022) have modelled different scenarios of how the future energy consumption caused by video streaming could develop. In the worst case, energy consumption could increase eightfold by 2030. In conclusion, it seems evident that digitalization unleashes the potential to produce more economic growth related emissions rather than leading to dematerialisation of the economy (Lange et al., 2020). Furthermore, the construction of data centres can be a source of environmental conflicts due to their disruptive nature, impact on local communities and their natural environments -e.g. excessive water consumption, as well as their impacts on landscapes and human health.

The logical layer

There is also a logical layer that regulates many aspects of the stack such as communication protocols, rules and policies to coordinate and shape cyberspace. The basic structure of the internet, the backbone, consists of companies, government, and academic direct links known as Tier 1 connections. Tier 1 links are Internet Protocol (IP) networks that can reach every other network on the Internet via settlement-free interconnections, which means they exchange traffic with other Tier 1 networks without paying any fees (Blum, 2012). There exist only 15 Tier 1 networks, also called Tier 1 Internet Service Providers (ISP). The Internet mega-infrastructure is then a network of independently-managed networks, woven together by standardised communication protocols. All these protocols were designed to guarantee interoperability among diverse physical infrastructures and softwares on one hand; on the other hand, they were planned to be scalable and allow a virtually endless expansion of the network. For example, the protocol IPv6, which upgrades the IP systems, can uniquely address a trillion trillion times the number of devices currently connected to the Internet. Such a dynamic governance of the internet, in principle, would allow a downscale of the network that would theoretically preserve the same functionality. However, in practice the way internet governance has worked to date has been based on the assumption of endless expansion of access demand and content provision. This is evident in the over-dimensioning strategy adopted in the design and implementation of both the physical infrastructures and the protocols that govern the network. As Libório et al. (2020) show, for example, over-dimensioning strategies could be particularly attractive for companies because they substantially reduce future investment in the network between thirty and forty one per cent. Oversize strategies are common in the design of many web

infrastructures in order to respond to peak usage. The crucial variable here is the capability of the network to transfer data. The trend is to create applications that use more data (videos) and to connect devices that acquire more data (big data for AI, sensing, surveillance systems etc.). Media content (Netflix and other video streaming platforms already represent the majority of internet traffic, and this increased during the pandemic), big corps interested in big data acquisition and processing push for bandwidth increases. This treadmill of digital data production is perfectly embedded in a global hyper competitive market economy in which the main actors, mainly digital giants, expect ever increasing returns on investment. As a result, even if the original architecture of the physical layer was designed to be flexible and, at least in principle able to descale, the financial superstructure that makes the internet functioning seems to be clearly set around expectations of endless expansion.

Growth Built-in Mechanisms

As discussed above, the internet infrastructure has been not explicitly designed with built-in mechanisms that compel the network to grow indefinitely. It is rather an emergent phenomenon of clusters of separate infrastructures that were in their origin unplanned and unmanaged. Nevertheless, although there's no deliberate 'growth design', we can observe clear incentives to grow in the way the physical layer has evolved and the way the logical layer functions. What emerges from our analysis is that at least two broad growth built-in mechanisms, or as Hickel et al. (2022) have called 'growth dependencies' are in place today in the internet mega-infrastructures: network-design and governance-financial.

Network-design

Originally the internet was thought to be a flexible, resilient and scalable infrastructure. However, the technologies on which it is based, especially electronic, software and telecommunication technologies, have shown exponential rates of innovation, with vast improvements in terms of (Brock & Moore, 2006). Such a spectacular historical trend has shaped the expectations of companies and users that access, bandwidth and speed of connection will increase forever. This is evident in the way submarine cables are installed with lit capacity much lower than their potential capacity, and in the way that the fiber-optic technology outruns the full exploitation of working cable links. Furthermore, infrastructures for digital communication, routers, computers, and electronic boards, have been traditionally overdimensioned to be upgraded and rarely to be downgraded favouring the growth of humans and non-human users (e.g. bots), the latter already representing a majority of all internet traffic.

The increasing share of private ownership of crucial infrastructures such as submarine cables and data centres seems to reinforce the embedded scaling potential offered by digital technologies. Big content providers have an interest

in increasing the network capacity to accommodate their business models based on big data acquisition for AI, video streaming etc. To make matters worse, there is the fact that advanced applications such as AI algorithms require ever increasing amounts of data and computational power, and energy as a consequence, in order to improve their accuracy (Hao, 2019). In addition, social media tend to create accumulative effects by design. Big Data actors require an ever-increasing amount of data generated by the users to be monetised and sold. The increasing control over the stack by big players is likely to restrict states' and users' capabilities to question and negotiate alternative uses of the infrastructures that constitute the internet. Finally, the manufacturing and maintenance of submarine cables and data centres require continuous flows of energy and new materials which are supplied according to the logic of growth that underlies global capitalism. This means that electronic equipment, fiber-optic, motherboards and the like are usually affected by all sorts of planned obsolescence mechanisms with the intention to be upgraded by new technologies with augmented capabilities and potential for expansion (Slade, 2006).

Governance-Financial

If the growth built-in mechanisms that we observed in the physical infrastructure design seem to be, at least in principle, reversible, the economic models that sustain the internet clearly show 'growth dependencies'. Similar to a gigantic Ponzi scheme, the need for endless growth of the stack is a direct effect of the process of financialization (O'Neill, 2019) of the internet infrastructure. In this sense, the internet is characterised by the same growth dependencies that affect virtually any sector of modern market economies. It is interesting to note, rather than enabling a diversity of institutional settings, the internet has had a standardising effect on institutions around the world. Despite their diversity,

"the computational architecture of their operations is increasingly the same, varying only according to the minimal options offered by parameterized systems—from logging, billing, visualisation, data authentication, predictive analytics, business intelligence, search, conversion, publication, and backup" (Rossitier, 2016: 240).

This means that on one hand, the model has crystallised around financial capitalism and on the other the digitalization has unleashed new potential for expansion creating positive feedback that leads to new cycles of capital accumulation and growth (Wark, 2021). In addition, all sorts of vulnerabilities created by the uncertainties of climate change are likely to influence the financial models that sustain the internet. Submarine cable maintenance for example, which is already extremely expensive, is likely to be affected in unforeseen ways in the future. There are also uncertainties related to the

refrigeration of data centres if average global temperatures increase (Gartenberg, 2020). Moreover, microchip scarcity and their rising costs represent other huge uncertainties that push internet companies to promise and seek high returns to justify ever increasing investments (Celasun et al., 2022). These factors suggest that the financial model that maintains the internet infrastructures condemns the network to scale up rather than taking into consideration the possibility of a smaller, less energy intense internet.

Conclusion

Designed to be scalable and surrounded by expectations to dematerialise the economy, the internet has become a mega-infrastructure that drives growth and, at the same time, is driven by it. We can assume that the internet in a degrowth society would use only a fraction of its present energy and material consumption, and would be under social control. Nevertheless, it is hard to imagine how the intricate mesh of submarine cables, data centred protocols and power relations that sustain the 'stack' would survive the reductions of energy and resources that are needed to meet climate targets. Here we contemplate a number of plausible scenarios. First, there is a scenario of collapse in which the vast energy and material flows that sustain the stack are no longer available or must compete with other uses like food or other primary goods production. The internet in its current form collapses and only basic links with limited bandwidth will be available. This scenario does not necessarily mean that the internet as we know it will disappear. Rather, a collapse could lead to extreme forms of commodification whereby large companies and internet providers restrict access to elites. Although the internet has enabled the emergence of neoliberal globalisation, it can also facilitate non-market forms of exchange conducive to new modes of organisation and ways of life, including Common Based Peer Production, free information sharing, and the immense possibilities for self- organisation offered by the network. If degrowth means completely abandoning the internet megastructure it also means renouncing these opportunities. In other words, an internet collapse would seriously affect the potential for implementing degrowth imaginaries.

A more desirable scenario might involve a sober internet. Given the vital importance of the internet to deliver many essential services, and the finite bandwidth available in such a context, it would be important to make collective moral decisions about its usage and distribution. Specific policies, caps and quotas could not only slow down the current trend towards ever expanding internet traffic, but also reverse them, without compromising universal access. In doing so, we should prioritise applications that have clear social and environmental benefits over those that serve aims defined purely in terms of economic utility maximisation. This scenario would necessarily combine sufficiency policies with an acceleration of data centres energy efficiency.

Of course, this is not an easy task. Big questions for degrowthers emerge from the above: how can the assemblages of submarine cables, data centres and multilayer software applications be made sustainable, and amenable to democratic governance, management and oversight? how can they be reimagined and reshaped as convivial technologies? When and for how long would it be legitimate to continue investing in their repair and maintenance considering the fact that we will have to coexist, probably for centuries, with the ruins of infrastructures designed on the premises of infinite growth? What are the social and political trade-offs?

To imagine a degrowth-minded reconfiguration of infrastructures is to acknowledge that they are often intrinsically designed to enable expansion and growth. In this paper, we have shown that the internet is captive, although not in a deterministic way, of at least two interdependent 'growth mechanisms' built-in, its technical design and its financial governance. On the one hand, the internet's physical layer is clearly characterised by growth-driven technological design, which is unsustainable in ecological terms. On the other hand, it was originally designed to be open enough to be used for many different purposes, even downscaled to a certain extent. Therefore, our research shows that the governance-financial layer is where the main problem lies. Financing mechanisms are designed expecting expansion whereas the governance layer pushes the physical layer to become a system predicated on growth.

The case of the internet is a key example because of the way the stack has become a pervasive technology that shapes the lives of a great deal of humanity. More generally, similar analyses should be conducted on other fundamental mega-infrastructures such as housing, transport systems, energy and water supply, military industry, and even entire monetary systems due to the way such infrastructures are central to any understanding of prosperity and well being. Yet their consumption of resources and energy can be significant and difficult to scale down without seriously compromising the quality of life they enable. It is unfortunate that, thus far, these issues have been largely overlooked within contemporary degrowth debates despite their significance in terms of conceiving a future without growth. Our work seeks to sketch out the foundations for long overdue further research in this area.

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Strict Environmental Regulation as a Driver of Innovation: A case study of Iran's oil and gas exploration sector

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Abstract

Environmental protection as one of the sustainable development goals has led to the attention of wide strategies in different countries. Strict environmental regulations are one of them, and there are different opinions regarding their positive or negative impact. It is said that in the short term and in high innovation uncertainty, they can have a negative effect on innovation. However, the evidence obtained from Iran's oil and gas exploration sector shows that these regulations have had a positive effect on the innovation system of a strategic technology called "HPHT Drilling Fluid" and even caused the simultaneous emergence of two motors of innovation. The importance of this issue lies in the large technological gap in Iran's oil and gas industry, which causes the companies active in this industry, mostly state-owned, to prefer innovating in the technologies of the exploration value chain. As a result, non-binding environmental regulations are insufficient to drive innovation. A review of historical events also revealed that strict environmental regulations have had an unexpected positive consequence on earlier misconceptions about the use of indigenous exploration technologies. These findings show in situations where there is high uncertainty in innovation, a large technology gap exists, and the industry is mainly state-owned, strict environmental regulations tend to stimulate innovation more than non-mandatory regulations.

Keywords: Strict Environmental Regulation, Innovation, Technological Innovation System, Oil and gas industry, HPHT Drilling Fluids

1. Introduction

In recent years, one of the key issues in sustainable development has been paying attention to the sustainable use of land as an intergenerational heritage, along with providing affordable energy needed for the growth of human societies, coinciding with the rapid growth of the world economy (Ashford and Hall 2011, Juan 2011, Dmitrieva and Romasheva 2020). Common actions, such as the "Millennium Development Goals" of the United Nations and the "Sustainable Development Goals" published in the 2030 document of UNESCO¹, are signs of the importance of these issues which have caused the convergence of policymakers in international society (Goyeneche, Ramirez et al. 2022). The most important reason for this convergence is that most developed and developing countries heavily depend on fossil fuels. Consequently, in addition to the unsustainable consumption of resources, they create many environmental hazards through the abundant use of chemicals (Wieczorek and Hekkert 2012). This matter has caused environmental regulations to play an important role in designing development policies in recent decades (Shao, Hu et al. 2020). The increasing attention to the analysis of environmental innovations both at academic research and at policy making is a sign of this issue (Costantini, Crespi et al. 2017).

On the other hand, exploration of oil and gas resources, as a process with high technological complexity and uncertainty, is the first human effort to benefit from hydrocarbon resources (Mojarad, Atashbari et al. 2018) and causes many changes in the structure of the earth and the environment around exploration fields. In other words, oil and gas exploration always creates many environmental challenges (Juan 2011, Mojarad, Atashbari et al. 2018). One of these challenges is the technical requirement to use drilling fluids, especially non-aqueous drilling fluids in some drilling stages (Almudhhi 2016, Ahmed and Kalkan 2019), which in addition to damages on the surface, causes contamination of underground water and the subsurface layers of the earth (Ahmed and Kalkan 2019, Sharafaddin and Onu 2021). These issues, along with environmental regulations affected by global agreements such as the Kyoto Protocol and sustainable development goals, have led to very strict limitations on many oil and gas exploration and production projects around the world in recent years (Patel and Ali 2003, Abduo, Dahab et al. 2016, Lv, Qi et al. 2020, Walls and Zheng 2021). Similarly, in recent years, the oil and gas industry in Iran, especially in the exploration and production sector, has faced strict environmental regulations that have caused interruptions or cessation of operations.

Now, the question arises as to what impact these strict environmental regulations have on technological innovation in Iran, and what should policymakers do regarding the strict or non-binding of environmental regulation.

A review of past studies shows that there is still no consensus regarding the relationship between environmental regulations and innovation (Ford, Steen et al. 2014, Wu, Liu et al. 2020). Although some of them, in line with Porter's theory (1991), consider strict environmental regulation as the driver of innovation (Ashford and Hall 2011, Fan, Zivin et al. 2019, Kesidou and Wu 2020, Lv, Qi et al. 2020, Wang, Jin et al. 2021), serious doubts have been raised about this effect in various studies after that. Some studies have shown that the implementation of strict environmental regulation, due to reasons such as increased compliance costs, can prevent innovation at least in the short term, although in the long term and with increased flexibility in regulations, the efficiency and competitiveness of companies will improve (Stewart 2010, Zhang, Peng et al. 2017, Meng, Xu et al. 2020, Shao, Hu et al. 2020, Wang 2020, Peng, Shen et al. 2021). It is also said that strict environmental regulations can only lead to the development of technologies and drive innovation when the dimensions of environmental risks are very broad and there is a consensus on the technological solution. Otherwise, strict environmental regulations may result in non-optimal and costly solutions (Kemp 2000). Some studies argue that in industries with high innovation uncertainty that is affected by factors such as technological complexity, regulations will have a negative impact on innovation and may even lead to innovation failure (Gossen and Velichkina 2006, Blind, Petersen et al. 2017). In addition, it is said that regulations can lead to innovation and the development of new products when companies, both existing producers in the industry and new companies, have the interest, capacity, and opportunity to enter the market (Ashford and Hall 2011).

Nonetheless, evidence obtained from the development path of one of the strategic technologies in the oil and gas exploration sector in Iran, called HPHT² Drilling Fluid, shows that strict environmental regulations have had a positive impact on its creation and development in the short term, despite the high level of innovation uncertainty in this sector. The technology gap in Iran's oil and gas industry has made technology developers, who are also few in number, prefer to use their capacity to develop technologies related to the exploration value chain instead of entering into environmental innovations. In this situation, non-mandatory regulations could not stimulate innovation, while environmental innovation was subsequently stimulated by the tightening of these regulations.

To investigate the reason for this issue, this study attempted to examine the impact of strict environmental regulations on the innovation system of this technology. The reason for using the TIS framework is that the investigation of the non-linear

development path of the desired technology requires a systemic approach. On the other hand, among innovative systems, TIS is better due to its ability to consider the dynamics of the system and analyze how to develop and exploit new opportunities (Van Welie, Truffer et al. 2019). For analyzing historical events, both autoethnography and semi-structured interviewing methods have been used.

The structure of this article is such that in the next section, after introducing HPHT drilling fluid technology, the Technological Innovation System will be briefly explained. In the third section, the research method will be presented, and in the fourth section, the innovation motors will be identified by analyzing historical events. In the fifth section, the positive impact of strict environmental regulations on the development of the desired technology will be discussed. Finally, the research summary and some recommendations will be presented in the sixth section.

2. Theoretical Foundation

2.1 High-Pressure High-Temperature (HPHT) Drilling Fluid Technology

Drilling oil and gas wells is one of the most important stages in the processes of oil and gas exploration (Ahmed and Kalkan 2019). Drilling fluid is also one of the important technologies used in this process, which has important tasks such as holding wellbore stability and preventing the well from blow out (Sulaimon, Adeyemi et al. 2017, JIANG, GUO et al. 2019, Rana, Arfaj et al. 2019). This technology is divided into three categories: water-based drilling fluids, oil-based drilling fluids, and synthetic drilling fluids (Ahmed and Kalkan 2019), and of course, in a more general category, it is divided into two types of Aqueous, and Non-aqueous fluids (Growcock and Patel 2011). The type of drilling fluid needed for a drilling well, is determined depending on the conditions and lithology of the areal rock formations (Almudhhi 2016). Non-aqueous fluids are usually used in the drilling of reservoir layers as well as in the drilling of formations with high shale content, where the use of water-based muds causes technical problems (Almudhhi 2016, Ahmed and Kalkan 2019). On the other hand, deep drilling has many operational challenges due to exposure to high pressure and high temperature (HPHT) conditions (Radwan and Karimi 2011, Shadravan and Amani 2012). One of these challenges is the need to use a special drilling fluid that can maintain its properties under HPHT condition (Radwan and Karimi 2011, Abduo, Dahab et al. 2016, Ofei, Bavoh et al. 2017, Sindi, Pino et al. 2019, Sulaimon, Akintola et al. 2021). Typically, temperatures above 300 degrees Fahrenheit and pore pressures above 0.8 psi are considered as HPHT conditions (Shadravan and Amani 2012). For drilling in HPHT conditions, depending on the lithology of the drilling formations, special drilling fluids are used, which are called HPHT drilling fluids. HPHT drilling

fluids can also be in two types, aqueous and non-aqueous (Abduo, Dahab et al. 2016, Sulaimon, Adeyemi et al. 2017).

It should be mentioned that on-aqueous drilling fluids have more environmental risks compared to the water-based type due to the presence of toxic, non-degradable and non-renewable additives, as well as the use of fluids such as diesel and oil in their production (Sulaimon, Adeyemi et al. 2017, Sharafaddin and Onuṭu 2021). As a result, in recent years, researchers have been able to reduce environmental damages by improving the properties of water-based drilling fluids and developing environmentally friendly drilling fluids (Patel and Ali 2003, Abduo, Dahab et al. 2016, Smith, Rafati et al. 2018, Sindi, Pino et al. 2019). The use of waste management technology is also one of the other ways to reduce the environmental risks of drilling fluids. This method also does not completely reduce environmental risks. Despite the use of this technology, the layers of the earth, underground water and the air around the drilling well will still be exposed to severe environmental pollution (Veil 2002).

2.2. Technological Innovation System

Since Carlson and Stankiewicz (1991) first introduced the concept of technological innovation system (TIS), numerous studies have been conducted on the capabilities of this type of innovation system, and many technologies in different countries, especially in low-income countries, have been analyzed using its framework (Kebede and Mitsufuji 2017, Van Welie, Truffer et al. 2019, Markard 2020). This approach focuses on the dynamics of the system and can effectively examine how to develop and exploit business opportunities, which are sometimes overlooked in other innovation system approaches (Van Welie, Truffer et al. 2019).

Research studies in this field also indicate that institutions both soft and hard, along with actors, interactions, and infrastructures, are structural dimensions that affect the development of a particular technology and the creation of technological innovation systems (TIS) (Wieczorek and Hekkert 2012, Bergek, Hekkert et al. 2015). In addition to structural dimensions, various activities have been introduced so far which are effective in the development, dissemination and use of technological innovations, one of the most prominent of which is the Hekkert et al. classification (2007). "They introduce 7 main functions of "entrepreneurial activities" (F1), "knowledge development" (F2), "knowledge diffusion " (F3), "guidance of research" (F4), "market formation" (F5), " mobilization of resources" (F6), and " creation of legitimacy " (F7) (Hekkert, Suurs et al. 2007, Hekkert and Negro 2009, Wieczorek and Hekkert 2012). Based on these functions, Suurs (2009) and Suurs and Hekkert (2009) have introduced four motors of sustainable innovation that are formed by feedback loops and enable the examination of how a

technological innovation system is formed, developed, or even failed (Suurs 2009, Suurs and Hekkert 2009) and make it possible to examine the impact of structural dimensions such as institutions in the path of technological development. These motors, which are derived by examining the historical trends of events, are the "science and Technology Motor," the "Entrepreneurship Motor," the "System Building Motor," and the "Market Motor" (Suurs 2009, Suurs and Hekkert 2009). To correctly track these functions in a TIS, some indicators are needed, which are provided by Kebede and Mitsufuji (2016) and are suitable for developing countries (Kebede and Mitsufuji 2017).

Suurs (2009) also emphasizes that several sub-technologies with different structural characteristics may develop simultaneously in a technological innovation system. In this situation, more than one motor will be derived which may collide or complement each other (Suurs 2009).

3. Research Method

It has been said that the framework of technological innovation system is a suitable method for examining how different structural factors, such as institutions, affect the formation of an innovation system. Therefore, in this study, by analyzing the historical events and identifying the sequence of events and matching them with the functions of the technological innovation system, the innovation motors are identified (Hekkert, Suurs et al. 2007, Hekkert and Negro 2009, Suurs, Hekkert et al. 2010).

For analyzing historical events, the autoethnographic method was used as a qualitative method since one of the authors of this article is an individual involved in the innovation system of HPHT Drilling fluid (Poerwandari 2021). This method provides reliable and primary access to research data (Frankelius, Norrman et al. 2019). However, since the autoethnographic method may be biased (Frankelius, Norrman et al. 2019, Poerwandari 2021), upper-level documents and published reports on the subject were reviewed, and then a semi-structured interview method was used with seven other experts and individuals active in the mentioned TIS to ensure the accuracy of the analysis.

To conduct the interview process, identified historical events were shared with the interviewees to gain more confidence in the historical trajectory and important milestones of the innovation system under study. Then, the participants were asked to provide more details about the events that occurred in the development of the desired technology. The participants were seven active actors in the innovation system of the desired technology. In the next step, the interview texts were carefully evaluated, and by matching them with the functions of the technological innovation system, the innovation motors were identified.

Therefore, the impact of strict environmental regulations on this TIS will be investigated by analyzing historical events and examining how to create innovation motors.

4. Technological Innovation System of HPHT Drilling Fluid in Iran

The history of using drilling fluids in Iran dates back to well number one, which was the first oil well in the Middle East and was located in the southwest of Iran. The drilling of this well with a depth of about 370 meters was started in 1908 by Darcy Consortium. According to the old documents available, water and soil fluid were used to drill this well. Since then, drilling fluid technology has been continuously developed with the aim of increasing the speed of drilling and reducing its risks. Also, cost-effectiveness and recyclability have been other goals of this technology development.

On the other hand, the first oil well in Iran with high-pressure high-temperature (HPHT) condition was detected while drilling an exploratory well at a depth of 4759 meters in 1966. But much later in the 1990s, with the development of the central oil and gas fields, as well as the huge gas fields of southern Iran, high pressure fluid technology (HPHT) was used. In the following, the development path of the innovation system of this technology in Iran is presented.

4-1- Science and Technology Motor of HPHT Drilling Fluid

In the 1990s, international companies that provided drilling fluid services in Iran imported the additives needed to make all kinds of HPHT drilling fluid, and for the first time in that decade, HPHT drilling fluid technology was used in some Iranian fields. positive results of using this type of fluid led the National Iranian Oil Company to use this technology in other oil and gas fields as well [F4]. Due to demand, in the early 2000s, some domestic service providers of drilling fluid began importing the additives needed to make HPHT fluid. Subsequently and in the late 2000s, a number of government research projects were defined in the form of research and development contracts with universities and research institutions to localize this technology [F6]. These universities and research institutions, which were also government-affiliated, have conducted various studies, feasibility assessments, and technical knowledge development [F2], and events such as specialized seminars and expert panels related to the subject have been held [F3]. As a result, the first loop of the Science and Technology Motor [F4F6F2,3] was formed. On the other hand, some government companies affiliated with the National Iranian Oil Company, due to facing drilling under high pressure and high temperature conditions, took action to provide the necessary financial resources for the development of the desired technology. With their direct entry into this

field, the second loop of the engine driving science and technology was also formed [F1F4F6].

Until the mid-2010s, attention to drilling wells under high pressure and high temperature conditions faded for some reasons. Nevertheless, the indigenization of high-temperature high- pressure drilling fluid technology still received attention from government universities and research institutions. During that period, many theses and articles were published inside and sometimes outside the country by Iranian professors and students (continuing the first loop). Also, due to the coincidence of this period with the increase in advances in the development of water-based HPHT fluid technology in the world [F4], some studies were also devoted to the development of knowledge for producing water-based HPHT fluid [F2,3].

4.2. Entrepreneurship Motor of HPHT Drilling Fluid

In the mid-2010s, with the increase in exploration activities in various regions and the discovery of suitable horizons for production with HPHT conditions, the importance of using HPHT drilling fluid increased. Of course, before this period, other fields with high-pressure and high- temperature conditions had been discovered, and their development was also on the agenda to increase oil and gas production. Since obtaining this technology from abroad was difficult due to the increasing restrictions caused by international sanctions, the localization of the technology received more attention than before [F4]. Due to the mentioned restrictions, companies providing drilling services have also faced financial constraints, and their main priority has been to maintain the status quo. That is, their goal has been to focus on supplying materials and equipment that are the current and guaranteed needs of the industry by managing resources. As a result, technology localization was not particularly a priority for these companies. On the other hand, the few private companies developing technology also preferred to spend their resources on developing technologies with lower operational risk. The existing technological gap in Iran's oil and gas industry and operational managers' distrust in the use of indigenous technologies (Ghazinoory, Tatina et al. 2020) were the cause of this issue. As mentioned in section 2, the use of drilling fluid in high-pressure and high-temperature conditions poses serious challenges, and this technology is not low-risk (Radwan and Karimi 2011, Shadravan and Amani 2012).

At the same time, environmental regulations for oil and gas exploration and production activities became stricter. Environmental considerations have been included in some parts of Iran's constitution, and they have also been taken into account in the 5-year development plans that have been compiled for about three decades (Khosravi, Jha-Thakur et al. 2019). However, the review of technical

documents and the statements of the participants in this research show that until the late 2000s, the environment was not the focus of Iran's oil and gas industry. Since the late 2000s, environmental care in the upstream sector of Iran's oil and gas has been given more attention, affected by issues such as the Millennium Development Goals and the increase in the sensitivity of public opinion. The spread of waste management services is one of the results of this issue. Due to the high costs of using non-aqueous fluid waste management technology, this technology has not been widely used in Iran. Instead, special equipment is used to transfer and storage non-aqueous fluid to reduce pollution on the surface of the earth. Obtaining the necessary permits, especially for drilling with non-aqueous fluids, became an important challenge for conducting exploration activities due to these regulations.

In 2017, the National Iranian Oil Company appointed a group consisting of a domestic university, a private company providing drilling fluid services, and a government company [F1] to develop water-based HPHT fluid technology. This decision was made due to the strategic importance of localization of HPHT drilling fluid and strict environmental regulations [F4]. By providing the necessary financial resources [F6], the main loop of the entrepreneurship motor was formed [F6F1F7]. Subsequently, the development group, which participated in the formation of the first motor, began to manufacture high-pressure high-temperature water-based drilling fluid on a laboratory scale in cooperation with other academic groups. The repetition of the main cycle [F6F1F7] and the development and dissemination of knowledge [F2,3] in the interaction between industry and university brought favorable results. As a result, a water-based drilling fluid was created that, in addition to tolerating HPHT conditions on a laboratory scale, had a good ability to control the collapse of shale formations and stabilize the wellbore. Although the main loops of the entrepreneurial motor had been established by the late 2020s, but no exploratory wells with HPHT conditions were being drilled for the technology to be used in the field. Additionally, in the exploration program of hydrocarbon resources, no well with HPHT conditions was on the agenda at that time. The risk associated with using newly developed technologies, as well as the potential consequences of failure, made it difficult to convince operational managers to use the developed drilling fluid. As a result, there was still no artificial or niche market as a primary market to strengthen and complete the Entrepreneurial Motor [F5]. To drive innovation and create demand for emerging technology, it is necessary to develop artificial markets (niches) that are not usually developed in the TIS itself (Suurs 2009).

This is where the ability of the developed fluid to reduce environmental hazards became a turningpoint in the HPHT drilling fluid technology innovation system.

4.3. Strict Environmental Regulation as a Driver of Innovation

In 2021, severe shale collapse and instability of the wellbore during the drilling of one of the exploratory wells caused the drilling operation to face the risk of being stopped. It was stated that non-aqueous fluids are used for wellbore stability in drilling wells with shale formation (Almudhhi 2016, Ahmed and Kalkan 2019). It was also stated that due to strict environmental regulations, drilling with non-aqueous fluid requires necessary permits and provision of special equipment. However, since the use of non-aqueous fluid was not anticipated for drilling that well at that depth, it was necessary to obtain special equipment and environmental permits. Obtaining a permit took time, and as a result, drilling had to be stopped for a while. This provided a good opportunity for the water-based HPHT fluid development group. Negotiations with operational managers finally led to the use of this fluid in drilling that exploratory well which had conditions close to HPHT.

In a short period of time, this fluid was used in the drilling of another exploratory well with conditions close to HPHT. The interesting thing is that for drilling this well, it was possible to obtain the environmental permits for drilling with a non-aqueous fluid, but the successful results of using the developed fluid had increased the confidence of operational managers in this indigenous technology. In early 2022, severe shale collapse and wellbore instability stopped drilling operations in another exploratory well. The temperature and pressure conditions of this well were far from the HPHT conditions, but the lack of equipment required for drilling with non-aqueous fluid and the inability to obtain the environmental permits led to the use of native HPHT fluid for the third time. These events make the entrepreneurship motor of the desired innovation system complete with the formation of the niche market [F5].

In addition to the important role of strict environmental regulations in creating a niche market for HPHT fluid technology, the drilling of the third well also created a new market for the developed technology. As mentioned, that well did not meet the HPHT conditions and water-based HPHT fluid was forced to be used. This fluid, which is formulated with appropriate additives for HPHT conditions, is more expensive compared to other water-based fluids. Therefore, by optimizing the formulation and developing a new, cheaper technology, it can be used in the absence of the required equipment for drilling non-HPHT wells with non-aqueous fluid. In response to this new market, the private company that was a member of the water-based HPHT fluid technology development group has started a new project with non-governmental funding, relying on the existing knowledge base. The aim of this project is to improve the formulation and produce a new drilling fluid. According to what was mentioned in the final part of section 2-2, this means creating a new sub-technology with different structural features and formation

reasons. This leads to the creation of more than one innovation motor simultaneously in a technological innovation system (Suurs 2009). Figure 1 schematically shows the new conditions of the innovation system. Dashed lines are related to the science and technology motor for new technology. As seen in Figure 1, the market created in the entrepreneurship motor [F5] caused the development of new technology [F'4]. As a result, the mentioned private company, with its financial resources, started a new project [F'1] and based on the technical knowledge developed in previous motors [F2,3], started the study and testing of improved models [F'2,3]. Because the new motor does not involve external financing, it differs from the science and technology motor introduced as a basic motor (Suurs 2009).

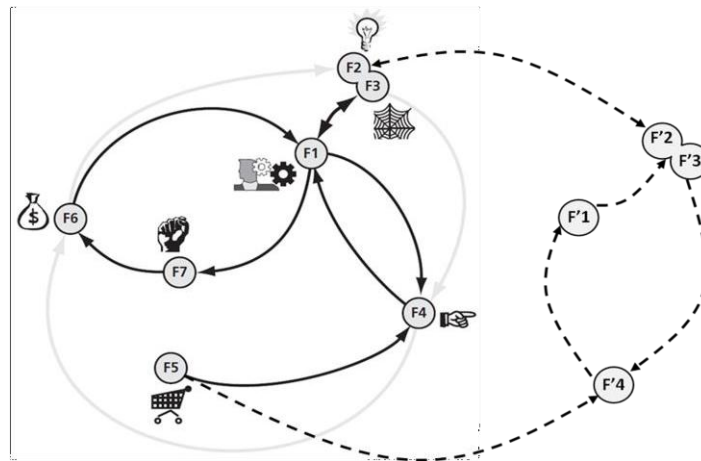


Figure 1. Current situation of HPHT Drilling Fluid TIS

5. Discussion

It was mentioned in section 2 that the strict environmental regulations may have a negative impact on innovation in the short term (Stewart 2010, Zhang, Peng et al. 2017, Meng, Xu et al. 2020, Shao, Hu et al. 2020, Wang 2020, Peng, Shen et al. 2021), especially if an industry has a high level of innovation uncertainty (Stewart 2010, Ashford and Hall 2011). However, it was observed that despite the high level of uncertainty and technological complexity of Iran's oil and gas exploration sector (Mojarad, Atashbari et al. 2018), strict environmental regulations in the short term were not an obstacle to the development of the studied technology. On the contrary, they could play an effective role in guiding [4], legitimizing [7], and forming the primary market [5], thereby contributing to the creation of the motors of the innovation system.

As seen in the previous section, the main actors and infrastructures of the HPHT technology innovation system, such as the National Iranian Oil Company and its affiliated companies, many universities and scientific institutions, and even some developer companies, were government-owned. Subsequently, the financial resources needed for the development of this technology also came from the government. Therefore, issues such as competition within the industry or profitability were not the only effective components in decisions. For example, in the development of the first motor, although until mid-2010, the industry's focus was not on drilling wells with HPHT conditions, the localization of the desired technology did not go out of focus. Similarly, as environmental regulations become more stringent, the development of HPHT fluid technology focused on the water-based type. If only the exploration and development of oil and gas fields with HPHT conditions was considered, HPHT drilling fluid could also be made using the knowledge developed in oil-based fluids. However, because the developer of this technology was the government, compliance with strict environmental regulations and preventing stoppage of operations was also influential in decision-making. Before the stricter environmental regulations in the oil and gas industry, non-aqueous drilling fluid was used and the only way to protect the environment against the risks of this type of fluids was the use of fluid transfer and storage equipment. It was pointed out that this method, like waste management technology, can only reduce environmental risks on the earth's surface. However, technology development companies have not attempted to develop environmental technologies, nor has there been much desire to transfer environmental technologies such as non-aqueous fluid waste management. The primary reason is that due to the technology gap in Iran's oil and gas industry (Ghazinoory, Tatina et al. 2020), technology developers focus on technologies that have a lower risk of use and are needed in the value chain of oil and gas exploration. In other words, when there are many technological needs in the oil and gas industry, environmental innovation will not be a priority unless there are strict regulations.

In addition, non-governmental technology developers, who are very few in number, have a lower preference for environmental innovation in non-binding terms due to the existing technological gap. There are other technological challenges in Iran's oil and gas exploration sector that have a lower risk of innovation. Technologies that are in high demand and have a definite market are preferred. Nevertheless, it was observed that a non-governmental company started developing a new environmental technology without attracting government resources when stricter environmental regulations were implemented, and the innovation risk was reduced. It should be noted that part of the new technology development path has been taken with government resources and its risk acceptance by government institutions. An issue that increases the risk of other private companies entering

environmental innovation. Especially in situations where environmental regulations are non-binding. It is expected that if the development of this new technology is successful, new environmental regulations will also be established. This is because the technology not only reduces the environmental hazards of the earth's surface but also greatly reduces the pollution of the earth's layers and underground water.

According to the above, in a situation similar to Iran's oil and gas exploration sector, where the uncertainty of innovation is high, a large technology gap exists, and the industry is mainly state- owned, stricter environmental regulations stimulate innovation more than non-mandatory regulations.

On the other hand, the high costs of technology failure in the oil and gas industry make managers and operational decision makers avoid being "early users" of emerging technologies. As a result, the industry is known for its conservatism and resistance to new technologies (Roberts, Flin et al. 2021). This issue is more severe in Iran's oil and gas industry due to distrust and unwillingness to use technologies developed inside the country, which have historical and cultural roots (Ghazinoory, Tatina et al. 2020). However, in the drilling of the first well, it was stated that strict environmental regulations left operational managers with a choice between "stopping drilling operations completely" or "using the developed HPHT fluid technology." The choice of the second option and the success achieved in it influenced the previously formed beliefs about indigenous technologies in Iran's oil and gas exploration sector. The use of indigenous technology in the drilling of the second well was due to the trust created in the operational managers, not the fear of stopping the drilling operations. This can be seen as an unintended positive impact of strict environmental regulations.

6. Conclusion and Recommendation

This study showed that to evaluate the impact of strict environmental regulations, it is necessary to pay attention to the governance structure, policy-making models, as well as the number and type of actors active in technology development networks in each country or industry. The effects of strict environmental regulations can vary in different countries or industries, depending on their context. In a situation similar to the exploration sector of Iran's oil and gas industry, strict environmental regulations are driving innovation in the short term by directing government actors. As the innovation system continues, strict regulations support innovative solutions through legitimization and subsequently make the technology market attractive. As a result, sufficient motivation, opportunity, and capacity are provided for technology developers, especially private companies, for environmental innovation.

Now considering that the innovation system of High-Pressure High-Temperature Drilling Fluid is in its Entrepreneurial Motor, some recommendations can be proposed for the continuation of this innovation system as follows:

- The lack of confidence among managers in Iran's oil and gas industry is a significant obstacle to the use of local emerging technologies, which slows down the pace of technology development. To overcome this mistrust, it is essential to take measures to reduce it. One such measure could be a letter of appreciation that declares consent for the use of developed technology. This action can have a positive effect on the mistrust by legitimizing the technology and increasing managers' trust in other government companies to use the desired technology, as well as other indigenous technologies. Legitimizing or supporting advocacy coalitions has a central role in entering the System Building motor and also strengthens the functions of "Market Formation" and "Guidance of the Search" (Suurs 2009, Suurs and Hekkert 2009). Additionally, by revising the operating instructions for the use of drilling fluids, it can be used in qualified wells.
- According to the needs of the industry in the exploration and development of some fields with ultra-high pressure and ultra-high temperature conditions (Shadravan and Amani 2012), the development and dissemination of knowledge should continue. In the current situation, this requires government funding. Of course, if the market is developed and the use of new technology is guaranteed, it is possible to attract non-governmental sources. In this way, the government can play a facilitating role in the entry of private companies and non-governmental financial resources.
- Iran's proximity to other oil and gas producing countries presents a good opportunity to develop the HPHT fluid market and new technology under development. Furthermore, Iran's economic situation allows the developed technology to have a lower price, providing a competitive advantage. Therefore, export facilitation policies and innovation diplomacy can be used to expand the market for these technologies, creating and strengthening the third motor of innovation. This will lead to the formation of the Market Motor in the future, creating a mass market for the technologies of this innovation system.
- Although the mentioned private company has started environmental innovation relying on its own financial resources, it is necessary to provide sufficient support for it. The new technology protects the environment better than the existing technologies in Iran because it also reduces the environmental risks inside the earth. Therefore, existing environmental regulations can be intelligently tightened in favor of new technology. For this purpose, according to the progress of this technology, the use of non-aqueous-based fluids can be prohibited in the conditions where the new technology can be used, even if equipment for transferring and maintaining non-aqueous-based fluids is provided.

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Notes

¹ United Nations Educational, Scientific and Cultural Organization

² High-Pressure High-Temperature

Tricks of the trade: How technology-intensive manufacturing firms in India export

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Abstract

India has seen a surge in the exports of technology-intensive manufacturing products in recent decades. We believe that this may be due to increased investments by firms in building technological capabilities. We empirically examine this using the Quasi- Maximum Likelihood Estimation (QMLE) approach for firm-level panel data from 2008-09 to 2019-20. Our estimates show that firms that invest in in-house R&D and human capital, apart from imported technology have a higher export intensity. This validates the argument that firms need to build indigenous capabilities to effectively utilize the knowledge involved in imported technology to perform better in the export market.

Keywords: Technological capability-building, exports, Technology-intensive, QMLE

JEL classification: F14, L6, O14

1. Introduction

The significance of technology intensive exports for the growth of an economy cannot be stressed enough. Such exports are reflective of the economic complexity of the country which has a bearing on its global competitiveness and export performance (Lall, 2000; Erkan & Yildirimci, 2015). Countries specialized in these have been growing faster as they have greater income elasticities and scope for faster substitution of older products and generation of new demand (Lall, 2000). Moreover, they create spillovers which lead to the upgradation of the country's industrial structure and long-term growth (Hausmann et al, 2005; Falks, 2009; Shrawan, 2019)¹.

Even though the export of technology-intensive products is important for the industrial as well as economic growth of countries, many fail to enter and sell these products in the global market. As technology-intensive products require substantial investments in capital and know-how, a functioning innovation system, as well as continuous upgradation through R&D and product differentiation to keep up with the rapidly evolving market, only a few countries dominate the world market in the export of these products (UNIDO, 2002; Hout and Ghemawat 2010; UNCTAD, 2021). Data suggests that such countries belong to the high-income group². Recent empirical evidence nonetheless indicates a rapid growth in the export of technology intensive products and an increasing presence of developing countries in it (Srholec, 2007). A pronounced shift from resource-based and low technology products to high technology goods has also been observed in the developing world, in the recent past (Lall, 2000; Anand et al., 2015). While some see this shift as a 'statistical illusion' - as these countries specialize in the labor-intensive segments of technology intensive products which costs less to produce, others argue that it may be due to the catching up of developing economies on the technology ladder (see for instance, Lall, 2000; Mayer et al, 2003; Srholec, 2006).

India's experience is also similar to that of other developing countries. The export of technology intensive products grew significantly between 1990-91 to 2020-21 from USD 2.22 billion to USD 83.13 billion. The share of high technology (HT) products in the country's total manufacturing export also doubled during this period³. High technology (HT) here includes industries classified both as 'high technology' and as 'medium-high technology' by the OECD⁴. While the annual average growth rate of high-tech exports (HTX) in India's manufacturing exports was -4.41 per cent between 1990 and 2000, it increased to 8.75 percent in the 2000-2021 period. India's HTX as a proportion of the world's HTX as well as the world's total manufacturing exports have also been increasing continuously since 2000-01 and exponentially after 2008 (See Figure A1 in the appendix).

The objective of this study is to understand the process behind the increase in India's HTX from 2008 onwards. Grazzi et al. (2021) points out that the existing empirical literature on the drivers of HTX in developing countries is rather new and focuses on countries' participation in the cost-effective labor-intensive segments of HT products as a strategy to enter and sustain in the international market. However, we believe that technological upgradation may have a role to play in the HTX performance of emerging countries like India. We use firm level data of HT manufacturing industries for this purpose, as firms determine the volume of export of a country. Technological capability building of firms through investments in research and development (R&D) activities and human capital, apart from import of advanced technologies improves their competitiveness which enhances their export performance. Our empirical study finds evidence for this in the case of HT manufacturing firms in India. The results suggest that the higher export of HT products from India in recent years is the result of its firms learning from imported technologies as well as generating and managing indigenous capabilities by investing in R&D and human capital.

The paper is organized into five sections, including the introduction. Section two reviews the existing theoretical and empirical literature pertaining to technological change and exports. Section three gives the source of the data, explains the model and the variables. The fourth section presents the issues in the estimation of the model and discusses the results. The last section concludes the study and highlights its implications.

2. Review of Literature

2.1. Theoretical literature

The differences in industrial performance between countries in terms of their ability to compete and sustain in the international markets is driven by their technological capabilities (Lee & Malerba, 2018). The significance of technological progress as the source of dynamic trade advantage has been advocated quite early on by the neo-technology theorists such as Posner, 1961 and Hufbauer, 1966. They highlighted different mechanisms of technological dissemination between a leader and follower countries (Hufbauer, 1966). This traditional understanding of technical change differentiates between innovation and diffusion and assumes that developing countries are mere consumers of the innovation undertaken by the early industrializers. For this reason, developing countries need not accumulate indigenous innovation capabilities. Technology here is viewed as codified knowledge which can be transferred easily through capital goods or blueprints. Further, the choice, acquisition and adaptation of technology are costless for developing countries.

The technological capability approach put forward by Lall (1992; 2000) suggests that the tacit knowledge embedded in technologies ensures that the ability to

import technology is not the same as the ability to use it. The underlying idea being that technology cannot be reduced merely to capital goods or codified information. Explicit and tacit knowledge transferred from developed countries is utilized to varying extents by firms based on their existing knowledge base as well as their 'intensity of effort' (Cohen and Levinthal, 1990). The degree of utilization depends on the internal capabilities of the firm or their 'absorptive capacity' (Cohen & Levinthal, 1990). Therefore, firms in developing economies are not passive users of technology, but are involved actively in the process of technological progress through incremental innovations by cultivating competencies in the domains of production, investment and innovation (Bell and Pavitt, 1995; Kim, 1999).

Bell and Pavitt (1995) further delineate the role of technological capability in the process of economic catch up. They argue that technology entails 'complex bundles of information' which are only partially transferable. Once transferred, it needs to be adapted to suit the levels and specifications of individual firms. The modified technology further needs to be consistently monitored and managed to ensure that it meets the constantly evolving international efficiency standards. The dynamic capabilities framework which attempts to explain the potential for wealth creation of individual firms in a rapidly changing technological environment argues on similar lines. They underline that the success of the particular firm is dependent on its ability to refine its internal technological, organizational and managerial capabilities (for instance see Teece, Pisano & Shuen (1997)).

Experience or 'learning by doing' alone cannot guarantee economic catchup for latecomer firms in the global market (Bell & Pavitt, 1995). The sustained competitiveness of firms depends on the specialized resources at their disposal such as skilled labour. However, the nature and sources of technological accumulation conducive for different industries may be different. A mixed model involving imports of technology, coupled with indigenous R&D and employment of skilled labour may be relevant for science-based industries. (Pavitt, 1984).

2.2. Empirical review

High technology exports being an important factor influencing long-term economic growth, and many scholars have attempted to examine its determinants empirically. Most of the studies in this stream of literature are cross-country analyses which analyze the macro picture of why certain countries have higher high-tech exports than others. Our objective in this review is to scrutinize the factors impacting export capability at the firm level. Since firm-level exports make up countries' total exports and they are the actual players in the export market, it seems pertinent to examine the variation in their exports and the reasons for the same.

It is well established that innovative firms are more exportive in nature (Yi, et al., 2013; Forbes, N. 2022). Hence, most of the studies that examine the determinants of high-tech exports include the innovation potential of the firms as a key variable in their analysis. Innovation leads to the introduction of new products and processes which increases the firms' competitiveness in the export market (Becker and Egger, 2008).

Scholars like Zhang (2007) underline that the innovation potential of firms is directly related to their technological capabilities (TC). Technological capability-building takes place through two channels: the import of technology from advantaged countries and investment in in-house R&D which can help firms 'master and use' the imported technologies to their advantage. In the Indian context, a recent study by Grazzi et al. (2021) finds that R&D has a significant impact on both the probability as well as the intensity of export of manufacturing firms. However, studies such as Kumar and Siddharthan (1994), Aggarwal (2002), Bhat & Narayanan (2009), Srinivasan and Archana (2011), Goldar (2013) and Ghosh and Roy (2018) highlight the significance of the import of technology, apart from R&D expenditure in explaining firms' export performance.

Industry-specific studies on medium and high technology industries have also verified the relevance of technological capability-building through R&D and imported technology. Aggarwal (2002) supports the view that R&D and technology imports have a complementary relationship and that in technology-intensive sectors, firms' internal capabilities have a bearing on their export performance. On undertaking a disaggregated analysis based on the technological intensity of exporting firms, Aggarwal (2002) notes that investment in R&D significantly affects the export performance of medium-high tech industries. Bhat & Narayanan (2009) finds that for firms in the chemical industry who have entered the export market already, R&D and import of capital are very important to keep up and enhance their export competitiveness through continuous product innovation, quality enhancement and diversification. In the case of firms in the pharmaceutical industry in India, Goldar (2013) observes that in-house R&D efforts are associated with increased export intensity. This relationship is stronger in firms whose technical efficiency is high and who are closer to the technological frontier.

While undertaking a firm-level analysis of the export performance of Italian high-tech firms, D'Angelo (2012) notes that product innovation and external research collaborations with universities boost exports. Interestingly, he observes that innovation capabilities are embedded in human capital. He finds that while R&D employees impact export performance, R&D expenditure does not. The significance of skilled labour in making use of imported technology has also been highlighted by others. Since there is an underlying component of tacit knowledge involved in technology transfer, importing countries have to build

“absorptive capacity” in order to effectively utilise it in the production process (Lall, 1992). This can be done by imparting training and improving the skill levels of the employees. According to Aggarwal (2002), there are two requirements to utilize the imported technology: “First, the firm must hire skilled persons and train them and two; the firms must organise to make use of employees’ skills effectively”. Joseph et al. (2021) highlights the significance of staff training as an important factor affecting the productivity of firms in India. However, few studies have highlighted the significance of skilling workers in firms’ export performance.

Francis & Collins-Dodd (2000) argue that since high technology industries work under dynamic and turbulent market conditions with short technology cycles, firm-specific features including a strategic ‘export orientation’ and ‘entrepreneurial management’ which involve actively seeking out new markets, networks and relationships can positively affect export performance. For Indian manufacturing firms, Bhat & Narayanan (2009) Srinivasan and Archana (2011) and Ghosh and Roy (2018) underline the significance of effective distribution channels, as well as marketing and advertisement activities to gain traction in the international market.

Studies also indicate that firm-specific characteristics such as age, size and affiliation with multinational companies influence the export capabilities of firms (see Srinivasan and Archana, 2011; Ghosh and Roy, 2018; Bhat & Momaya, 2020; Anand, 2022). Location of firms also impacts their export capabilities. Firms located in a region or state with a conducive business environment with access to finance and knowledge partners are more likely to export (Cooke, 2001; Pradhan and Das, 2013).

The recent paper by Grazzi et al. (2021) which analyzes the probability and intensity of exports of manufacturing firms in India stands close to ours. However, their measures of firm innovation, R&D dummy and investment intensity do not account for technology transfers from advanced countries. This is a significant channel of technological capability-building for developing countries such as India, as indicated by previous studies such as Aggarwal (2002), and Bhat & Narayanan (2009) among others. Moreover, Grazzi et al. (2021) consider manufacturing firms in all industries and the period of their analysis is between 1995 and 2011. However, the global export market has significantly changed in the last decade and there is a shift towards technology-intensive products (Mani, 2021). In our study, we use the most recent data and focus on the export performance of technology-intensive industries, as we believe that innovation and technological capability-building is more relevant for them.

We hypothesize that the technological capabilities of high-technology firms have a positive influence on their export performance. Firms situated in regions

with greater innovation activity, ease of doing business and access to finance tend to do better in the export markets.

3. Model, Variables and Data

3.1. Econometric model

The review of empirical studies in the previous section informs us that firms spending on developing in-house R&D capabilities, import of capital goods and raw materials, and payments against the purchase of licenses and blueprint of foreign technology help in the process of technological catch-up, thus improving their export performance. Further, other firm-specific factors (Age, Size, expenses on promotional and distributional activities, domestic raw material intensity, outsourcing intensity, skill intensity and affiliation to MNEs) and locational advantages (Number of patents, size of knowledge-intensive firms, ease of doing business and availability of credit) also improves firms' competitiveness and export performance. Our empirical model tests the impacts of these variables on the intensity of export of the HT manufacturing firms. The model is presented below.

$$EXPIN_{ft} = \alpha + \beta_1 Technological_{ft} + \beta_2 Firmspecific_{ft} + \beta_3 Locationspecific_{rt} + \xi_t + F_{ft} \quad (1)$$

Where,

$EXPIN_f$: Export intensity of firm f in time t

v_i : Industry specific dummy

ξ_t : Time dummy

$F_{ft} \sim (0, \sigma^2)$: Random disturbance term with mean 0 and constant variance

The definition and construction of explanatory variables are explained in detail in the next subsection.

3.2. Construction of variables

The available theoretical and empirical literature indicates that technological investments have a bearing on the export performance of high technology firms in developing countries. Based on the insights from the literature, we have identified a set of explanatory variables which are defined in Table 1.

Table 1: Definition and construction of variables

Variables	Abbreviations	Definitions
Dependent variable: Export intensity	$EXPINT_{ft}$	Export/Sales
<i>Firm-level Technological factors</i>		
Research and development intensity	$RDINT_{ft}$	Spending on research and development/Sales

Capital goods import intensity	$CGIINT_{ft}$	Expenses on the import of capital goods/Sales
Raw material import intensity	$RMINT_{ft}$	Expenses on imported raw materials/Sales
Intensity of royalties payments	$RPINT_{ft}$	Payments on licencing and blueprints/Sales
<i>Firm-specific factors</i>		
Indigenous raw material intensity	$INDRMINT_{ft}$	Expenses on the purchase of domestic raw material/Sales
Intensity of advertisement, marketing and distribution activities	$ADVINT_{ft}$	Advertisement, marketing and distribution expenses/Sales
Outsourcing intensity	$OUTINT_{ft}$	Expenses on outsourcing manufacturing and professional activities/Sales
Intensity of staffs training	$STINT_{ft}$	Staff welfare & training expenses/Sales
Affiliation to MNEs	$MNEs_f$	Dummy variable with value 1 if firms' foreign equity share is more than 10 percent or a foreign owned firm
Firms' age	AGE_{ft}	Calculated from the year of incorporation
Firms' size	$SIZE_{ft}$	Log values of gross fixed assets
<i>Locationspecific</i>		
Number of patents in a region	$PATENT_{rt}$	Number of patents in a state
Number of knowledge intensive firms in a region	$KFIRMS_{rt}$	Number of knowledge intensive firms in a region
Ease of doing business	$EASE_r$	Rank of states bases on their average score for ease of doing business between 2015 and 2018.
Bank branches	$BANK_{rt}$	Number of bank branches in a state

3.3. Data

The data on HT manufacturing firms is obtained from the Prowess database hosted by the Centre for Monitoring Indian Economy (CMIE). This database provides detailed information about the balance sheet and various heads of income and expenditure of firms in the organised sector in India. The firms in the CMIE database account for more than 70% of the economic activity in the organized industrial sector of India. The data on manufacturing firms is collected

for the period from 2008 to 2020. To clean the data, we first drop all those firms which do not report their sales figures during the period of study. Secondly, we remove firms that never entered the export market between 2008 and 2020 and also those firms that exported 100 per cent of their sales. The latter group of firms are known as ‘born global’ firms. Such firms export their full potential right from their inception and their exports are unlikely to be highly impacted by technological upgrading. In comparison to firms that export only a fraction of their sales, these firms are outliers and are thus removed from our data. We keep only those firms that are present at least thrice during the study period. Our final dataset is an unbalanced panel of 2,334 firms and 21,718 observations for the whole HT manufacturing industry. Information on the number of firms and observations for individual industries is given in the Table A1 of the Appendix.

In addition, we follow the same procedure to clean the data for individual industries too. Table A1 in the appendix explains the number of firms and observations for each of the HT industries considered.

The literature indicates that apart from firm-specific factors, location-specific variables can also impact the export performance of firms. Innovative regions are more likely to have firms that export more. The innovation potential of individual states reflected in the number of patent applications filed in a year is collected from the publications of the Office of the Controller General of Patents, Designs and Trademarks, Department for Promotion of Industry and Internal Trade (DPIIT), Ministry of Commerce & Industry. The state-level ‘ease of doing business scores’ (calculated by DPIIT) were taken from the Handbook of Statistics on the Indian States brought out by the Reserve Bank of India (RBI). Other variables including the number of bank branches and denoting access to finance were also taken from RBI’s Handbook of Statistics on the Indian States. The data on the number of knowledge-intensive firms was taken from CMIE’s Prowess database⁵. A table with the descriptive statistics of the variables, Table A2, is given in the appendix.

4. Estimation and Results

4.1. Estimation of the model

The relationship between technological capability and the export performance of firms is specified in Equation 1. A major challenge in estimating this model is related to the nature of the dependent variable. Export intensity (EXPINT) in our data is obtained by dividing firms’ exports by their sales. Firms either abstain from the foreign market or export a part of their sales. For this reason, EXPINT varies from 0 to 1. In our data, out of 21,718 observations, 6,479 have zero values for EXPINT and its maximum value is 0.99. Our dependent variable is thus fractional in nature with a larger number of observations clustered at zero, i.e. $0 \leq EXPINT < 1$

1. Given the fractional nature of the dependent variable and accumulation of observations at one end of the distribution, the standard least square method is not appropriate. OLS does not guarantee that the predicted values of EXPINT, $E(\text{EXPINT} | X)$, falls within the unit interval (Papke & Wooldridge, 1996, 2008; Ramalho et al. 2011). This results in inconsistent estimates of β .

A number of methods have been developed for the consistent estimation of the parameters when the dependent variable is of bounded nature. Log-odds ratio, beta distribution, two-limit Tobit model and Quasi Maximum Likelihood Estimators (QMLE) are important among those (Papke & Wooldridge 1996 and Ramalho et al. 2011). QMLE method for the fractional dependent variable was proposed in the seminal work of Papke & Wooldridge (1996). This estimation procedure (1) does not require any ad-hoc transformation of data like the log odds ratio, (2) it can be applied even if observations are not clustered at both ends of the distribution which is essential for two limits Tobit model and (3) lastly, it is not based on the idea that each observation of the dependent variable, from 0 to 1, is taken with probability zero, which is the case for the beta distribution.

The QMLE is defined as

$$(\text{EXPINT} | x) = (x\beta) \quad (2)$$

Where $(\cdot)$ is a nonlinear function and $0 \leq (\cdot) \leq 1$. This is necessary for $(\text{EXPINT} | x)$ to be in the unit interval.

In Papke & Wooldridge (1996), $(\cdot)$ is a cumulative distribution function (cdf) and expressed

$$\text{as } G(\cdot) = \frac{\exp(\cdot)}{[1 + \exp(\cdot)]} \text{ or } G(\cdot) = \Phi(\cdot). \text{ Here, } \Phi \text{ is the standard normal cdf.}$$

In equation 2, β can be estimated consistently through nonlinear least squares (NLS). NLS is used more frequently because it directly estimates $(y | x)$, even though its estimators suffer through a number of limitations (See Papke & Wooldridge, 1996).

However, β in QMLE is estimated in the following way

$$I = \text{aggmax} \beta \sum N L Li(b) \quad (3)$$

Where (b) is Bernoulli log-likelihood function and it is given by

$$(b) = y_i[G(x_i b)] + (1 - y_i) \log[1 - G(x_i b)] \quad (4)$$

The estimated value of β in equation 3, irrespective of the distribution of y , is consistent and asymptotically normal.

Using the QMLE procedure, the final model we estimate is given below:

$$\text{EXPINT}_{ft} = \alpha_{ft} + \beta_1 \text{RDINT}_{ft} + \beta_2 \text{CGINT}_{ft} + \beta_3 \text{RMINT}_{ft} + \beta_4 \text{RPINT}_{ft} + \beta_5 \text{INDRMINT}_{ft} + \beta_6 \text{ADVINT}_{ft} + \beta_7 \text{OUTINT}_{ft} + \beta_8 \text{STINT}_{ft} + \beta_9 \text{MNES}_{ft} + \beta_{10} \text{AGE}_f$$

$$+\beta_{11}SIZE_{ft} + \beta_{12}PATENT_{rt} + \beta_{13}KFIRM_{rt} + \beta_{14}EASE_{rt} + \beta_{15}BANK_{rt} + v_i + \xi_t + s_{ft} \quad (5)$$

The equation 4 is used to find out the export determinants of HT industries as a whole. For the individual industries, we estimate the same model by removing the industry-fixed effect, ξ_t , from the equation⁶. We also estimate the Tobit model as a robustness check.

4.2. Results

The results of QMLE models for the whole HT industry are presented in Table 1, along with the results of Tobit models. In Table 2, the values for the Wald and F statistics are significant suggesting that the models are properly fit. The results of individual HT industries are presented in Table 3 and Table 4. While Table 3 explains the coefficients of the Tobit model, Table 4 presents the results of QMLE. The F and Wald statistics in these two models are also significant. Given the nature of our dependent variable, QMLE approach is more appropriate. Hence, this section explains the coefficients of QMLE models in Table 2 and Table 4.

Table 2 : Results: Overall HT manufacturing

VARIABLES	Tobit (Model 1)	Tobit (Model 2)	QMLE(Model 1)	QMLE (Model 2)
LRDINT	0.212** (2.334)	0.209** (2.300)	1.169** (2.374)	1.168** (2.356)
LIRMINT	0.273*** (19.84)	0.271*** (19.71)	1.801*** (22.32)	.786*** (22.13)
LCGINT LRPINT	0.138** (2.478) -0.552** (-2.565)	0.143** (2.558) -0.562*** (-2.595)	0.784** (2.513) -5.075** (-1.984)	1.818*** (2.604) -5.245** (-2.031)
LSTINT	0.317 (1.568)	0.286 (1.423)	2.616* (1.878)	2.386* (1.710)
INDRMINT	0.041*** (5.887) -0.096*** (-3.248)	0.042*** (5.985) -0.098*** (-3.337)	0.382*** (6.634) -0.762*** (-2.895)	0.390*** (6.749) -0.784*** (-2.964)
ADVINT	-0.0250 (-0.628)	-0.032 (-0.820)	-0.267 (-0.721)	-0.335 (-0.890)
OUTINT	0.001*** (-13.91)	0.001*** (-14.33)	0.010*** (-13.28)	0.010*** (-13.71)
AGE	0.0005 (0.548)	0.0006 (0.604)	0.005 (0.636)	0.005 (0.704)
SIZE	0.0006 (0.124)	0.0002 (0.050)	0.0228 (0.515)	0.0205 (0.464)
MNC		2.85e-05 (1.356)		0.0002 (1.152)
KFIRMS		-4.97e-06 (-1.385)		-3.73e-05 (-1.173)
PATENT				
EASE		-0.0001		-0.0006

BANK		(-0.357) 12e-06*** (3.028) 0.051***		(-0.204) 34e-05*** (3.141) -2.652***
Constant	0.0682*** (7.240)	(4.153)	-2.493*** (-28.86)	(-24.44)
Observations	18,773	18,773	18,773	18,773
Industry FE	YES	YES	YES	YES
Time FE	YES	NO	YES	YES
Pseudo R-squared	-2.330	-2.374		
Log pseudolikelihood	367.5	367.5	-6365.23	-6358.28
wald Ch2	55.79 (0.00)	49.15 (0.00)	1626.93(0.00)	1634.46 (0.00)
F-stat				

Note: Figure in the parenthesis are robust t statistics, except for the chi2 test. For F and chi2 tests parentheses present probability values.

*** < 0.01, ** < 0.05 and * < 0

Table 3 : Tobit results of Individual HT Industries

VARIABLES	NIC 20		NIC 21		NIC 26		NIC 27		NIC 28		NIC 29	
	Tobit (Model 1)	Tobit (Model 2)	Tobit (Model 1)	Tobit (Model 2)	Tobit (Model 1)	Tobit (Model 2)	Tobit (Model 1)	Tobit (Model 2)	Tobit (Model 1)	Tobit (Model 2)	Tobit (Model 1)	Tobit (Model 2)
L.RDINT	1.071*** (3.173)	0.982*** (2.835)	0.406** (2.353)	0.409** (2.426)	-0.531*** (-4.435)	-0.536*** (-4.592)	0.551 (0.983)	0.573 (1.044)	-0.862** (-2.164)	-0.810** (-2.026)	-0.476*** (-5.670)	-0.484*** (-5.617)
L.IRMINT	0.217*** (9.224)	0.209*** (9.002)	0.471*** (9.966)	0.491*** (10.20)	0.331*** (8.950)	0.333*** (8.985)	0.465*** (12.76)	0.457*** (12.65)	0.201*** (6.076)	0.202*** (6.102)	0.0102 (0.377)	0.0101 (0.376)
LCGINT	-0.0703 (-0.880)	0.0527 (0.634)	0.105 (0.634)	0.121 (0.721)	0.310 (1.263)	0.314 (1.320)	0.249 (1.393)	0.245 (1.386)	0.267*** (2.614)	0.254** (2.501)	0.0801 (0.895)	0.0896 (1.001)
LRPINT	-1.601*** (-4.981)	-1.758*** (-5.315)	-0.390 (-0.429)	-0.798 (-0.868)	0.681* (1.774)	0.690* (1.829)	0.154 (0.248)	0.0902 (0.148)	-0.392* (-1.830)	-0.441** (-2.009)	0.0718 (0.478)	0.0657 (0.433)
LSTINT	-0.818* (-1.898)	-0.484 (-1.111)	-1.238*** (-3.629)	-1.332*** (-3.532)	2.596** (2.556)	2.245** (2.350)	3.116*** (4.126)	2.648*** (3.514)	0.188 (0.550)	0.319 (0.919)	-0.271 (-0.703)	-0.284 (-0.704)
INDRMINT	0.0777*** (4.955)	0.0761*** (4.855)	0.229*** (6.791)	0.225*** (6.595)	0.0457 (1.630)	0.0522* (1.852)	- (-4.639)	- (-4.569)	0.0259** (1.966)	0.0215 (1.634)	0.0409*** (2.954)	0.0410*** (2.975)
ADVINT	-0.158*** (-4.268)	-0.176*** (-4.755)	0.0734 (0.873)	0.0222 (0.266)	-0.269 (-1.522)	-0.194 (-1.133)	-0.215*** (-4.571)	-0.223*** (-4.651)	0.0656 (0.675)	0.0465 (0.474)	1.035*** (6.967)	1.054*** (7.042)
OUTINT	-0.0216 (-0.282)	-0.0340 (-0.467)	-0.125 (-1.528)	-0.107 (-1.358)	0.0468 (0.444)	0.0390 (0.357)	-0.00428 (-0.0397)	0.0188 (0.171)	-0.0144 (-0.205)	0.000192 (0.00273)	0.204 (1.337)	0.221 (1.431)
AGE	-0.001*** (-5.829)	-0.001*** (-6.908)	-0.002*** (-11.37)	-0.003*** (-11.97)	-0.002*** (-5.368)	-0.002*** (-4.961)	-0.0002 (-1.089)	-0.0002 (-0.997)	-0.001*** (-8.197)	-0.001*** (-8.584)	-0.0002 (-1.174)	-0.0002 (-1.171)
SIZE	- (-2.380)	-0.00347* (-1.913)	0.0254*** (6.542)	0.0258*** (6.448)	0.0129*** (3.310)	0.0134*** (3.376)	- (-4.686)	- (-4.430)	0.00237 (1.176)	0.00296 (1.485)	- (-2.602)	-0.0068*** (-2.781)
MNC	0.00436** (-2.380)	-0.043*** (-1.913)	0.0385** (6.542)	0.0327* (6.448)	0.0873*** (3.310)	0.0808*** (3.376)	0.0110 (-4.686)	0.00992 (-4.430)	0.0238** (1.176)	0.0268*** (1.485)	- (-2.602)	-0.0275*** (-2.781)

	0.0445***										0.0277***	
	(-4.116)	(-4.033)	(2.057)	(1.717)	(3.744)	(3.481)	(0.756)	(0.687)	(2.536)	(2.858)	(-3.724)	(-3.673)
KFIRMS		9.97e-05**		0.000113		-		-6.58e-05		0.000177***		-7.36e-05*
		(2.180)		(1.270)		(-2.265)		(-1.387)		(4.409)		(-1.770)
PATENT		-9.05e-06		-3.30e-06		3.56e-06		-2.05e-06		-3.64e-05***		2.23e-05***
		(-1.312)		(-0.270)		(0.282)		(-0.267)		(-4.644)		(2.590)
EASE		-0.003***		0.00467***		0.00161		0.00216**		0.00185**		-0.000597
		(-3.846)		(3.970)		(1.055)		(2.571)		(2.225)		(-0.697)
BANK		5.31e-06**		3.75e-06		9.53e-06***		5.43e-06**		7.16e-06***		-5.37e-06**
		(2.289)		(1.227)		(2.877)		(2.203)		(2.595)		(-2.003)
Constant	0.175***	0.164***	0.0468	-0.0348	0.0807***	-0.00674	0.115***	0.0571**	0.106***	0.0931***	0.107***	0.110***
	(10.70)	(6.887)	(1.518)	(-0.872)	(2.672)	(-0.149)	(6.126)	(2.233)	(6.803)	(4.087)	(4.982)	(4.203)
Observations	4,988	4,988	2,235	2,235	1,614	1,614	2,722	2,722	4,330	4,330	2,884	2,884
Industry FE	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R-squared	2.045	2.556	0.534	0.579	0.772	0.824	-1.004	-1.025	-0.272	-0.301	-0.0812	-0.0854
Log pseudolikelihood	-86.24	-86.24	-379.6	-379.6	-161.5	-161.5	286.6	286.6	426.7	426.7	937.6	937.6
F-stat	23.07(0.0)	22.55(0.0)	23.67(0.0)	20.82(0.0)	9.611(0.0)	9.088(0.0)	12.80(0.0)	11.03(0.0)	9.417(0.0)	9.33(0.0)	6.381	5.615

Note: Figure in the parenthesis are robust t statistics, except for the chi2 test. For chi2 test parentheses present probability values.

*** < 0.01, ** < 0.05 and * < 0.1

Table 4 : QMLE results of Individual HT Industries

VARIABLES	NIC 20		NIC 21		NIC 26		NIC 27		NIC 28		NIC 29	
	QMLE (Model 1)	QMLE (Model 2)	QMLE (Model 1)	QMLE (Model 2)	QMLE (Model 1)	QMLE (Model 2)	QMLE (Model 1)	QMLE (Model 2)	QMLE (Model 1)	LE (Model 2)	QMLE (Model 1)	QMLE (Model 2)
LRDINT	6.751*** (4.213)	6.314*** (3.819)	2.288*** (2.968)	2.494*** (3.195)	-8.450*** (-5.710)	-8.779*** (-5.594)	7.049 (1.494)	7.212 (1.570)	-7.470* (-1.927)	-6.996* (-1.819)	-5.78*** (-5.029)	-5.853*** (-4.884)
LIRMINT	1.439*** (10.21)	1.403*** (9.886)	2.371*** (10.39)	2.504*** (10.55)	2.116*** (9.933)	2.115*** (9.919)	3.271*** (14.99)	3.190*** (14.59)	1.357*** (6.803)	1.371*** (6.842)	0.136 (0.472)	0.131 (0.463)
LCGINT	-0.750 (-1.071)	0.319 (0.490)	0.661 (0.738)	0.761 (0.787)	1.448 (1.186)	1.405 (1.218)	1.361 (1.562)	1.352 (1.594)	1.444*** (2.691)	1.326** (2.489)	0.850 (1.083)	0.954 (1.219)
LRPINT	-25.90*** (-3.254)	-27.08*** (-3.387)	-0.517 (-0.0938)	-3.048 (-0.538)	3.691* (1.956)	3.886** (2.089)	4.707 (0.779)	3.829 (0.637)	-3.361 (-1.606)	-3.842* (-1.819)	0.512 (0.319)	0.410 (0.248)
LSTINT	-6.139 (-1.402)	-3.453 (-0.803)	-15.52*** (-3.260)	-18.37*** (-3.503)	16.59** (2.287)	14.18** (2.251)	25.88*** (4.405)	22.09*** (3.709)	1.460 (0.524)	2.696 (0.945)	-3.576 (-0.748)	-3.687 (-0.738)
INDRMINT	0.566*** (5.211)	0.558*** (5.071)	1.343*** (7.329)	1.333*** (7.073)	0.460** (2.112)	0.487** (2.217)	-0.597*** (-3.609)	-0.582*** (-3.521)	0.236** (2.109)	0.203* (1.831)	0.475*** (3.137)	0.481*** (3.187)
ADVINT	-2.094*** (-4.835)	-2.129*** (-4.896)	0.475 (0.911)	0.119 (0.220)	-2.277 (-1.644)	-1.638 (-1.250)	-2.593*** (-3.499)	-2.660*** (-3.534)	0.449 (0.649)	0.258 (0.365)	9.041*** (8.445)	9.229*** (8.529)
OUTINT	-0.219 (-0.317)	-0.362 (-0.502)	-1.271 (-1.405)	-1.107 (-1.291)	0.0944 (0.0956)	0.0606 (0.0609)	0.110 (0.113)	0.367 (0.387)	-0.168 (-0.247)	-0.0200 (-0.0295)	1.196 (1.397)	1.360 (1.505)
AGE	- 0.00937*** (-5.656)	-0.011*** (-6.581)	-0.0196*** (-9.956)	-0.022*** (-10.63)	-0.0204*** (-5.022)	-0.019*** (-4.636)	-0.00248 (-1.009)	-0.00207 (-0.847)	-0.01*** (-7.796)	-0.0114*** (-8.310)	-0.00243 (-0.973)	-0.00243 (-0.969)
SIZE	-0.0327** (-2.363)	-0.0243* (-1.759)	0.160*** (7.307)	0.161*** (7.112)	0.103*** (3.578)	0.108*** (3.690)	-0.107*** (-4.019)	-0.096*** (-3.601)	0.0227 (1.338)	0.0282* (1.680)	-0.07*** (-2.715)	-0.0770*** (-2.891)
MNC	-0.393***	-0.386***	0.249**	0.238**	0.599***	0.542***	0.113	0.0888	0.209***	0.240***	-0.33***	-0.337***

	(-3.693)	(-3.631)	(2.318)	(2.160)	(4.328)	(3.922)	(0.820)	(0.653)	(2.874)	(3.288)	(-3.428)	(-3.362)
KFIRMS		0.000611		0.000751		-0.00111*		-0.000807		0.00168***		-0.00091*
		(1.518)		(1.271)		(-1.951)		(-1.611)		(4.475)		(-1.887)
PATENT		-5.03e-05		-4.00e-07		-1.01e-05		2.72e-05		-0.0003***		0.0002***
		(-0.794)		(-0.004)		(-0.111)		(0.319)		(-4.719)		(2.63)
EASE		-0.023***		0.024***		0.0113		0.0178**		0.0168**		-0.00725
		(-3.786)		(3.293)		(1.026)		(2.088)		(2.435)		(-0.787)
												-6.04e-
BANK		4.3e-05**		1.59e-05		7.0e-05***		4.23e-05		6.58e-05***		05**
		(2.228)		(0.749)		(2.960)		(1.640)		(2.821)		(-2.078)
Constant	-1.521***	-1.697***	-2.328***	-2.778***	-2.258***	-2.846***	-2.211***	-2.781***	-2.12***	-2.242***	-2.12***	-2.135***
	(-11.10)	(-8.796)	(-11.31)	(-10.48)	(-9.186)	(-8.358)	(-10.25)	(-9.255)	(-14.71)	(-11.32)	(-8.607)	(-7.016)
Observations	4,988	4,988	2,235	2,235	1,614	1,614	2,722	2,722	4,330	4,330	2,884	2,884
Industry FE	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Time FE	Yes	YES	Yes	YES	Yes	YES	Yes	YES	Yes	YES	Yes	YES
Log pseudolikelihood	-1799	-1780	-922.9	-915.3	-582.3	-579	-734.2	-732.3	-1411	-1406	-755.4	-754.1
Wald Ch2	372.1(0.0)	445.9(0.0)	438.9(0.0)	442.8(0.0)	233.3(0.0)	266.2(0.0)	403.2(0.0)	409.5(0.0)	229.9(0.0)	258.4(0.0)	162.9(0.0)	169.3(0.0)

Note: Figure in the parenthesis are robust t statistics, except for the chi2 test. For chi2 test parentheses present probability values.

*** < 0.01, ** < 0.05 and * < 0.1

It can be seen from the three tables that the coefficients estimated by the QMLE model have a higher explanatory power than those of the Tobit model. R&D intensity is observed to be positive and highly significant for the hi-tech industry. A unit change in R&D intensity leads to a 1.17 unit increase in the export intensity of firms. There are two channels through which R&D affects export performance. It is an indicator of innovation which directly affects the firm's competitiveness (Sharma, 2012; Joseph et al, 2021; Sahoo et al, 2021) In-house R&D expenditure is also necessary to build 'absorptive capacity' which helps firms to utilize the knowledge embedded in imported technology (Cohen & Levinthal, 1990). Our results show that the import of technology through the import of capital goods and raw materials is positively significant. While export intensity increases by 1.8 units with a unit increase in import of raw materials, it increases by 0.8 units in the case of capital goods. Reading these together, we can infer that R&D expenditure is contributing to enhancing the absorptive capacity of firms. However, expenditure on R&D alone is not enough. As is evident from the literature, skilled workers capable of utilizing the knowledge embedded in imported technology are essential to building technological capability in firms (Pavitt, 1984; Lall, 1992). This is clear from the positive and significant coefficient of the expenditure on staff training (LSTINT). However, we see that the import of disembodied technology (LRPINT), which is also an important factor that contributes to capability-building, is detrimental to the export competitiveness of high-tech manufacturing firms in India. In fact, the coefficient seems to be negative and significant; a unit increase in LRPINT causing a decline of 5.24 units in export intensity. It is interesting to note that this is however driven by a particular industry.

The coefficient for LRPINT for the Chemical industry (NIC 20) is very high and negatively significant. This is in line with the findings of Bhat & Narayanan (2009) whose study on the Chemical industry shows that a unit increase in payments on disembodied technology dampens firms' export intensity by -118.13 units. Firms in the chemical industry constitute 31.15% of our total observations, the largest share among all HT industries, which may have disproportionately affected the LRPINT coefficient in Table 4. Interestingly, the coefficient of LRPINT is positively significant only for the Computer and Electronics industry (NIC 26). This is not surprising as the proportion of royalties to net sales, profit and capital employed in the electronics industry has increased exponentially after 2006 (Damodaran & Marippan, 2018). In this industry, we also find that the import of raw materials (LIRMINT) and staff training (LSTINT) is also positive and significant, which implies that the recent surge in India's electronics exports can be attributed to technological capability building through the import of technology. A similar process of capacity building is visible in the electrical equipment industry (NIC 27) as well. On the other hand, the technological capability-building in industries like Chemical (NIC 20) and Pharmaceutical (NIC 21) seems to be driven by investments in in-house R&D and the import of raw materials.

However, these processes of technological capability building are not enhancing the firms' export competitiveness in the Automobile industry (NIC 29). Interestingly, export intensity in this industry is affected mainly by firms' expenditure on Advertisement, Marketing and Distribution. Another peculiar case is that of the Machinery and Equipment industry (NIC 28). For this industry, the import of raw materials and capital goods are significantly contributing to firms' export intensity. However, R&D intensity and expenditure on staff training, two important components for building absorptive capacity are negative or insignificant.

When it comes to firm-specific factors, we find only age to be statistically significant for the high-tech manufacturing industry in India. This is in line with the existing studies such as Goldar et al. (2017). An increase in firm's age by one year reduces its exports by 0.001 units, implying that younger firms tend to export more. We find similar results for individual industries as well. However, other firm-specific variables such as Size and MNE affiliation are significant with varying signs for individual industries, even though they are insignificant for all high-tech manufacturing. Our results partially support the common explanation that firms in developing countries adopt cost-effective strategies to improve export performance. The use of domestic raw materials has a positive and significant impact on the export intensity of firms in overall as well as individual specifications. However, outsourcing manufacturing jobs and professional services does not seem to significantly affect export. Our results indicate that region-specific factors except for access to finance (BANK) are insignificant in explaining firms' export intensity for HT firms. Even though 'ease of doing business' (EASE) and BANK are significant for a few individual industries, their coefficients are very small and hence have less explanatory power.

From the above discussion, we can summarize that firms' technological capabilities play a major role in determining their export intensity.

5. Conclusion

The last two decades have seen a phenomenal growth in high-tech exports from developing countries. India's case is no different as we see its exports of technology-intensive manufacturing products have grown exponentially in the period after 2008. The literature points out that this is a 'statistical illusion' as developing countries' high-tech exports are driven by their participation in the low-cost segments of high-tech products. However, we believe that technological upgradation also has a role to play in explaining India's high-tech export growth. We show this using firm-level data of the high-tech manufacturing industry in India for the period 2008 to 2020. Technological upgradation at the firm level happens through capability- building using the purchase of foreign technology, together with in-house R&D and skill

development of workers. Investment in R&D and human capital not only improves firm export directly but also creates the absorptive capacity required for the effective utilization of imported technology (Lall, 1992; 1999; Cohen & Levinthal, 1990). Our results indicate that all the above technological factors have a positive and significant impact on firms' export intensity in the high-tech manufacturing industries. However, at the individual industry level, expenditure on R&D is relevant in explaining the capability building and export intensity of the Chemical (NIC 20) and Pharmaceutical (NIC 21) industries, staff training expenditure is significant for Electronics (NIC 26) and Electrical (NIC 27) industries. Both these processes of technological capability building are absent in the Motor Vehicle Industry (NIC 29) where export seems to be driven by advertising, marketing and distribution expenditure (ADVINT). Our results also partially support the hypothesis that firms opting for low-cost strategies have higher export intensity, as indicated by the positive and significant coefficient of domestic raw material intensity.

Our study shows that to sustain in the dynamic and competitive export market, firms should continuously build their in-house capabilities through investments in R&D and human capital, apart from purchasing frontier technology from advanced countries. The current R&D tax credit system incentivizes large firms to invest in capacity building. However, smaller firms may not be able to afford this. Government should support such firms through specialized technical skilling initiatives and dedicated R&D grants.

Word count: 8335

Declaration of interest

The authors report that there are no competing interests to declare. The data and estimated results can be provided upon request.

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Appendix

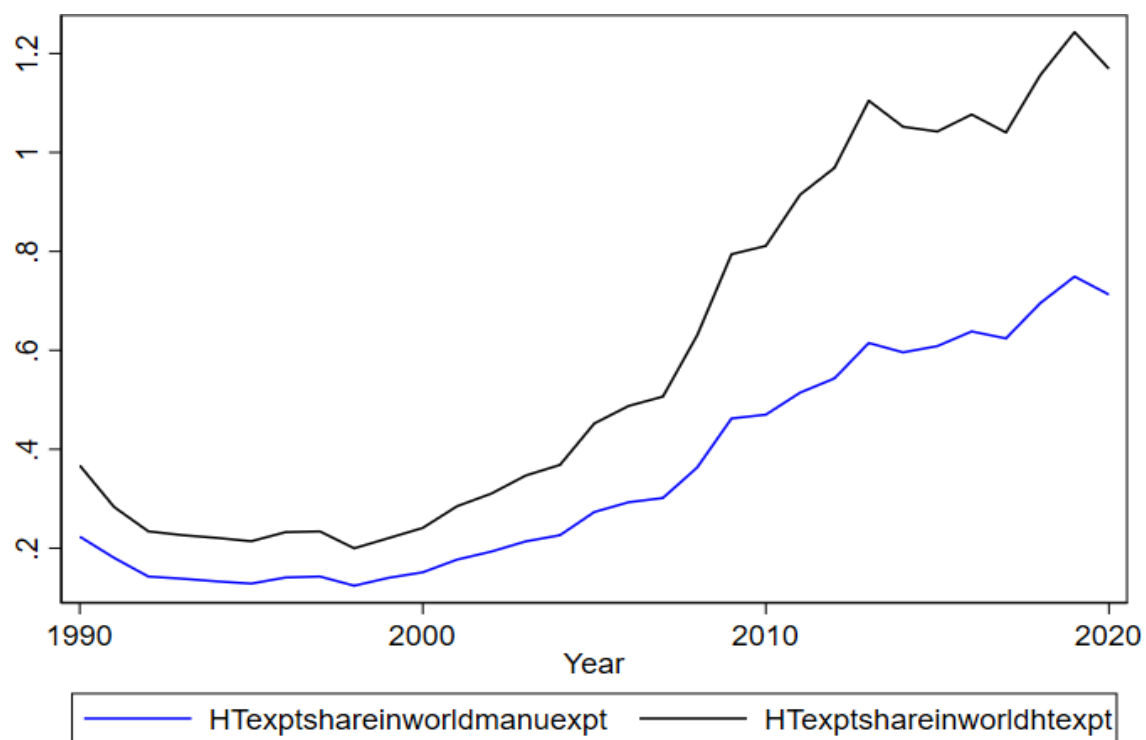
Table A1: Number of firms and observations

Industry Name and its NIC code	Number of firms	Number of observations
Manufacture of Chemicals and Chemical Products (NIC 20)	594	5,743
Manufacture of Pharmaceuticals & Medicinal Chemicals (NIC 21)	266	2,580
Manufacture of Computer & Electronic (NIC 26)	223	1,909
Manufacture of Electrical Equipment (NIC 27)	340	3,155
Machinery & Equipment (NIC 28)	573	5,046
Manufacture of Motor Vehicles (NIC 29)	338	3,285

Table A2: Descriptive statistics of all HT industries

Variables	Observations	Mean	Std. Dev.	Min	Max
EXPINT	21,718	0.16	0.24	0.00	0.99
RDINT	21,718	0.01	0.03	0.00	0.90
IRMINT	21,718	0.10	0.16	0.00	0.99
CGIINT	21,718	0.01	0.04	0.00	0.89
RPINT	21,718	0.00	0.01	0.00	0.57
STINT	21,718	0.01	0.01	0.00	0.39
INDRMINT	21,718	0.22	0.24	0.00	1.00
ADVINT	21,718	0.04	0.05	0.00	0.90
OUTINT	21,718	0.01	0.05	0.00	0.95
AGE	21,713	32.34	17.36	3.00	141.00
SIZE	21,718	6.31	1.77	-2.38	13.03
MNC	21,718	0.13	0.33	0.00	1.00
KFIRMS	21,718	222.44	169.35	0.00	533.00
PATENT	21,718	1847.03	1472.04	0.00	5225.00
EASE	21,718	11.03	5.57	1.00	26.00
BANK	21,718	7671.96	3496.75	18.00	17902.00

Figure A1: Share of India's HT export in Worlds' manufacturing export and World's HT export.



Notes

¹ This is because firms engaged in HT exports often adopt advanced technologies and best practices, which can be diffused to other firms in the domestic economy. As a result, domestic firms are able to upgrade their production processes and become more competitive in the global market.

² For instance, in 2020 export of high and medium high technology products of high income countries contributed to more than 36 percent of the world manufacturing export.

³ The share of HT export in total manufacturing exports of India increased from 16.05 percent in 1990-91 to 35.18 percent in 2020-21. The share of HTX of low and middle income countries in the world's manufacturing export increased from 3.5 percent in 1991 to 19.01 percent in 2020-21. These figures are based on the authors' calculation using data from WITS.

⁴ The classification of Technology Intensive industries by OECD can be found here, see <https://www.oecd.org/sti/ind/48350231.pdf>.

⁵ Eurostat, the statistical office of the European Union identifies certain industries to be Knowledge Intensive Activities' based on the level of tertiary educated persons in sectors of economic activity. We map the same into the National Industries Classification and identify corresponding industries to be knowledge-intensive. From CMIE's Prowess database, we find the number of firms belonging to knowledge-intensive industries in each state and use that for our analysis.

⁶ Note that, in equation 4 we have not considered firm level fixed effects, which includes for example the risk taking attitude of the managers and may affect firms export. Recently, Ramahlo et al (2016) proposed an exponential fractional response fixed effect model (EFRM) to address the issues. The fixed effects in their model are captured either by including industry specific dummies or by mean differencing the variables. Both the options in our case are not applicable because (1) given the micro panel with 2,334 number of firms, estimating the model with a very large number of dummies is not feasible; (2) mean differencing is not appropriate when variables involve a large number of zero observations. Though our model consider time and industry specific fixed effects, it fails to capture firm specific fixed effects.

Drivers of India's Energy Transition towards Renewable Sources

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Abstract

Government of India has set targets to achieve net-zero emissions by 2070 and is implementing several policy measures to achieve these targets. India needs to provide affordable, reliable, sustainable, and modern energy to all its citizens (SDG7) by 2030. To achieve this goal, renewable energy sources, particularly solar and wind, are considered the future backbone of India's energy system. This paper examines the trends in the share of fossil fuels from 1971 to 2021 and explores the factors contributing to this trend. By employing a time series analysis, the study focuses on the effects of India's GDP, international crude oil price, share of imported coal, and energy intensity of GDP, imposition of coal cess and India's signing of Paris Agreement on the fossil fuels share. We have used an Autoregressive Distributed Lag (ARDL) model to test the role of each variable in explaining the energy transition. We observe an inverted-U-shaped Kuznets curve relationship between GDP and share of fossil fuels. India's transition towards cleaner energy sources began in 2010 due to the imposition of coal cess and accelerated after 2015 (Paris Agreement). The Indian government has set targets to achieve net-zero emissions by 2070 and is implementing several measures to achieve this target. Therefore, we conclude that India is on the right track to reducing its carbon footprint from energy consumption.

Keywords: Fossil fuel, Energy, GDP, Paris Agreement, Coal cess, Time Series

JEL Code: Q35, Q42, E10, Q58, Q58, C10

1. Introduction

India is one of the world's fastest-growing economies and is expected to be the most populous country by 2027. India's energy demand is also rising steadily, driven by economic growth and a growing population. Currently, most of India's energy needs are largely fulfilled by fossil fuels, making the country one of the largest emitters of greenhouse gases globally. The need to reduce greenhouse gas emissions, increase energy security, and access to all has made India's transition to a sustainable energy system a top priority. The country had planned to install 175 GW of renewable energy capacity by 2022. However, it has only achieved 66% of this target so far. At the 26th Conference of Parties (COP26) in November 2021, Prime Minister Modi declared five energy-related targets (Panchamrit) for India. These targets include adding 500 gigawatts of non-fossil energy capacity, fulfilling 50% of energy needs through renewable sources, reducing one billion tonnes of carbon emissions, reducing carbon intensity of growth by 45% by 2030, and a commitment to net-zero emissions by 2070. Following the PM's announcements at COP26, the union budget 2022-23 and 2023-24 have announced a number of measures to achieve the energy transition. However, achieving these targets stumble upon several challenges, including limited financial resources, inadequate infrastructure, and policy and regulatory barriers.

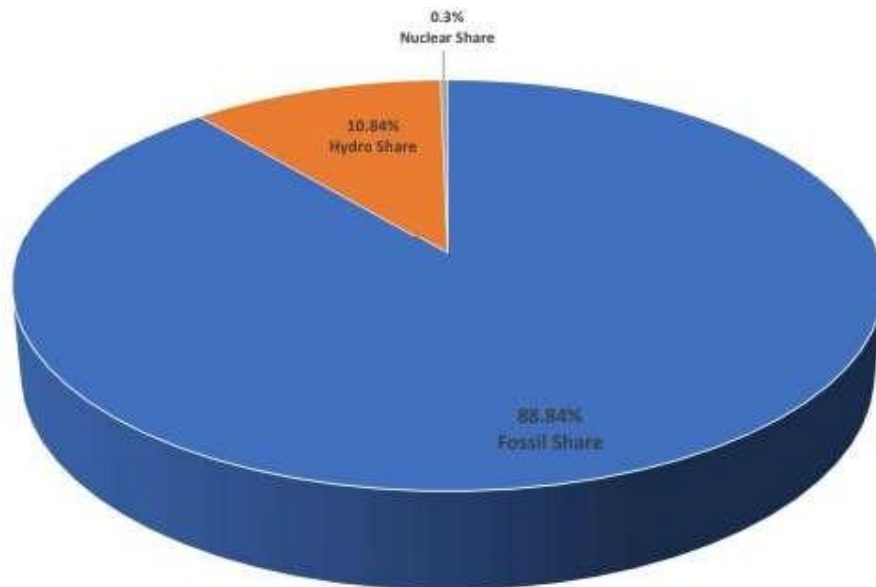
The energy transition towards the low-carbon economy considers three major goals. (i) The shift from fossil fuel-based electricity generation to renewable energy-based generation (electricity sector); (ii) The transition from petrol and diesel-based vehicles to Electric Vehicles (EVs) and the hydrogen-based vehicle in the transport sector, and (iii) transition from conventional cooking fuel to modern (LPG and electricity) sources of cooking fuel in household sector. Energy transition is mainly driven by growing demand for clean energy sources, decrease in the cost of renewables, change in the share of renewables, taxation and subsidy policy and pricing policy. For the faster transition towards clean energy, it is noteworthy to understand the factors that influence the choice of renewable energy by the producers and consumers (Gozgor et al., 2020).

1.1. Current Energy Scenario in India

India's current energy scenario is characterized by a heavy dependence on fossil fuels, primarily coal and oil, to meet its energy needs. Figure 1 and Figure 2 represent the composition of energy mix in India in 1972 and 2022, respectively. It is noted that fossil fuels account for approximately 60% of the total energy needs in India at present (Figure 2). However, these non-renewable sources are considered as unsustainable over the long term due to various environmental concerns. Hence, adopting alternative energy sources is crucial for India and other countries to fuel their economies in a cost-effective, environmentally sustainable, and

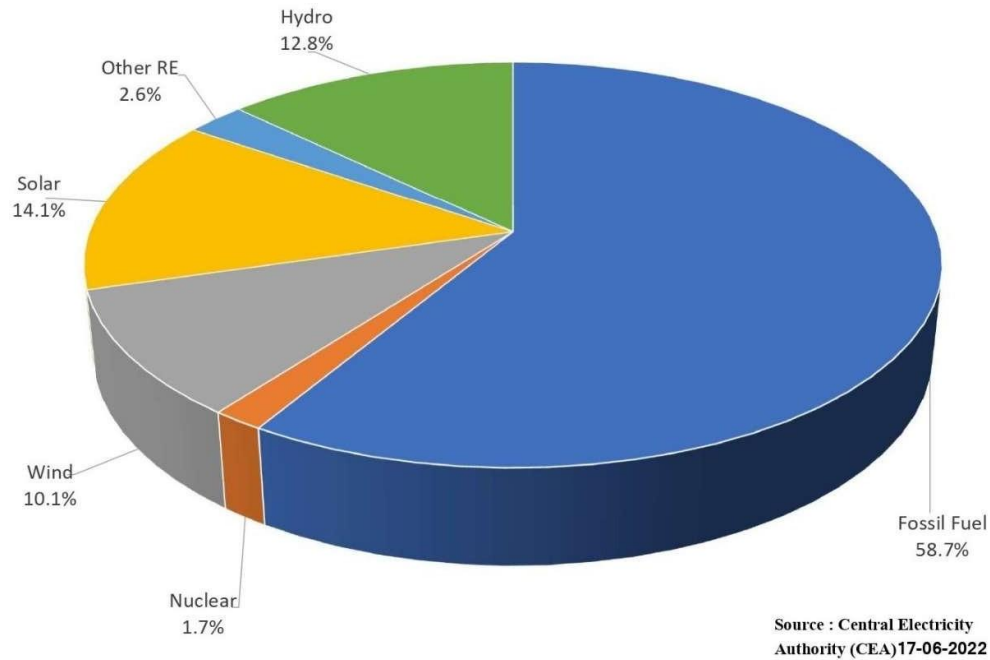
efficient manner. This process of transitioning from traditional energy sources to renewable and sustainable energy sources is known as energy transition. According to the International Renewable Energy Agency (IRENA), energy transition is the transformation of the energy sector from fossil-based to clean, renewable, and sustainable energy to achieve zero-carbon emissions. Given the unsustainability of fossil fuels over time, it is important to analyze their trends.

Figure 1: Composition of Energy Basket in India in 1972



Source: Our World in Data

Figure 2:Composition of Energy Basket in India in 2022



This paper aims to provide a detailed exploration of the energy transition process in India, including an analysis of the major drivers behind this process. The study goes beyond the previously identified variables in the existing literature and adds variables into the analysis.

2. Transition towards alternatives energy sources: Insights from literature

Several studies have analyzed the current energy scenario of India and other countries. The existing body of literature shows that the share of renewable energy sources is increasing in the energy basket, particularly, the share of solar and wind, (Gozgor et al., 2020) (Johnsson et al., 2019). However, (Grover, 2020) argues that no other technology is safe for electricity generation other than nuclear. Many other studies point out that hydrogen energy can create a carbon-neutral society and help in reaching sustainable development goal 7 (affordable, clean energy) (Bhattacharyya et al., 2022; Kovac et al., 2021; Falcone et al., 2021; Zuttel et al., 2010; Barret et al., 2003). Johnsson et al., (2019) explored the relationship between fossil fuel reserves and the changing share of fossil fuels and renewable energy in 10 countries, including India, with a comparison between fossil-fuel-rich countries and fossil-fuel-lean countries from 2004 to 2015. They have pointed out the increasing share of renewables (wind and solar) in total energy

demand since 2004. Nevertheless, total renewable energy demand growth remains low compared to fossil fuel. Fossil fuel accounts for over 80% of the global primary energy supply. According to IEA (2015b), India is responsible for almost 10% of the global primary energy demand increase between 2000 and 2013 due to its high population. IEA suggests the right carbon pricing systems, emphasis on green innovation, appropriate industrial policies, and assessment of Emission Performance Standards (EPS) to achieve a low-carbon economy.

Numerous studies have investigated the determinants of transition to clean energy in various sectors, including the electricity, household, and transport sectors. Reddy and Balachandra (2002) identified factors such as population growth, energy prices, urbanization, family income, economic growth, and the availability of indigenous energy sources that influence energy demand in India. However, Janardhanan (2012) pointed out that India faces significant challenges in transitioning to clean energy, including high dependency on coal, a lack of specific administration and legal mechanisms, and finance-related issues. To overcome these challenges, India must adopt the least-cost clean energy sources. Sharma and Dash (2022) examined the drivers of energy transition in the household sector. They identified income sources, female decision-making, physical assets, and forest areas as significant factors influencing household cooking energy preferences in India. Additionally, social factors such as caste and religion, geographic factors such as climatic conditions and sector, and state effects such as GSDP and HDI also impact fuel choice decisions using the energy ladder hypothesis and fuel stacking concept (Dutta & Sahu, 2022). Moreover, Ghose et al. (2020) explored the factors contributing to and promoting the growth of solar energy usage in India. Their regression analysis revealed that government policy, participation of local people, finance for solar energy, and climatic conditions positively influence the growth of solar energy usage in India.

Dubash et al. (2018) deployed a scenario-based modeling approach to explicate the future of India's energy and emissions. They analyzed current policy trends, particularly in the electricity sector, and proposed an accelerated shift from coal to renewables. In addition, the authors projected emissions for 2030 after the Paris Agreement, utilizing reference scenarios from 2015. Their analysis demonstrated that fossil fuel displacement had expedited the decarbonization of the electricity sector. Similarly, Sembiring (2021) examined the changing share of renewable energy sources in electricity production, considering domestic coal production as a hindrance.

Limited research has analyzed the transition of the transport sector. Chaudhury and Das (2022) recently published an article titled "Personal, passenger, and heavy vehicle segments need distinct strategies for energy transition." The authors elucidated several challenges that hinder the transition in this sector, such as the lack of supportive infrastructure, the absence of battery recycling guidelines, and import dependency on batteries. Using natural gas and hydrogen in different

vehicles is less polluting than electric vehicles (EVs). It can address import dependency, energy vulnerability, initial investment requirements, and infrastructure development issues. Moreover, transforming compressed natural gas (CNG)-based vehicles to hydrogen-based ones is relatively easier than developing infrastructure for EVs. Prior to this article, Zhang (2020) conducted a comparative study of 17 countries to examine the role of the transport sector in energy transition and climate change mitigation. The study investigated how behavioral and technological factors impact energy use and emission trajectories and which transport policies and strategies effectively achieve a low-carbon future.

Several studies have examined the energy transition across different countries and the challenges they encounter. One such study by Dietzenbacher et al. (2020) used structural decomposition analysis to measure the effects of energy transition across 41 countries. The study addressed two main questions: what are the drivers of the energy transition at the global level, and what is the role of the energy transition? The authors defined energy transitions as substituting non-renewable energy with renewable energy and vice versa. The study found that significant drivers of the energy transition at the global level include technology changes, changes in trade structure, changes in final demand per capita, changes in population, and changes in the intensity of renewable energy in production processes and households. Geographically, the energy transition has had positive effects on the EU and the United States but negative effects on China, India, and the Rest of the World. Another study by Gozgor et al. (2020) analyzed the determinants of renewable energy consumption. The study examined the relationship between economic globalization and the use of renewable energy in 30 OECD countries using panel data from 1970 to 2015. The authors found that per capita income, per capita carbon dioxide emissions, and the real price of oil positively impact the use of renewable energy. Additionally, economic globalization enhances the use of renewable energy in both OECD and developing countries. Bhattacharyya et al. (2022) estimated the minimum energy consumption per capita needed for transitioning to net-zero emissions in India and compared its current energy scenario with other countries. The authors focused on hydrogen combustion, nuclear power, and solar power and emphasized the importance of linking energy planning with waste management, recycling, and use. Hydrogen can be an essential component of transportation in this context.

Kinley (2017) offered a detailed account of the shift in global climate conditions that followed the Paris Agreement of COP 21 in 2015. The primary objective of COP 21 was to end the use of fossil fuels and ensure that the global temperature does not exceed a rise of 2°C above pre-industrial levels. This ambitious target necessitates a radical transformation of the world's energy sector. Since the Kyoto Protocol of 1997 and the Paris Agreement, concerted efforts have been directed toward augmenting the proportion of renewable energy sources, especially solar and wind power, in the overall energy mix.

2.1. Research Gap

The review of the existing literature indicates that a number of macro-level factors, including economic growth, technological advancements, population dynamics, and reliance on coal significantly influence global energy transitions. At the micro-level, factors such as income, female decision-making, education, and forest coverage are crucial in shaping the energy transition process. Nevertheless, systematic studies on the drivers of India's energy transition towards renewable sources are sparse. Few studies have examined the pattern of conventional energy (fossil fuel) consumption in India. Similarly, there are few studies on how India's signing of the Paris Agreement and imposition of coal cess have impacted use of fossil fuels in India. In this context, our study examines the drivers of India's energy transition towards renewable sources.

3. Theoretical framework

The Environmental Kuznets Curve hypothesis suggests that as the Gross Domestic Product (GDP) of a country increase, environmental degradation initially increases, but eventually decreases after a certain level of economic development is achieved. The composition of the energy mix in India has undergone a transformation over time, with varying proportions of conventional and renewable energy sources. This energy sector transformation is shaped by the co-evolution of technologies, markets, institutions, and societal values (Haug & Haug, 2011).

At the household level, low-income households are more reliant on conventional energy sources, especially biomass fuels. However, as households' incomes increase, they tend to shift towards cleaner energy sources, as hypothesized by energy ladder hypothesis. Similarly, at lower levels of GDP, less developed or developing countries such as India tend to rely more on conventional energy sources, mainly fossil fuels, as they are cheaper and more affordable. However, as countries' GDP increases, they tend to substitute cleaner energy sources for conventional sources. To further explore this dynamic, we have included the share of imported coal in total coal consumption and international crude oil prices in our model. We assume that an increase in the share of imported coal in total coal consumption with high international crude oil prices will be costly for the country in the long run. As a result, countries will try to switch to alternative energy sources other than fossil fuels, resulting in a decline in the share of fossil fuels in the total energy basket. It is important to note that including these two variables as explanatory variables may create multicollinearity problem during analysis.

In this study, two dummy variables are incorporated, which indicate policy intervention, namely the imposition of coal cess and the Paris Agreement (21st Conference of Parties), with the primary objective of investigating the changing pattern of fossil fuels in India's energy mix subsequent to the implementation of

the coal cess and the declaration of distinct commitments in the Paris Agreement, respectively. The inclusion of these variables enables an examination of the potential effects of these policy interventions on fossil fuel usage, thereby contributing to a more comprehensive understanding of the dynamics of energy transition in the context of contemporary climate change mitigation efforts.

Economic growth and technological advancements are two critical factors that impact India's adoption of renewable energy sources. Population dynamics and reliance on coal also play a significant role in the energy transition process. In summary, this study aims to examine the relationship between economic growth, technological advancements, population dynamics, and the adoption of renewable energy sources in India.

4. Objectives, Data sets and Methodology

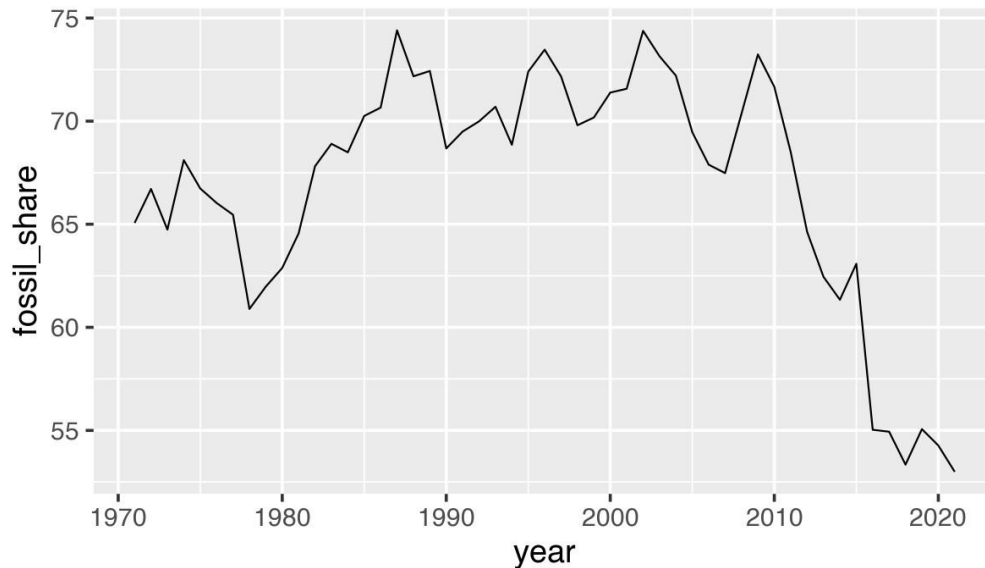
This paper aims to investigate the changing share of fossil fuels in the total energy production of India from 1971 to 2021. Various secondary sources of data are used to analyze the trend of fossil fuel usage in India over the period. Additionally, the paper seeks to identify the factors that impact the share of fossil fuels in total energy production. We aim to provide a more comprehensive understanding of the drivers of the changing energy scenario in India.

4.1. Data sources

In this study, data are collected from secondary sources. The sources of data used for different indicators are described in Table 1 with their definitions and units of measurement. In this study, a time series analysis is conducted to investigate the relationship between the share of fossil fuel in total energy production as the dependent variable and several independent variables such as Gross Domestic Product (GDP), Brent Crude oil (international crude oil price), the share of imported coal in total coal consumption and energy intensity of GDP. Along with the above explanatory variables, we have taken two dummy variables, imposition of coal cess (0=prior to the imposition of coal cess, 1=after the imposition of coal cess) and targets declared in Paris Agreement (0=prior to Paris Agreement, 1=after the Paris Agreement), as the explanatory variables. Coal cess refers to the imposition of a tax on coal. It was started in 2010 as a means of financing clean energy initiatives and mitigating the adverse effects of coal on the environment. and Paris Agreement refers to the global climate agreement signed in 2015 to limit global warming to well below 2^o Celsius above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 degrees Celsius.

Table 1: Variable Construction and Data Sources			
Variable Name	Explantion	Unit of Measurement	Data Sources
FOS	Share of fossil fuel in total energy production(Dependent variable)	Percentage	Author's calculation from India's Energy
GDP	Gross Domestic Product measured at 2015 constant price	Constant 2015 US\$	World Development Indicator Database
BRT	Brent Crude Oil Prices	US\$/bbl	World Bank data Sheet)
COAL	Share of imported coal in total coal consumption	Share of imported coal in total coal consumption	
ENT	Energy Intensity	J/US\$	Our World in Data
CESS	Coal Cess	Dummy Variable (0,1)	
PA	Paris Agreement	Dummy Variable (0,1)	

Figure 3: Share of Fossil Fuel in India's Energy Basket



Source: The Author.

Figure 3 illustrates the share of fossil fuel in India's energy mix between the years 1970 to 2022. The data reveals an increase in the share of fossil fuel from 65% in 1970 to almost 75% in the early 2000s. However, a gradual and consistent decline in the share of fossil fuel has been observed since 2010, with a significant drop to nearly 50% in 2021.

4.2. Hypotheses

- Relationship between the share of fossil fuel in total energy production and GDP.
H0: There is no significant relationship between the share of fossil fuel in total energy production and the GDP of India.
H1: There exists a significant relationship between the share of fossil fuel in total energy production and the GDP of India.
- Relationship between fossil share and international crude oil price.
H0: No significant relationship exists between fossil shares and the international crude oil price.
H1: A significant relationship exists between fossil shares and the international crude oil price.
- Relationship between fossil fuel share and imported coal share.
H0: There is no significant relationship between fossil share and the share of imported coal in total coal consumption.
H1: A significant relationship exists between fossil share and the share of imported coal in total coal consumption.
- Relationship between fossil share and energy intensity of GDP
H0: No significant impact of energy intensity on fossil fuels share. H1: A significant impact of energy intensity on fossil fuels share.
- Relationship between fossil share and coal cess and Paris Agreement.
H0: The imposition of coal cess and the Paris Agreement has no significant effect on the fossil fuel share.
H1: The imposition of coal cess and the Paris Agreement are significantly affecting the fossil share.

4.3. Methodology

To ensure the reliability of using any model, it is essential to check whether the dataset is stationary. In this study, we assessed the stationarity of each variable separately using four different tests: the Augmented Dickey-Fuller test (ADF), the Phillips-Perron test (PP), Dicky-Fuller Generalized Least Squares (DF-GLS) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS). The result of the tests is shown in Table 3.

Table 2: Descriptive Statistics.

Statistics	FOS	GDP	BRT	COAL	ENT
Mean	4.19	27.24	3.59	1.58	16.56
Median	4.22	27.18	3.59	1.78	16.55
Maximum	4.30	28.63	4.62	3.27	16.73
Minimum	3.97	26.03	1.92	-1.53	16.35
Std. Dev.	0.09	0.83	0.66	1.32	0.10
Skewness	-1.19	0.18	-0.49	-0.62	-0.30
Kurtosis	3.56	1.74	2.91	2.55	2.37
Jarque-Bera	12.69	3.65	2.13	3.23	1.59
Probability	0.001	0.16	0.34	0.19	0.44
Observations	51	51	51	44	51

Source: The Authors.

Table 3: Results of Unit root tests

Variables	ADF	PP	DF-GLS	KPSS
Levels				
FOS	-0.82	-0.82	-0.95	0.95
GDP	-3.02	-3.02	-1.64	0.99
BRT	-2.66	-2.66	-2.14	0.31
COAL	-4.31***	-4.31***	-3.30**	0.41
ENT	-2.02	-2.02	-1.08	1.13
First Difference				
FOS	-7.41***	-7.41***	-7.48***	0.053***
GDP	-7.56***	-7.56***	-6.64***	0.10***
BRT	-6.94***	-6.94***	-6.81***	0.08***
COAL	-	-	-	0.02***
ENT	-9.59***	-9.59***	-8.49***	0.05***

Source: Author's calculation.

Notes: ***, **, and * denote test statistics are significant at 1%, 5%, and 10% levels, respectively. The null hypothesis for all tests except for KPSS test is "series is non-stationary." The null hypothesis for KPSS test is "series is stationary."

From the results of unit root tests, we found that all variables are stationary at the first difference level $I(1)$ except COAL. The variable COAL is stationary at level $I(0)$. It means that the changes in the variables over time were consistent. To estimate the share of fossil fuels in total energy mix of India, we adopted the ARDL (Auto-Regressive Distributed Lag) model proposed by Pesaran et al. (2001) as the model has the advantage in the joint estimation of short- and long-run dynamics with a mixture of $I(0)$ and $I(1)$ variables. The model considers endogeneity and provides robust results for a limited sample size. Additionally, the ARDL bounds test allows us to cointegration between $I(0)$ and $I(1)$ variables. Nevertheless, the method is invalid when the variables are $I(2)$. Our sample size is limited, and we are also interested in both short- and long-term dynamics. Thus, the ARDL model looks suitable for the analysis. We have also used the Multiple Regression Analysis for comparison purposes.

4.4. Model Specification

$$FOS_t = (GDP, BRT, COAL, ENT, CESS, PA) \quad (1)$$

In order to minimize the variation in our model, natural logarithm has been applied to all the variables except two dummy variables. Equation (1) can be transformed into the following form.

$$FOS_t = \beta_0 + \beta_1 GDP + \beta_2 BRT + \beta_3 COAL + \beta_4 ENT + D_1 CESS + D_2 PA + \varepsilon_t \quad (2)$$

$\beta_1, \beta_2, \beta_3, \beta_4$ measure the effect of changes in GDP, changes in oil price, changes in coal imports on the share of fossil fuels in total energy production and changes in energy intensity, respectively. ε_t is the error term.

$D_1=0$: Before the imposition of coal cess

$D_1=1$: After the imposition of coal cess

$D_2=0$: Before Paris Agreement

$D_2=1$: After Paris Agreement

Based on the Equation (2), the ARDL bounds test equation can be written as follows;

$$\begin{aligned} \Delta FOS_t = & \mu_0 + \sum_{i=1}^{n1} \alpha_{0i} \Delta FOS_{t-i} + \sum_{i=0}^{n2} \alpha_{1i} \Delta GDP_{t-i} + \sum_{i=0}^{n3} \alpha_{2i} \Delta BRT_{t-i} + \\ & \sum_{i=0}^{n4} \alpha_{3i} \Delta COAL_{t-i} + \sum_{i=0}^{n5} \alpha_{4i} \Delta ENT_{t-i} + \delta_1 CESS + \delta_2 PA + \gamma_0 FOS_{t-1} + \gamma_1 GDP_{t-1} \\ & + \gamma_2 BRT_{t-1} + \gamma_3 COAL_{t-1} + \gamma_4 ENT_{t-1} + P_1 \end{aligned} \quad (3)$$

Where, μ_0 is the drift parameter, Δ is the first difference operator and $n_1, n_2, \dots, n_5$ are the respective lag lengths of the variables. The coefficients $\alpha_{0i}, \alpha_{1i}, \dots, \alpha_{4i}$ explain short-run dynamics whereas $\gamma_0, \gamma_1, \dots, \gamma_4$ captures long-run dynamics and δ_1, δ_2 are the coefficients of CESS and PA, respectively. P_1 is the error term. The above Equation (3) provides both short-run and long-run dynamics. The null hypothesis for bound test to test cointegration is ($H_0: \gamma_0 = \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$) against the alternative hypothesis ($H_A: \gamma_0 = \gamma_1 = \gamma_2 =$

$\gamma_3 = \gamma_4 \neq 0$). Rejection of null hypothesis implies that the acceptance of alternative

hypothesis which means cointegration exists between the dependent variable and a set of explanatory variables. Whether to accept or reject null hypothesis, Pesaran et al. (2001) come up with a set of upper bound and lower bound critical values. If estimated F statistic from the above null hypothesis is greater than the upper bound critical value, then we reject the null hypothesis of no cointegration and accept the alternative that there is existence of cointegration. We found estimated F statistic to be greater than upper bound critical value at 5% significance level (see Panel C of Table 4). Hence, there is cointegration. After confirming the existence of cointegration, we can write the equation for short-run dynamics.

$$\Delta FOS_t = \omega_0 + \sum_{i=1}^{n_1} \rho_{0i} \Delta FOS_{t-i} + \sum_{i=0}^{n_2} \rho_{1i} \Delta GDP_{t-i} + \sum_{i=0}^{n_3} \rho_{2i} \Delta BRT_{t-i} + \sum_{i=0}^{n_4} \rho_{3i} \Delta COAL_{t-i} + \sum_{i=0}^{n_5} \rho_{4i} \Delta ENT_{t-i} + \delta_1 CESS + \delta_2 PA + \phi_{ect_{t-1}} + \vartheta_t \quad (4)$$

5. Empirical Results and Analysis

The result of ARDL model is presented in Table 4. The table is divided into 4 parts: Panel A, B, C and D. Panel A and B presents short-run and long-run estimates, respectively. Panel C presents the result of bounds test, and Panel D reports the results of diagnostic tests. The estimated F statistics from the bounds test is above the upper bound critical value associated with 5% significance level, suggesting us to reject the null hypothesis of no cointegration and accept alternative hypothesis of the existence of cointegration between the FOS and a set of explanatory variables.

Table 4 : ARDL (1, 0, 2, 0, 0, 2, 2) short-run and long-run estimates

Panel A: Short-run Estimates			Panel B: Long-run Estimates	
Lag Order	0	1	Variables	Coefficients
Δ GDP	-	-	FOS _{t-1}	-0.29 ** (0.03)
Δ COAL	-	-	GDP	-0.03 (0.14)
Δ BRT	-0.0 (0.98)	-0.04*** (0.006)	BRT	0.03** (0.02)
Δ ENT	-	-	COAL	0.02** (0.01)
CESS	-0.03 (0.10)	0.03 (0.15)	ENT	0.12*** (0.00)
PA	0.05** (0.02)	-0.11*** (0.00)	CESS	-0.09*** (0.00)
ECT _{t-1}	-0.29 (0.00)		PA	-0.11*** (0.00)

Panel C: Bound Test Result				Panel D: Diagnostic Test	
Estimated F Statistic	k=6	4.25***		RESET	0.80
Significance Level	Lower bound	Upper bound		LM	0.42
10%	1.75	2.87		ARCH	0.97
5%	2.04	3.24		JB	0.42
1%	2.66	4.05		CUSUM	Stable
				CUSUMSQ	Stable

Source: The Authors.

Notes: ***, and ** denote test statistics are significant at 1%, and 5% levels, respectively. P- values are in parentheses. RESET=Ramsay test for model misspecification; LM=Lagrange multiplier test for serial correlation; ARCH=Autoregressive Conditional Heteroscedasticity test for heteroscedasticity; JB=Jarque-Bera test for normality. The values for RESET, LM, ARCH and JB tests are their respective probability values. CUSUM and CUSUMSQ are cumulative sum and cumulative sum of square tests for stability of the model, respectively. The optimal lag lengths of the ARDL model have chosen using Akaike Information Criterion (AIC).

We found all the variables except BRT and PA are insignificant in the short-run. The coefficients associated with PA and their lags are largely negative and significant, implying the shares of fossil fuels reducing after the declaration of Paris Agreement. It also confirms with the long-run coefficient associated with PA. The speed of the adjustment parameter is negative (-0.29) and significant at 1% level. The effect of BRT on fossil share is negative and significant in the short-run, implying that in the short run, the rise in international crude oil prices reduces the share of fossil fuels in total energy basket of India. However, we observe positive relation in the long-run.

The impact of coal cess and Paris agreement are negative and significant in the long-run, implying a significant reduction in the share of fossil fuels due to the imposition of coal cess and target declared in the Paris Agreement. The effect of imported coal is positive, meaning country's demand for coal is increasing.

The diagnostic test results pertaining to the estimated ARDL model indicate that the P-values associated with RESET test, LM test, ARCH test and JB test lie above the 0.05, suggesting our model does not exhibit any model mis-specification, serial correlation, heteroscedasticity and non-normality. We performed cumulative sum (CUSUM) and cumulative sum square (CUSUMSQ) to check the stability of the model. The cumulative sum of residuals and squared residuals fall within the error bands corresponding to a 5% significance level, indicating our model is stable throughout the analysis.

In this study, the Environmental Kuznets Curve (EKC) for energy transition was analyzed using the Ordinary Least Square (OLS) technique to provide a comprehensive understanding. The results of the Multiple Regression Model are presented in Table 5. Considering all the variables, we have examined the effect of each variable on the fossil share. However, when we run regression including all the variables, we found most of the variables to be insignificant (M12 model). The coefficients of GDP and GDP² enable us to explain the EKC mathematically. A positive value for GDP, coupled with a negative value for its square, signifies the presence of an inverted-U shaped EKC curve. Remarkably, this finding holds true for all the models, which include both GDP and GDP². Further, figure 4 illustrates the relationship between GDP and share of fossil fuels.

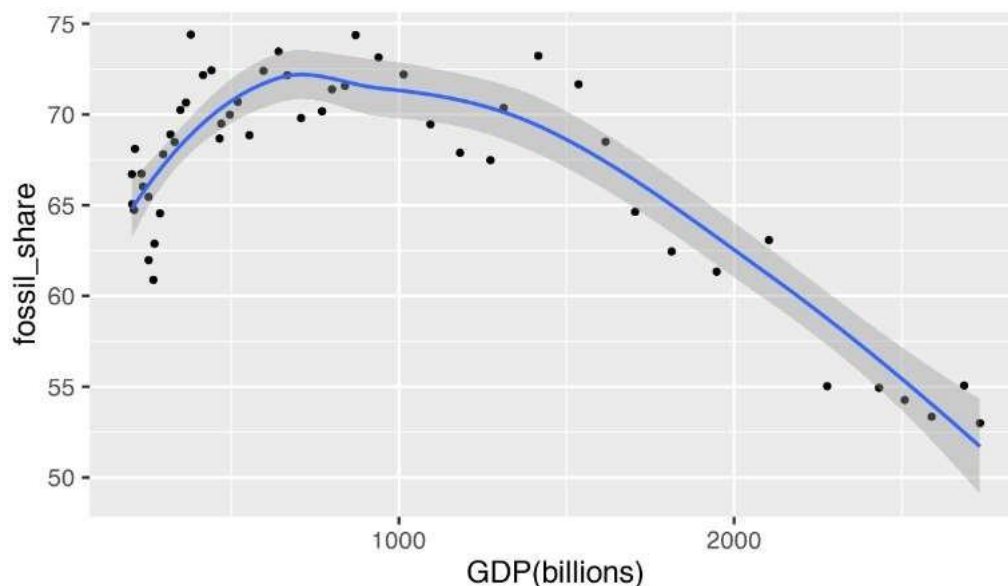
Table 5: Result of Regression Analysis

Dependent Variable: Share of Fossil fuels in total energy mix of India												
Independent Variables	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
GDP	6.83***						0.04***	9.22***	6.96***	10.24***	4.42***	11.39***
GDP ²	-0.12***							-0.17***	-0.12***	-0.18***	-0.08***	-0.20***
COAL		-0.02**								-0.003		0.007
BRT			-0.04**							0.03**	-0.01	0.03
ENT				0.67***				-0.33**	-0.23			-0.17
CESS					-0.14***		-0.11***			0.03	-0.01	0.04
PA						-0.21***	-0.18***		-0.08***		-0.11***	0.009
C	-	4.24***	4.35***	-7.03***	4.23***	4.22***	2.96***	-	-	-	-	-
	88.39***							115.1***	86.43***	135.2***	56.11***	147.4***
R ²	0.79	0.11	0.09	0.57	0.48	0.65	0.75	0.81	0.84	0.89	0.84	0.89
Adj-R ²	0.78	0.09	0.07	0.56	0.47	0.65	0.74	0.80	0.83	0.87	0.82	0.87

Source: Author's calculation.

Notes: ***, **, and * denote test statistics are significant at 1%, 5%, and 10% levels, respectively. All the variables are in logarithm form except twodummy variables; coal cess and Paris agreement. M1, M2,.....,M12 show the different regression models.

Figure 4: Inverted-U shaped Environmental Kuznets Curve



Source: The Author.

Figure 4 displays the correlation between the share of fossil fuel in total energy production and the country's GDP. The data depicts a quadratic function, indicating an initial increase in the share of fossil fuel in total energy production with a rise in GDP, followed by a subsequent decline. The relationship can be attributed to the notion that at a certain level of income, individuals tend to substitute conventional energy sources for cleaner and more modern ones. This reveals the inverted U-shaped Kuznets Curve which shows that increase in income creates a higher demand for cleaner energy, resulting in a declining share of fossilfuel. This pattern marks the beginning of the energy transition process.

Figure 5: Impact of Imported Coal share on Fossil fuel Share

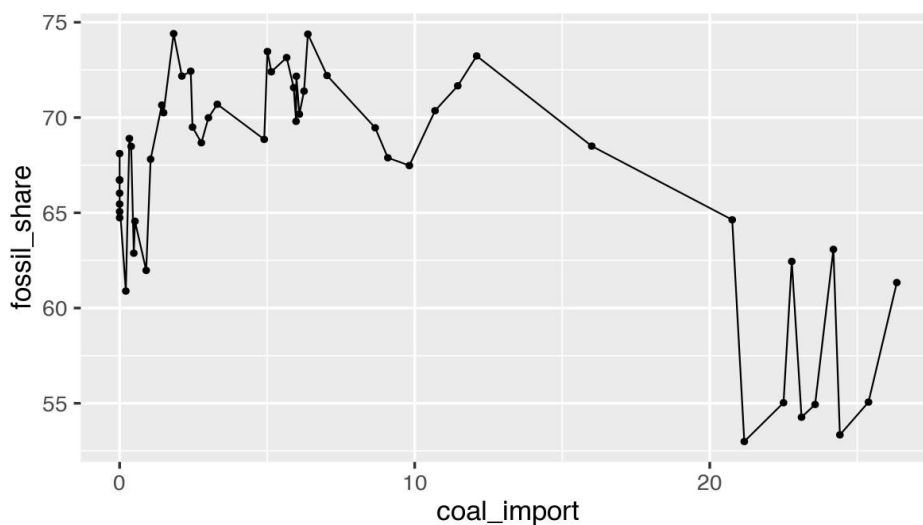


Figure 5 depicts the correlation between the share of fossil fuel in total energy production and the share of imported coal in total coal consumption. The data suggest that an increase in the share of imported coal leads to a shift in the country's energy mix towards alternative energy sources, eventually decreasing the share of fossil fuel in total energy production. This pattern can be explained by coal being a part of fossil fuels. As the share of imported coal increases, people tend to substitute it with cleaner and more sustainable energy sources, leading to a decline in the overall share of fossil fuel in the energy mix. This finding highlights the significance of imported coal in shaping the country's energy sector and the potential for energy transition towards a cleaner and more sustainable future.

6. Conclusion and Policy Implication

The paper presents an analysis of the trends in the share of fossil fuel in India's total energy production over the period from 1971 to 2021. Through a time series analysis, we have identified the factors contributing to the declining trends observed in the share of fossil fuels over time. Specifically, the study examines the influence of India's GDP and implications of the imposition of coal cess and the Paris Agreement, on the transition towards cleaner and more sustainable energy sources.

The results of the analysis reveal an inverted-U shaped Kuznets curve relationship between GDP and the share of fossil fuels. This suggests that with the rise in the income of the India initially although the share of fossil fuel in the total energy basket increased, it has started falling from the early 2000s, especially from 2010 onwards. India's fossil fuel share increased until the GDP reached USD 50 billion and has steadily fallen thereafter. From this we can infer that with the rise in the income level of India, the nation is able to afford clean energy sources and preference for clean energy sources are increasing. Additionally, the study found that the imposition of coal cess and Paris Agreement treaty have significantly contributed to the transition towards sustainable energy in India. Thus it implies that India has been compliant to the international treaties on climate change, especially in moving towards reducing the carbon emission from energy sources. International crude oil prices do not seem to have significant effect in reducing the share of share of fossil fuels in the total energy basket. This could be due to fact that India's energy production largely depends upon coal and very less on the petroleum products and gases. Imposition of coal cess seem to have influence to reduce the share of fossil fuel.

Although the paper focuses on the trends of non-renewable energy sources, it does not examine the trends of renewable energy sources. Therefore, future research should explore this phenomenon. The impact of the targets declared at the 26th Conference of Parties (COP 26) on India's energy sector should be explored. It is crucial to enhance Research and Development (R&D) efforts in the energy sector and implement measures that align with the targets of COP 26.

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Global Agency in Multi-Scalar Sustainability Transitions

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Abstract

The literature on sustainability transitions increasingly recognizes that sectoral structures transcending national boundaries can both hinder and promote sustainability transitions. Yet we have only limited evidence on the roles of global actors in multi-scalar transitions. To explore the mechanisms of global agency, we develop a conceptual framework and illustrate it with a case study of the World Bank's engagement in the water and sanitation sector. Based on a Socio-Technical Configuration Analysis of World Bank projects combined with expert interviews, we demonstrate how a paradigm shift in the global sanitation sector was initiated by a coalition of actors, and subsequently promoted by the World Bank. We thus illustrate how international 'advocates' initiate change by creating novel configurational templates, which are disseminated by 'change vehicles' as guiding principles around the world. The paper thus provides evidence of how 'global advocacy' transition trajectories may lead to transformative sectoral change.

Keywords: Geography of Sustainability Transitions, Multi-Scalar Transitions, Global Agency, Socio-Technical Configuration Analysis, Citywide Inclusive Sanitation

1 Introduction

Society today is confronted with a multitude of global sustainability challenges, such as poverty, inequality, demographic change, climate change and biodiversity loss (Johnson et al., 2017). Addressing these challenges requires radical transformations of socio-technical systems, i.e., the structures that fulfil societal functions such as energy, water, and food supply. However, in most sectors, well-aligned ‘configurations’ of actors, institutions and technologies that have become established and globally legitimized give rise to strong path dependencies favoring incremental rather than radical innovation (Fuenfschilling and Truffer, 2014; Truffer and Coenen, 2012; Markard et al., 2012). Transitions literature conceptualizes these path dependent structures as socio-technical regimes and is concerned with understanding how to achieve shifts from established configurations towards more sustainable ones, involving changes not only in technologies but also in markets, user preferences, and institutions (Coenen et al., 2012; Geels and Turnheim, 2022).

Recently, scholars have started to investigate the geography of sustainability transitions (GeoST), analyzing 1) how multi-scalar transition processes transcend national boundaries (Coenen et al., 2012; Coenen and Truffer, 2012; Truffer et al., 2015; Miörner and Binz, 2021), 2) global regimes as supranational sources of path dependence in rigid and locked-in sectors (Fuenfschilling and Binz, 2018), and 3) how global regimes continuously get reproduced in space (Miörner et al., 2022a). Scholars have argued that the traditional ‘niche cumulation and upscaling’ trajectory found in much of the transition literature represents a too narrow spatial understanding of transition processes, neglecting dynamics playing out directly at the global scale or in multi-scalar actor networks (Sengers and Raven, 2015; Loorbach et al., 2020; Miörner and Binz, 2021). They point to the role of actors operating at the global level when it comes to institutionalizing alternative socio-technical configurations (or de-institutionalizing established ones) and developing configurational templates that can be re-scaled to different local contexts simultaneously (Miörner and Binz, 2021).

Although processes of (de-)institutionalization at the global scale hold significant transitions potential, we lack a thorough conceptual and empirical understanding of the role of ‘global agency’ in such processes. So far, we do not know which (global) actors are actually capable of bringing about structural change in global sector structures and what mechanisms provide them with strong agency. In this paper we focus on actors who operate predominantly at a supranational level (e.g., multinational corporations (MNCs), international non-governmental organizations (INGOs), international organizations (IOs)) and ask what roles they play in global institutionalization processes and whether these roles differ for different types of actors.

To address these questions, we draw on insights from transition studies, economic geography and organizational institutionalism to develop a framework which specifies global agency in sustainability transitions. While the literature on institutional entrepreneurship suggests that actors must be able to depart from established structures while being powerful enough to institutionalize an alternative configuration (Battilana et al., 2009), we suggest that in reality no single actor is able to do so. Instead, our conceptual model outlines how global institutionalization processes are characterized by distributed agency among actors whose agency is constrained differently by their social position in global regime structures (Garud and Karnøe, 2003). We outline three potential actor roles, namely *advocates* who envision and initiate change, *change vehicles* who translate visions and disseminate change, and *implementers* who realize change within material infrastructures and institutions.

To illustrate our conceptual model empirically, we conduct a case study of the World Bank's (WB) past and current engagement in the water and sanitation sector. The sector is known for being reluctant to embracing innovation and sticking to the same 'gold standard' (extensive pipenetworks and large (waste-)water treatment plants) despite huge investment needs and increasing water scarcity (Baindur and Kamath, 2009; Schertenleib et al., 2021; Kiparsky et al., 2013). In the past, WB interventions have contributed to spreading this paradigm around the world, reinforcing status quo in the sector. Yet, in the past 5 years, a new (potentially transformative) infrastructure paradigm labelled "Citywide Inclusive Sanitation" (CWIS) has emerged in the sanitation sector, which is also being publicly promoted by the WB (Gambrill et al., 2020; Schrecongost et al., 2020).

To explore the mechanisms of global agency that have led to this paradigm shift in the sanitation sector, we 1) validate whether a strategy shift happened in the WB and 2) identify the mechanisms which induced it. To this end, we apply a mixed-methods approach consisting of a Socio-Technical Configuration Analysis (STCA) (see Mörner et al., 2022b) of WB project documents combined with semi-structured expert interviews to analyze the socio-technical configurations promoted by the WB in its water and sanitation projects between 2000 and 2021. The STCA of 93 WB project documents allows us to identify a structural shift in the socio-technical configurations promoted and financed by the WB (Heiberg et al., 2022), while the 14 semi-structured expert interviews provide us with insights into the dynamics of distributed global agency that enabled this shift.

By developing a novel conceptual framework for analyzing global agency and illustrating it empirically, we contribute to the literature on the geography of sustainability transitions in two ways. First, we are among the first to illustrate how sector transformations can be initiated and reinforced by global actors. In particular, we demonstrate how the social position of global actors enables them

to take on different roles in sustainability transitions, and how their interplay is necessary for transitions to occur. Second, by applying STCA to WB project documents, we further develop and improve the STCA methodology and demonstrate a new use case for this innovative method.

The paper proceeds as follows: Section 2 introduces the literature on sustainability transitions and presents the conceptual framework. Section 3 introduces data and methods, while section 4 presents the results of the empirical analysis of the WB's strategy shift in the sanitation sector. Section 5 includes a discussion of the results. In section 6, the paper concludes by highlighting that agency in global institutionalization processes is distributed among three types of global actors, namely advocates, change vehicles and implementers.

2 Conceptual Framework

Transition studies attribute the slow and rather incremental innovation patterns in many sectors to the existence of socio-technical regimes. Regimes represent the deeply institutionalized, dominant formal and informal rules that have co-evolved with technologies over long periods of time (Kemp et al., 1998; Markard and Truffer, 2008; Geels, 2019), and channel sectors into incremental development trajectories. Infrastructure sectors like electricity, transport, and urban water management, which are typically the focus of transition studies, tend to be particularly dominated by very stable socio-technical configurations 'that work' (Kemp et al., 1998). Those configurations comprise well-aligned sets of actors, technologies and institutions that have reached a high degree of institutionalization. They are thus taken for granted by many actors in the field. As a result, established actors usually reproduce, maintain, and incrementally improve the existing socio-technical configuration rather than introducing radical innovations (Fuenfschilling, 2019; Geels and Schot, 2007).

The conventional approach in transition studies has been to treat socio-technical regimes as a relatively homogenous structure evolving at the national level (Hansen and Coenen, 2015; Fuenfschilling and Binz, 2018; Miörner and Binz, 2021). Recent contributions to the literature have challenged this assumption in a broader agenda developing institutional, configurational, and geographically more elaborate perspectives on transition dynamics (Coenen et al., 2012; Fuenfschilling and Truffer, 2014; Heiberg et al., 2022).

First, scholars adopting insights from organizational institutionalism have conceptualized transitions as (de-)institutionalization processes (Fuenfschilling and Truffer, 2014; Fuenfschilling, 2019). Fuenfschilling (2019) argues that *"[t]ransitions toward sustainability are ultimately about the destabilization or de-institutionalization of existing socio-technical configurations and the creation and diffusion, hence institutionalization, of new potentially more sustainable ones"*.

Consequently, the socio-technical regime is conceptualized as the most deeply institutionalized core configuration in a socio-technical system (Fuenfschilling and Truffer, 2014; Heiberg et al., 2022). While some sectors exhibit monolithic regime structures, with one configuration strongly dominating the sector (e.g., centralized large-scale water systems as (waste-)water infrastructure), others are characterized by more polycentric or even fragmented regimes, in which several complementary or competing socio-technical configurations co-exist (e.g., different ways of providing urban mobility services) (Van Welie et al., 2018; Miörner et al., 2021). Transitions are more likely to occur when a socio-technical system is characterized by semi-coherence, expressed by a low degree of coherence between competing configurations, and a low degree of institutionalization of core configurations. Accordingly, an important source of transitions lies in the existence of institutional complexity and plurality within a socio-technical system (Fuenfschilling, 2019).

Second, scholars have conceptualized socio-technical regimes as potentially global constructs by taking into account multi-scalar actor networks and internationalized rationalities that originate in the values, beliefs, rules and practices that underpin particular socio-technical configurations (Fuenfschilling and Binz, 2018; Fuenfschilling and Truffer, 2014). A global regime constitutes the *"dominant institutional rationality in a socio-technical system, which depicts a structural pattern between actors, institutions and technologies that has reached validity beyond specific territorial contexts, and which is diffused through internationalized networks"* (Fuenfschilling and Binz, 2018,

p. 739). Global regime rationalities diffuse through international networks, structures and processes (e.g. corporate networks, standardization systems and processes, global investment flows) and become influential in different places around the world (Fuenfschilling and Binz, 2018; Miörner and Binz, 2021; Lesch, 2021). Consequently, in sectors with strong global regimes, different contexts are subject to the same mimetic pressures, resulting in socio-technical systems (and implemented infrastructure solutions) looking similar across countries, regions, and cities.

Based on these considerations, scholars have increasingly addressed the multi-scalar nature of transition processes and, in particular, the ways in which transformative innovations scale beyond initial 'niche' contexts. Recent studies have shown that transition trajectories not only transcend local/regional/national contexts, but also increasingly unfold at a global scale (Sengers and Raven, 2015; Binz and Truffer, 2017; Loorbach et al., 2020; Miörner and Binz, 2021). To enhance our understanding of global-level agency, we will next introduce and further develop the notion of multi-scalar transition trajectories before developing a conceptual model for analyzing the agency of global actors.

2.1 Multi-scalar Transition Trajectories

Miörner and Binz (2021) have used the institutional lens outlined above to specify how multi-scalar transitions can follow different spatial and scalar trajectories. In their framework, they point to the 'global' and 'territorially embedded' scales at which *institutionalization* processes take place and 'configurational templates' for legitimate solutions emerge (Fig. 1). Since transitions are by definition processes of (de-)institutionalization, institutional work (Lawrence and Suddaby, 2006), including formulating new rationalities and mobilizing support for their codification in formal rules, material structures, and practices, is critical to challenging local and global regime strategies alike. In addition to the process of (de-)institutionalization, the framework also considers the mechanism of *re-scaling*, which refers to how actors engage in strategic agency to translate rationalities between scales into the regulatory, normative, and cultural-cognitive structures of another spatial scale.

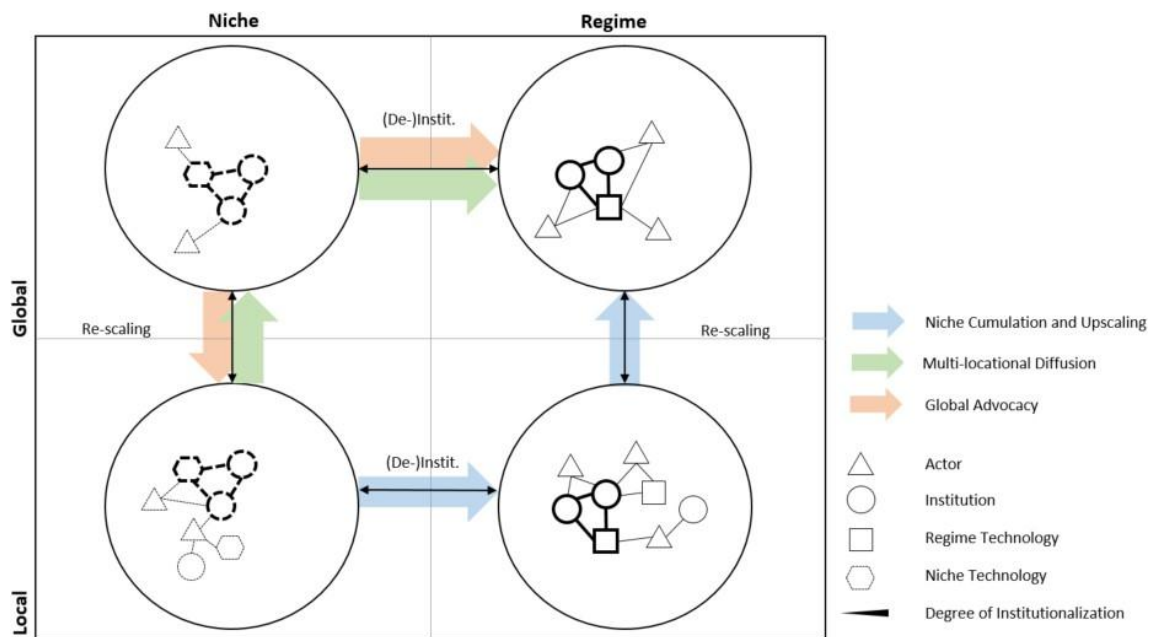
Based on these two general mechanisms (institutionalization and re-scaling), different transition trajectories for reconfiguring global regime structures can be outlined. Traditionally, transition scholars have referred to a 'niche cumulation and upscaling' trajectory as depicted by the blue arrows in Fig. 1. It is (often implicitly) assumed that transformative socio-technical configurations first develop at a local scale, then gradually cumulate and scale up to challenge the 'local/national' regime and only then start to transform global sector structures by diffusing across countries. This view has increasingly been challenged by research showing that niche innovation may travel and diffuse around the planet without transforming any 'local' regime first, or that transitions may be initiated directly by global actors (Sengers and Raven, 2015; Wieczorek et al., 2015; Loorbach et al., 2020; Miörner and Binz, 2021).

The framework further points to (at least) two additional multi-scalar transition trajectories that have not been given due attention in the literature, namely a 'multi-locational diffusion' and 'global advocacy' trajectory. In Fig. 1, the green arrows illustrate a multi-locational diffusion trajectory in which an alternative socio-technical configuration is developed in local niches and then directly re-scaled to a 'global niche' level without first changing local regime structures. In contrast, the orange arrows in Fig. 1 demonstrate how an alternative socio-technical configuration is constructed by global actors directly in a 'global niche' and then institutionalized as a new global proto-regime and re-scaled into diverse spatial contexts only ex-post. Whereas in both trajectories global actors are involved in the institutionalization of an alternative configuration at the global scale, the global advocacy trajectory is notable in that the novel configuration bears no relation to a configuration that has been previously implemented and proven to work "on the ground".

As a first illustration of the global advocacy trajectory, Miörner and Binz (2021) investigated the activities of the Bill and Melinda Gates Foundation (BMGF) (an international NGO), and a consortium of global and national actors, in the institutionalization of a new ISO standard for non-sewered sanitation. A key finding is that most of the rationalities reflected in the new global standard were constructed in a global actor network, which then directly institutionalized the novel standard in the sanitation sector's global regime, without considering ongoing innovation dynamics in local niche contexts. Another example of a transition process following the global advocacy trajectory is the institutionalization of a 'smart city' rationale for urban planning at the global level, where a concept was framed and pushed by a globally active private firm (IBM), and quickly taken up by urban planners in different local contexts (Söderström et al., 2014; Carvalho, 2015; Hayat, 2016).

However, while the empirical accounts of multi-scalar transition trajectories illuminate some general mechanisms and patterns of global institutionalization processes, we still lack a thorough understanding of the role of different (global) actor types and their agency in institutionalizing novel socio-technical configurations at the global sector level. More specifically, we do not know which global actors are actually capable of doing so, which is primarily related to the question of how changes in institutional rationalities and thus strategies of global actors might come about.

While it would be reasonable to identify actor types that are able to 'write the scripts' for global regimes and cross-connect transition dynamics taking place in different places and at various scales at once (Kranke and Quitsch, 2021; Fuenfschilling and Binz, 2018), we will argue below that no single type of actor is capable of doing so on its own. Rather, we follow the institutional entrepreneurship literature in proposing that agency is distributed (Garud and Karnøe, 2003), as the agency of different actor types is constrained differently by their social position in a socio-technical system.



Note: Illustration by the authors based on Miörner and Binz (2021).

Figure 1 Multi-scalar Transition Trajectories.

2.2 Global agency in multi-scalar transition trajectories

The literature on institutional entrepreneurship (DiMaggio, 1988; Battilana et al., 2009) provides useful inroads for assessing how certain individuals or organizations can deviate from existing institutional orders and create and transform existing institutions by leveraging various kinds of resources (Hoogstraaten et al., 2020). In this context, researchers have studied different types of institutional entrepreneurs, including individuals, organizations, governments, or civil society groups, investigating how they engage in (de-)institutionalization processes and who is best positioned do so (Fuenfschilling, 2019; Hoogstraaten et al., 2020; Hardy and Maguire, 2008). Yet, less attention has been given to factors and conditions that enable actors to engage in agency at the global level of a socio-technical system (Fuenfschilling and Binz, 2018).

2.2.1 Social Position as an Enabling Factor in Institutionalization Processes

In their seminar work on institutional entrepreneurship, Battilana et al. (2009) highlight factors that condition the scope for agency within a given social structure. Contextualizing agency in different spatial and sectoral structures is an important but often overlooked aspect when drawing on the institutional entrepreneurship literature to investigate agency in transition studies (Fuenfschilling, 2019). One important prerequisite for agency is the social position of actors, since *“actors social position mediates their relation to the environment in which they are embedded”* (Battilana et al., 2009, p. 76). Together with formal authority, the social position affects an actor's access to resources, legitimacy and prestige, as well as its own perception of a socio- technical system (Ferguson et al., 2013; Fuenfschilling and Truffer, 2016; Fuenfschilling, 2019; Hoogstraaten et al., 2020). Consequently, an actor's social position in terms of status and network position (i.e., its relationship to other actors) has a decisive impact on the actor's ability to change institutions (DiMaggio, 1988; Garud et al., 2002; Battilana et al., 2009).

Fuenfschilling (2019) argues that, on the one hand, high status and a central network position facilitate institutional entrepreneurship. Core actors in a network typically have access to and control over resources, knowledge flows and enjoy high social prestige. On the other hand, however, central actors typically benefit most from and are strongly embedded in the prevailing rationalities of the global regime, which limits their ability (and will) to deviate from them. In contrast, a low-status actor in the periphery of a sector' social networks does not have much to lose by deviating from established rationalities and developing radically new ideas and visions and, ultimately, future development paths. In institutionalization processes, however, peripheral actors are constrained by their unfavorable social position and the resulting lack of resources and influence on central actors' strategies.

In the global realm, this distinction between high-status central actors and low-status peripheral actors can be translated into two generic types of actors, namely 'advocates' and 'implementers' which will be introduced in more detail below. Yet, as already discussed, neither of those two actor types is usually motivated and/or able to institutionalize a divergent novel rationality in global sector structures. Instead, we follow Hoogstraaten et al. (2020) by arguing that global institutionalization processes need the involvement of a third actor type, which we characterize as an intermediary 'change vehicle' with mid-level status. In the next section, we will characterize global transition and (de-)institutionalization processes as distributed agency (Garud and Karnøe, 2003) between advocates, change vehicles and implementers.

2.2.2 Actor Roles in Global Institutionalization Processes

Advocates

Under advocates, we subsume peripheral actors (e.g. civil society organizations, academic institutes, NGOs, donor agencies, etc.), who stand somewhat apart from the key actors in a socio- technical system and have an incentive to create divergent visions, construct configurational templates and promote them through various forms of institutional entrepreneurship (Hardy and Maguire, 2017). Typically, these actors possess high social prestige but relatively limited financial resources, formal authority, and/or coercive power (Battilana et al., 2009).

Despite these limitations, it is increasingly recognized that advocates play a key role in constructing novel rationalities at the global scale. In particular, advocates with high interpretive power and moral authority have the capacity to “[...] create, reproduce, or alter regulatory, normative, and cultural-cognitive institutions” (Fuenfschilling, 2019, p. 15). Especially advocates who manage to simultaneously gain a certain level of status and resources without losing their outsider status are in a good position to mobilize allies, initiate new collaborations, and eventually occupy prominent positions in international arenas. Presence in these arenas allows advocates to participate in elaborating, legitimizing, and ultimately institutionalizing alternative rationalities (Fuenfschilling and Binz, 2018; Miörner and Binz, 2021). Nevertheless, advocates are unlikely to directly influence the strategy of the highest-status actors (implementers), such as governments and large MNCs, as these benefit most from existing institutional arrangements and typically have no incentive to deviate from established regime rationalities. However, as Battilana et al. (2009) note, advocates can mobilize coalitions with other actors, who, for example, have the formal authority to enforce their transformative agenda. We refer to this type of actor as a change vehicle.

Change Vehicles

Change vehicles meet the following criteria: 1) they hold a mid-status, brokerage position in a socio-technical system, 2) they are equipped with some degree of formal authority in technical, financial and/or legislative domain(s), and 3) they have transnational reach. Change vehicles contribute to the transformation of global regimes as they institutionalize the advocates’ novel visions and configurational templates by translating and codifying them into global standards, strategic principles or novel financial investment models (Miörner and Binz, 2021). Examples of potential change vehicles include consultancies, professional associations and international organizations (IOs) (Miörner and Binz, 2021; Loorbach et al., 2020; Schot and Kanger, 2018). While the relevance of consultancies and professional associations lies in their advisory role to various governments and firms around the world, IOs have the

potential to play a more direct role in global institutionalization processes. In the following, we will therefore use them as an ideal- typical example of the important role change vehicles may play.

An IO is defined as an organization operating at international scales, established by more than two nation states based on a formal agreement of collaboration that specifies its jurisdiction and responsibilities (Mingst, 2022). Examples of IOs include various organizations of the United Nations, multilateral development banks such as the World Bank, and the International Organization for Standardization. The role of IOs in transition processes is shaped by two factors. First, the spatial extent and transnational nature of IOs, combined with their institutional power in terms of technical, financial and legislative authority, may enable IOs to influence national policies by developing and disseminating solutions to a range of global problems (Béland and Orenstein, 2013; Kranke and Quitsch, 2021; Schot and Kanger, 2018). Second, IOs typically occupy a brokerage position in socio-technical systems, linking different elements of society such as governments, academia, private actors and civil society, and facilitating the flow of information between them (Fuenfschilling and Binz, 2018; Schot and Kanger, 2018).

In part because IOs are able to impose fines and sanctions to stabilize and enforce existing institutional arrangements, such as technological standards or trade regulations, they are often viewed as regime incumbents (Kranke and Quitsch, 2021). However, it has been shown that while IOs have difficulty in independently deviating from established rationalities, they may still absorb novel ideas circulating in their environment (Kern et al., 2020). Béland and Orenstein (2013) accordingly describe IOs as open systems that are not consistent in their ideas and values over time, but rather susceptible to the influence of political and ideological shifts, or expert inputs.

This results from the need of IOs to maintain their credibility and legitimacy and therefore to adapt to prevailing ideas, paradigms, and expert opinions in a sector (Béland and Orenstein, 2013). An illustrative example in this regard is the European Commission's adoption of the circular economy concept, which was strongly shaped by consultants in the Ellen MacArthur Foundation (Kern et al., 2020). Another example is the central role of the ISO in introducing a new global standard for on-site sanitation systems (Miörner and Binz, 2021).

In general, access to and influence on change vehicles is a valuable asset for advocates in sustainability transitions. Channeling investment flows (e.g., WB), defining industrial development paths (e.g., ISO) or influencing knowledge flows (e.g., consultants, professional associations) has a direct impact on the last category of global actors, namely implementers. These emulate and adapt to existing and novel socio-technical configurations to capture business opportunities, solidify their legitimacy and avoid longer-term disruptions

(Hoogstraaten et al., 2020).

Implementers

Implementers are key actors within global sector structures whose high levels of prestige and resources enable them to reproduce or transform global regimes by manifesting internationalized rationalities in the regulatory, normative, and cognitive institutions of different scales. We refer here, among others, to multinational corporations (MNCs) that integrate global patterns of production, distribution, and consumption and reinforce socio-technical configurations around the world (Fuenfschilling and Binz, 2018). MNCs can fundamentally alter global regime structures through their key role in the re-orientation and formation of new industries, markets and values chains (Hardy and Maguire, 2017; Johnstone and Newell, 2018). Besides MNCs, implementers may also be actors with the highest degrees of (formal) authority such as prestigious utility companies or national governments.

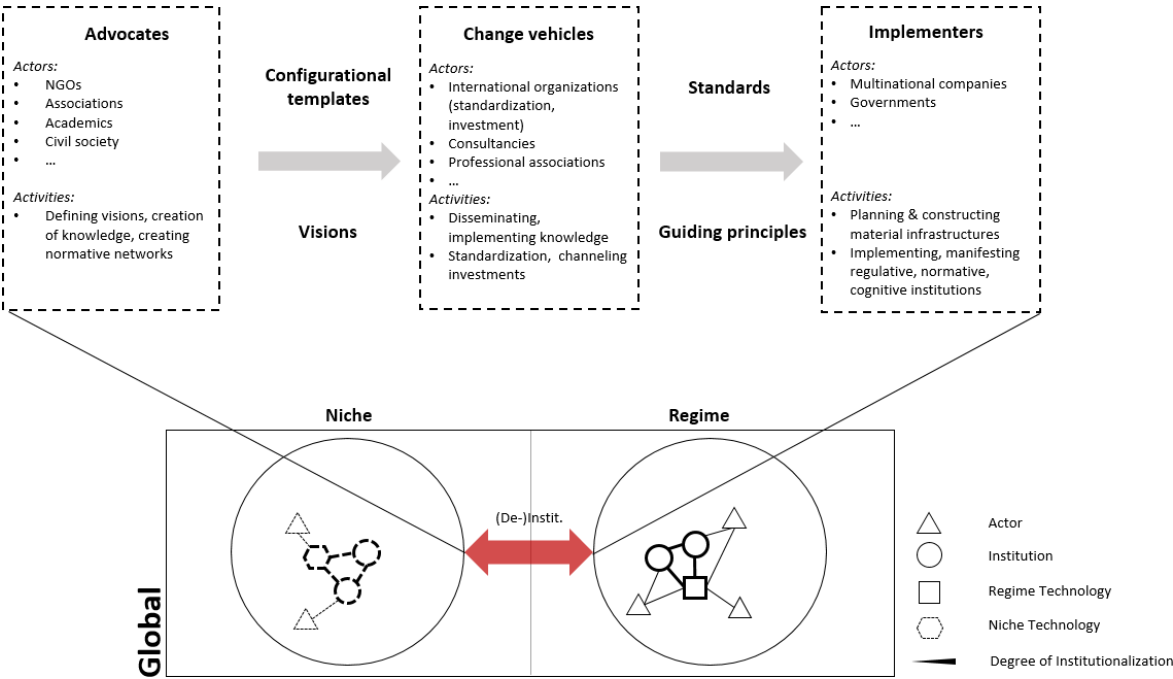
Implementers generally bear the responsibility for creating real-world solutions that will be used and evaluated by end-users. As a result, they tend to be risk-averse favoring well-proven technologies and business models. Consequently, while they certainly evaluate novel socio-technical configurations emerging in the international arena, they are unlikely to engage in radical innovation processes or with novel configurational templates created by advocates. Instead, implementers pick up socio-technical configurations primarily when they are imposed on them, e.g., by consultants, new ISO standards or changing investment conditions. Therefore, as champions of established socio-technical configurations, implementers contribute to a transition by consolidating emerging configurations in the global regime structure rather than by being the ones introducing novelty at a first instance.

Summary: Outlining a Global Institutionalization Process

Figure 2 summarizes the framework by illustrating how global advocacy transition processes are distributed across our three actor types and how their relationships evolve over time. In essence, it outlines a global institutionalization process in which an **advocate**, located in a global niche and not strongly associated with a global regime, successfully shapes a novel socio-technical configuration and guiding rationality directly at the global scale. While the advocate's position in the field allows it to deviate from established field logics and frame a transformative configurational template, its lack of formal authority, prestige and potentially resources prevents it from directly adapting relevant formal and informal institutions and influencing the strategies of implementers. To overcome this bottleneck, the advocate may leverage a **change vehicle** that occupies a brokerage position in the global regime and has the necessary formal authority to institutionalize an alternative template in international sectoral structures. While formal

authority enables the change vehicle to codify the novel configuration into standards, norms or resolutions, the translation into real-world changes, will finally depend on **implementers**, which turn the novel socio-technical configuration into material infrastructures and corresponding institutions in concrete territorial contexts.

Global agency is therefore distributed among advocates, change vehicles and implementers, whocrucially complement each other in global institutionalization processes. In the remainder, we will empirically illustrate and validate this general model with a case study in the water and sanitation sector that demonstrates how advocates sought and achieved a realignment of a change vehicle’s strategy in urban sanitation, thus structurally changing the playing field of implementers in the years to come.



Note: Illustration by the authors.

Figure 2 Global Agency in Global Institutionalization Processes.

3 Case Selection, Data and Methodology

In the following, we elaborate on 1) the selection of the case, 2) the analytical steps taken to validate the change vehicle's strategy shift, and 3) the analytical steps taken to examine the mechanism of global agency enabling this strategy shift.

3.1 Case Study: A Paradigm Shift Toward City-Wide Inclusive Sanitation

To explore global agency in multi-scalar transition trajectories, we examine how the institutional rationalities promoted by a global regime player, namely the WB, evolved in the water and sanitation sector, a sector characterized by a particularly strong global regime structure (Heiberg et al., 2022; Fuenfschilling and Binz, 2018; Miörner et al., 2022a). In doing so, we follow an extreme case sampling approach, which assumes that the relevant theoretical mechanisms are particularly observable in our empirical case (Flyvbjerg, 2006).

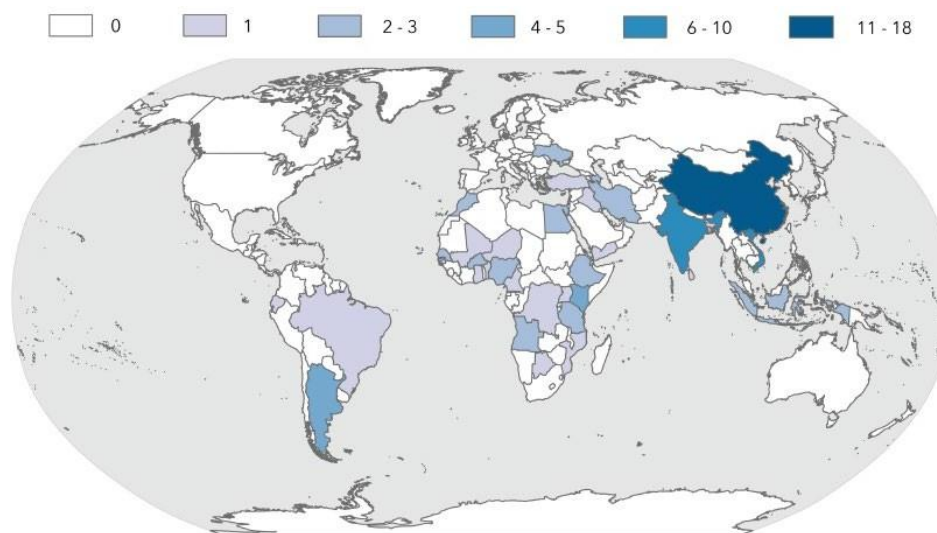
Prior studies have explored the water and sanitation sector's global regime, which is the source of great similarity when it comes to actors, technologies, values, organization, and financing, in infrastructure solutions around the world (Lieberherr and Fuenfschilling, 2016; Fuenfschilling and Truffer, 2014). A global institutional rationality (based on a combination of hydraulic- and market rationalities) dominates in the sector, exerting mimetic pressure to implement large-scale, centralized (waste-)water infrastructure as well as corresponding institutions (Heiberg et al., 2022; Fuenfschilling and Binz, 2018; Miörner and Binz, 2021). Although the sustainability of those centralized water and sanitation infrastructure is increasingly questioned (Lieberherr and Truffer, 2015; Markard et al., 2012), the application of alternative technologies (e.g., nature-based, small-scale, on-site water reuse solutions) following a water-sensitive or community rationality remains limited (Hoffmann et al., 2020). In particular, in low- and middle-income countries, development banks and agencies have played a key role implementing the global regime's centralized infrastructure paradigm. Especially the WB, the sector's largest lender (Winpenny et al., 2016; OCED, 2022), has been criticized for focusing on large-scale infrastructure, imposing neoliberal lending conditions, and creating a global consensus on water and sanitation privatization (Goldman, 2007; Heller, 2020).

Against this backdrop, it is surprising that one of the most recent attempts to institutionalize a new hybrid rationality for sanitation provision, namely 'City-Wide Inclusive Sanitation' (CWIS), is being actively promoted by the WB. Launched in 2016 following a Call to Action by the Bill and Melinda Gates Foundation (BMGF), Emory University, Plan International, the University of Leeds, Water Aid, and the WB, CWIS represents *"an approach to Urban Sanitation, where all members of the city have equitable access to adequate and affordable improved sanitation services through appropriate systems (sewered and non-sewered) of all scales, without any contamination to the environment along the entire sanitation value chain"* (Narayan and Lüthi, 2020, p. 19). CWIS thus calls for a paradigm shift in urban wastewater management by promoting a range of infrastructure solutions following diverging guiding rationalities (i.e., in particular, a market and community rationality) (Gambrill et al., 2020; Lüthi et al., 2020).

With CWIS also supported by other international development banks, development agencies, and a handful of governments and local regulators (Schrecongost et al., 2020), some authors speak of an extraordinary opportunity for a global transformation in urban sanitation (Gambrill et al., 2020). Thus, the emergence of CWIS may constitute an example of an ongoing multi-scalar transition process in which the WB has taken on the role of a change vehicle. To examine the mechanisms of global agency behind this process, we first address the question of how and to what extent a configuration corresponding to CWIS is actually being promoted by the WB. Second, we explore which actors and processes were involved in global institutionalization processes surrounding the ascent of CWIS as a new guiding rationality in the global sanitation sector.

3.2 Analytical Step 1: Assessing Past Paradigm Shifts in the WB's Lending Practice

To validate past shifts in the socio-technical configurations promoted by the WB, we analyzed WB documents using the STCA methodology, which allows tracing how socio-technical configurations transform across time and space based on network visualizations (Heiberg et al., 2022; Mörner et al., 2022b). In our case, we derived socio-technical configurations from project documents of high profile WB water and sanitation projects.¹ To this end, we first identified projects that meet the following criteria: 1) project start between 2000 and 2021, 2) project cost of more than US\$100 million, and 3) water supply, sanitation, or sewerage as the target sector.² The final dataset included 93 project (see Fig. 3 for an overview).



Note: Map compiled by the authors with map data by the department of Human

Geography, Lund University and project data by the WB (2022).

Figure 3 Spatial Distribution of Projects Included in the Database.

To identify socio-technical configurations based on the association of configuration elements with the same projects, we coded the entire project documents with project codes p and their project description sections according to an abductively derived coding scheme with concept codes c , which refer to the different technologies, targets and values mentioned.³ Subsequently, we extracted a two-mode project-concept matrix from Nvivo. In Table 1, X represents such a matrix with $e = 1$ indicating if a concept is included in a project or $e = 0$ if not. This representation also allows for the calculation of the column sum k , which provides a useful indicator of the degree of institutionalization of a concept, as it is conceivable that most deeply institutionalized concepts are included in all WB projects.

Next, in order to identify socio-technical configurations not only within projects but also across projects, we converted the two-mode project-concept matrix into a one-mode concept-concept matrix using the Jaccard normalization (see Appendix A for details) (Heiberg et al., 2022; Miörner et al., 2022b). In Y in Table 1, s establishes the relation between different concepts based on their

similarity s in terms of their frequent common use (s close to 1) or rare common use (s close to 0) in projects.

Table 1 Two-Mode Project-Concept Adjacency Matrix and One-Mode Concept-Concept Adjacency Matrix.

X			Y			
	$c1$	...		$c1$	...	c_m
$p1$	$e11$	...	$c1$	$s11$	...	$s1m$
...	...	...	...	...	...	...
p_n	e_{n1}	...	c_m	s_{n1}	...	s_{nm}

To assess the evolution of socio-technical configurations over time, in this research design reflecting a strategy shift of the WB, we visualized and characterized the concept-concept matrices in three different time periods using the software Visone (Baur, 2008). To illustrate coherent socio-technical configurations, we applied a Ward hierarchical clustering algorithm to our baseline network (Miörner et al., 2022b), and classified different concepts as belonging to specific clusters, which were colored accordingly. Furthermore, we characterized the networks with two indicators to evaluate reconfiguration

processes not only visually but also quantitatively (see Appendix A for a detailed derivation).

The first indicator $I = k/n$ refers to the relative frequency with which a concept was included in a project in a given period, and therefore ranges from 0 to 1, with values near 0 indicating a low degree of institutionalization and values near 1 indicating a high degree of institutionalization. The second indicator s assesses the relationship between individual concepts belonging to the same (s_s) or different configurations (s_d).

Different combinations of I and s can consequently be used to characterize the overarching architecture of a socio-technical system, regime, or in our case configurations promoted by a single actor. Due to an interest in the relationship *between* different configurations, we will only consider the interaction between I and s_d , hereafter referred to as s . To illustrate how our indicators can be used to describe configurations, we characterize three of the four sectoral regime configurations identified by Van Welie et al. (2018) in Table 2. We will draw on these throughout our analysis to assess the evolving semi-coherence of the configurational arrangements promoted by the WB. In the network visualization, I is expressed by node size, while s is expressed by link width and shading.

Table 2 The Semi-Coherence of Socio-Technical Configurations.

Monolithic Configuration	Fragmented Configuration	Polycentric Configuration
		
I : High for established configuration, low for emerging configuration s : Low	I : High for established configuration, relatively (high) for emerging configuration s : Low	I : High for established configuration, relatively (high) for emerging configuration s : (Relatively) high
		

Note: The established configuration is depicted in blue, while the emerging configuration is depicted in red. We do not include a splintered sectoral regime at this point because we will not consider (mis-)alignments *within* configurations (s_s) in our analysis. Inspired by Van Welie et al. (2018).

3.3 Analytical Step 2: Examining Mechanism behind Identified Paradigm Shifts

After validating the shift in socio-technical configurations promoted by the WB, we conducted, coded and analyzed 14 semi-structured expert interviews to understand the global agency through which CWIS was constructed and institutionalized within the WB. To this end, we created two different interview

guides based on our conceptual framework, one targeting WB staff and the other targeting advocates for transformative change in the sector. The interview guide for WB staff additionally addressed WB-internal processes that have led to changes in promoted strategies and approaches.

The identification of potential interviewees followed a snowballing technique (Flick, 2018), which resulted in 14 expert interviews being conducted by the first author via videoconferencing software (12 of 14 cases) or face-to-face (2 out of 14) between April and May 2022 (see Table A1 in Appendix A for an overview). The interviews lasted between 22 and 70 minutes and were recorded and subsequently transcribed by the first author. The transcripts were coded according to a coding scheme derived from the conceptual framework and combined with the concepts identified in the STCA. After coding the interview transcripts, we further triangulated the results using the WB project documents, scientific articles and grey literature (Creswell and Creswell, 2017), such as annual letters from BMGF or sector reports from UN institutions.

4 Results

In each of the following sub-sections, we will first use STCA to assess how the guiding rationality of major water and sanitation projects funded by the WB shifted over time, and then discuss how the respective changes can be explained in terms of our model of global agency using contextual knowledge gained through interviews.

As illustrated in the timeline in Fig. 4, we first explain the situation before a transition started, defined as the period from 2000 to 2009. In our view, this period constitutes an appropriate “baseline”, as in 2000 the global regime was first (unsuccessfully) challenged by the Millennium Development Goal (MDG) 7, which set an international target to halve the proportion of the population without sustainable access to improved drinking water sources between 1995 and 2015 (Schertenleib et al., 2021). We then explore a first shift in socio-technical configurations promoted by the WB around 2010, when the United Nations General Assembly recognized safe drinking water and sanitation as vital to the realization of all human rights (Schertenleib et al., 2021). Subsequently, we examine a second shift around 2016, when the Sustainable Development Goals (SDG) 6 for water and sanitation and CWIS were introduced.⁴

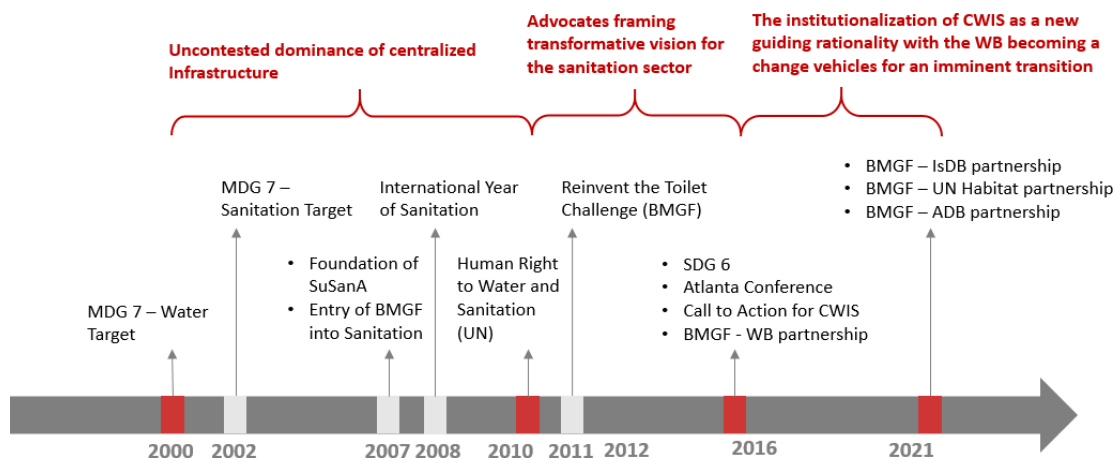


Figure 4 Evolution of the Water and Sanitation Sector.

4.1. Baseline Situation: Uncontested Dominance of Centralized Solutions

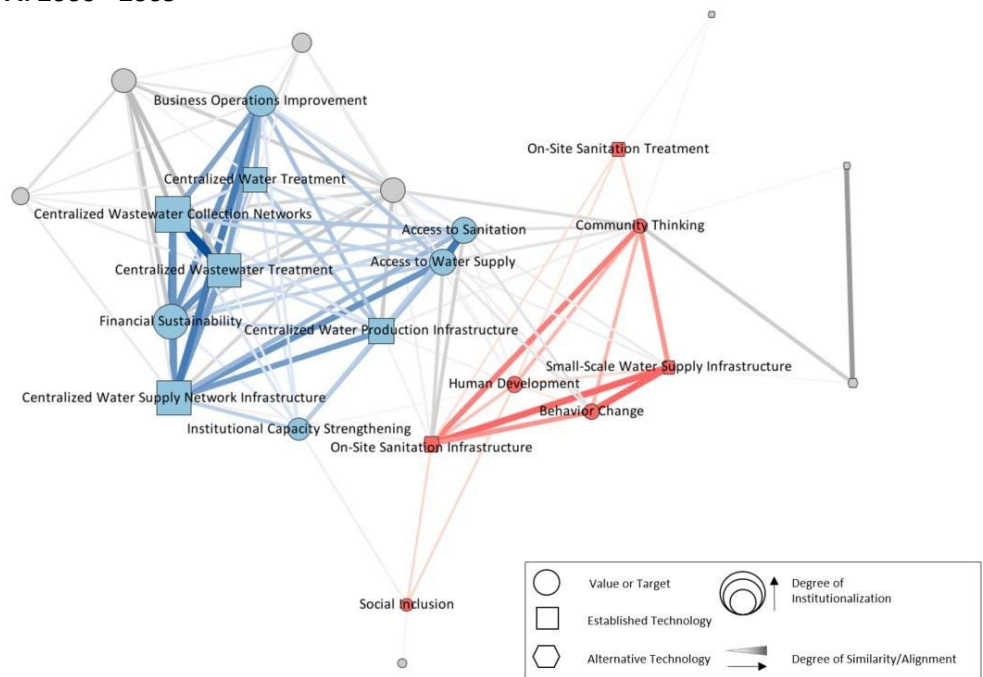
Results from the STCA

Fig. 5 maps the socio-technical configurations that were financially supported by the WB between 2000 and 2009. It shows a clear division between two concept clusters, which strongly differ in their degrees of institutionalization. The blue nodes and edges depict a dominant cluster, hereafter referred to as the “centralized cluster”, which includes *centralized water and wastewater infrastructure*, targets such as *institutional capacity strengthening*, *business operations improvement*, *access to water supply and sanitation*, and a core value of *financial sustainability*. In contrast, the “on-site cluster” (red) includes low-tech alternative technologies including *on-site sanitation infrastructure*, *on-site sanitation treatment*, *small-scale water supply infrastructure* and concepts such as *behavior change*, *community thinking*, *social inclusion*, or *human development*. The remaining concepts (gray) belong to two clusters containing more high-tech technologies and generic values and targets, like *physical well-being* and *environmental conditions improvement*. However, since they remain peripheral throughout our analysis period, we omitted them from further in-depth analysis.

In the first phase, the centralized and on-site cluster co-exist as two separate configurations with different degrees of institutionalization and limited interaction, which is reflected in the indicators I and s . While I indicates a high degree of institutionalization of the centralized cluster, ranging from 0.34 to 0.84, the value is much lower for the on-site cluster, ranging from 0.11 to 0.17. The low s between the concepts of the two clusters (averaging $s = 0.15$)

illustrates a poor alignment of both clusters, which are only linked by a few select boundary concepts such *access to sanitation*, *access to water supply* and *centralized water production infrastructure*.⁵ In the baseline situation, the configurations promoted by the World Bank thus reflect a fairly monolithic structure, which is dominated by a core rationality framed around providing *access to water* and *sanitation* through centralized infrastructures operated under market conditions.

Network A: 2000 - 2009



Note: Illustration by the authors based on WB (2022) data. For better representation, links between two concepts connected by a Jaccard index smaller than 0.2 have been omitted.

Figure 5 One-Mode Concept Network for the Period 2000 to 2009.

Sectoral development

Our interviews and secondary literature suggest that the strong dominance of the global regime rationality in WB projects in the baseline situation is a legacy from developments in the 20th century. In the late 1990s, when (urban) water management became a priority for international financing (In3), an ideology that framed water as an asset with economic value was adopted (see e.g., The Dublin Statement on Water and Sustainable Development (GDRC, 1992)), and also strongly promoted by the WB in its propagation of the Washington

Consensus (In5, 10) (Goldman, 2007). The guiding rationality was that the private sector could correct failures of the public sector in establishing functional water supply infrastructures (In2, 5, 13) (Bayliss, 2003). Sanitation, in contrast, was for a long time *“seen as something [...] very complicated, something to do after water is there”* (In13). As a result, in the late 1990s and the beginning of the new millennium, many advocates remained occupied with creating basic awareness about the importance of sanitation (In4, 10).

Lobbying by several stakeholders, including the Water Supply and Sanitation Collaborative Council led to the inclusion of a sanitation target in the MDGs in 2002 (In10).⁶ This resulted in the mobilization of resources for sanitation (In10). However, the MDG’s exclusive focus on *access* led donors (change vehicles) and governments (implementers) to focus on the *“lowest hanging fruit”*

(In10), i.e., large-scale water and sanitation infrastructure in urban areas that had already been institutionalized as the *“traditional approaches used in the developed world”* (In13). Within the WB, the MDGs thus served as a driving force that pushed the water, sanitation and hygiene (WASH) agenda (In5), but especially in terms of providing centralized infrastructure in urban areas, as evidenced in Fig. B1 in Appendix B. The excessive focus on centralized infrastructure in urban areas, however, increasingly exacerbated problems of equity of access, as infrastructure interventions mainly benefited the wealthier segment of the population (In7, 10).

Despite the sector’s strong focus on centralized infrastructure, some advocates developed alternative visions and configurational templates for on-site sanitation provision from time to time.⁷ However, these only marginally reached the WB (Gambrill et al., 2020), as WB engineers rejected anything but sewered systems (In10), and advocates were occupied with lobbying for the importance of sanitation rather than for alternative sanitation solutions (In10).

“The goal now was to convince people that sanitation is important. It does not help that we show alternatives, and people do not want anything else (In10).”

As a result, the WB implemented alternative on-site solutions only locally in a few projects in rural areas, where it focused on providing access to latrines, yet without sufficiently considering how human waste is effectively managed and treated (In1). The on-site configuration therefore appears as weakly institutionalized and as clearly separated from the centralized configuration in Fig. 4, linked only by framings in the context of the MDG goals, especially by *access to water supply* and *access to sanitation*. Consequently, the WB remained far from becoming a promotor of on-site approaches in the baseline situation. Nonetheless, the local application of on-site solutions in rural areas resulted in the regime rationality being not entirely without alternative.

And indeed, toward the end of the baseline period, high-profile sanitation

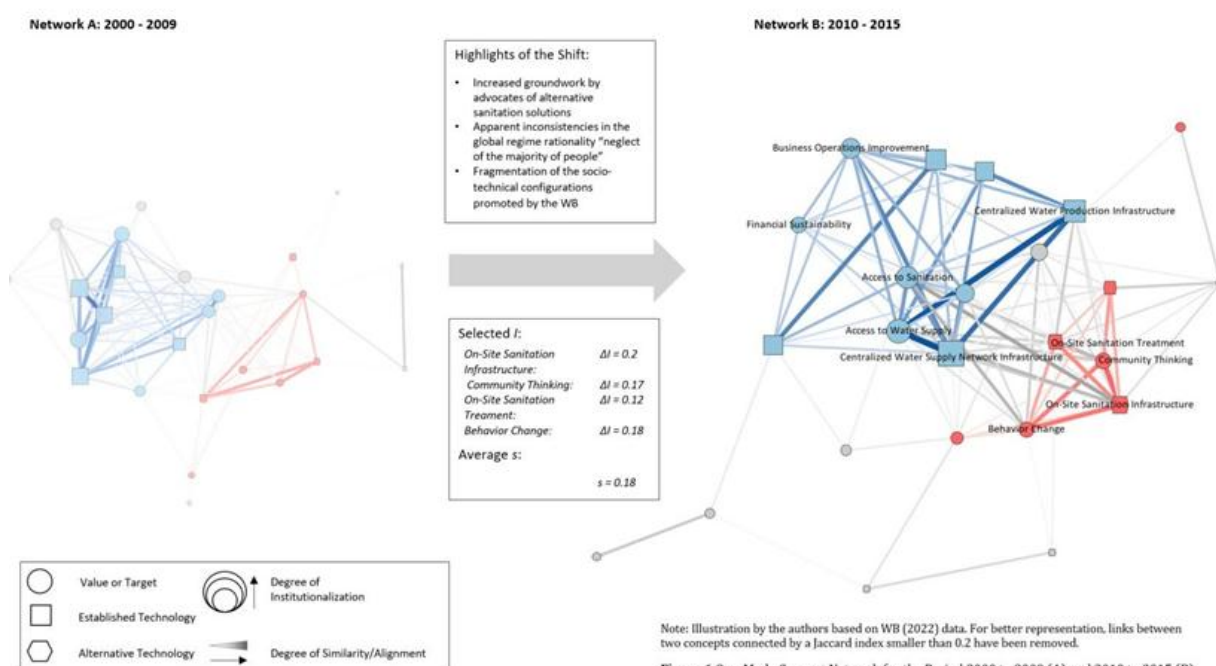
advocates emerged to promote these alternatives, most notably the two advocates Sustainable Sanitation Alliance (SuSanA) and BMGF (In1, 4). In SuSanA, several key sanitation advocates (e.g., Water Supply and Sanitation Collaborative Council) came together to coordinate their activities for the "International Year of Sanitation 2008", which was proclaimed by the UN General Assembly to accelerate progress toward MDG 7 (In1) (UN-Water, 2008). SuSanA defined criteria for sustainable sanitation and began advocating for a systemic approach to sanitation planning (Schertenleib et al., 2021). By advocating for a systemic approach that goes beyond the provision of toilet infrastructure, SuSanA implicitly challenged the access-only approach of the MDGs and directed the focus to the entire "sanitation chain", which includes not only access to a toilet and but also the transport, treatment, and potential reuse of human waste (In1) (Schertenleib et al., 2021). In this context, SuSanA served as a sounding board for a publication⁸ (2008) that demonstrated, in a technology-neutral manner, the feasibility of centralized and especially on-site approaches to serving entire sanitation chain (In1). According to a SuSanA official, this publication influenced BMGF in their decision to include on-site sanitation as a priority in their water, sanitation and hygiene program strategy (In4).

It may well be noted that the presence of these advocates is not yet reflected in the socio-technical configuration promoted by the WB. However, their appearance has laid the foundation for considerable transition potential, as insights from interviews complementing the analysis of a first shift in the WB-promoted socio-technical configurations will reveal.

4.2. Shift 1: Advocates framing transformative vision for the sanitation sector (2000 - 2015)

Results from the STCA

The comparison between Network A and B in Fig. 6 illustrates an increasing fragmentation of the socio-technical configurations supported and financed by the WB between 2000 and 2015. While I remains high for most centralized concepts, it also increases for almost all on-site concepts, particularly for *on-site sanitation infrastructure* ($\Delta I = 0.2$), *community thinking* ($\Delta I = 0.17$), *on-site sanitation treatment* and *behavior change* ($\Delta I = 0.12$). s , in turn, increases only slightly in the second phase (average $s = 0.18$). Thus, links between on-site and centralized concepts remain weak, with the exception of an increasing alignment between on-site technologies and the aforementioned boundary concepts.



Sectoral development and key actor activities

After 2010, the conditions for institutionalizing on-site sanitation infrastructure improved significantly. First, the Declaration of the Human Right to Water and Sanitation (2010) marked an important turning point in the sector, recognizing the importance of water and sanitation as a human right after years of debate (In13) (see also Schertenleib et al., 2021). Similar to SuSanA's systemic approach, this declaration fundamentally challenged the access-only focus of the MDGs by explicitly stating that all people should have access to water and sanitation, exposing the shortcomings (e.g., the focus on urban areas) of the established rationality in the international arena. It is conceivable that the declaration had a direct impact on the WB, with the bank increasing the number of high-cost projects channeling funding to rural areas from nine to 21. Consequently, support for on-site approaches increased slightly, leading to a fragmentation of the socio-technical configuration supported by the WB (see Fig. B2 in Appendix B).

Second, novel actor constellations around alternative sanitation solutions gained more significance in international arenas. For example, in 2011, BMGF's undertook a prominent foray into the sanitation sector in the form of the Reinvent the Toilet Challenge. To support people lacking sanitation facilities, BMGF invested substantial funds in a number of research initiatives with the goal of developing transformative toilet technology that can dispose of human waste in a decentralized, safe, and cost- and resource-efficient manner

(Schertenleib et al., 2021; BMGF, 2022). Yet, to date, the initiative has failed to achieve its goal of establishing a new technology as an inclusive, alternative solution to the centralized sewer system. Nevertheless, it helped promote recognition of on-site sanitation and treatment as sustainable, long-term options for sanitation, and stimulated several research projects and professionals exchanges among researchers, designers, investors, and community representatives (Schertenleib et al., 2021; BMGF, 2022).

While the attention to on-site sanitation infrastructure increased in the second period, equity issues persisted in urban areas, where the focus remained on centralized infrastructure that did not serve the majority of the people (In5). Advocates therefore faced the difficulty of diffusing the emerging on-site configuration beyond rural areas to challenge the established centralized paradigm fundamentally (In8). To achieve this, SuSanA and BMGF pursued different strategies toward the end of the second period.

SuSanA indirectly paved the way for a paradigm shift in urban sanitation (Lüthi et al., 2020), as its advocacy work was instrumental in shaping the SDG target towards a systemic approach to sanitation. Prior to 2016, SuSanA's various member (over 380 as of September 2022) lobbied their governments to advocate at the UN for an SDG target consistent with SuSanA's definition of sustainable sanitation (In4). SuSanA thus indirectly leveraged the UN as a change vehicle that translated its vision into a guiding principle in the form of an SDG target. The new sanitation agenda, which aims to achieve safely managed sanitation (SDG 6.2) and a reduction of the portion of untreated wastewater (SDG 6.3), naturally affected the World Bank as the largest donor organization. To maintain its social legitimacy, the WB adapted to the new, broader sanitation agenda focused on managing the entire sanitation chain in an inclusive manner (In13).

BMGF, on the other hand, became part of another network that decided to address the failure of the global regime rationality (i.e., centralized (waste-)water infrastructure) to serve the urban poor. In 2014, a group of advocates from Emory University, the University of Leeds, and the BMGF decided at an informal lunch to address the issue of slum sanitation and organized a conference in Atlanta (2016) to explore different ideas and develop a new vision for urban sanitation (In9). The group was very deliberate when deciding who to invite, having "*an idea of who needed to be there*" (In 9), and invitations were organized according to predefined categories. For example, representatives of development banks were considered important for inducing the scale up of a potential novel configurational template (In9). The Atlanta conference resulted in important outcomes including the decision to re-frame "slum sanitation" as "Citywide Inclusive Sanitation" to make the issue less politically sensitive and more attractive for change vehicles and investments. It also resulted in a Call to Action for CWIS (In9), which explicitly recognized that "*citywide inclusive*

sanitation means that: everybody benefits from adequate sanitation service delivery outcomes; human waste is safely managed along the whole sanitation service chain; effective resource recovery and re-use are considered; a diversity of technical solutions is embraced for adaptive, mixed and incremental approaches; and onsite and sewerage solutions are combined, in either centralized or decentralized systems, to better respond to the realities found in developing country cities (BMGF et al., 2016, p. 1)."

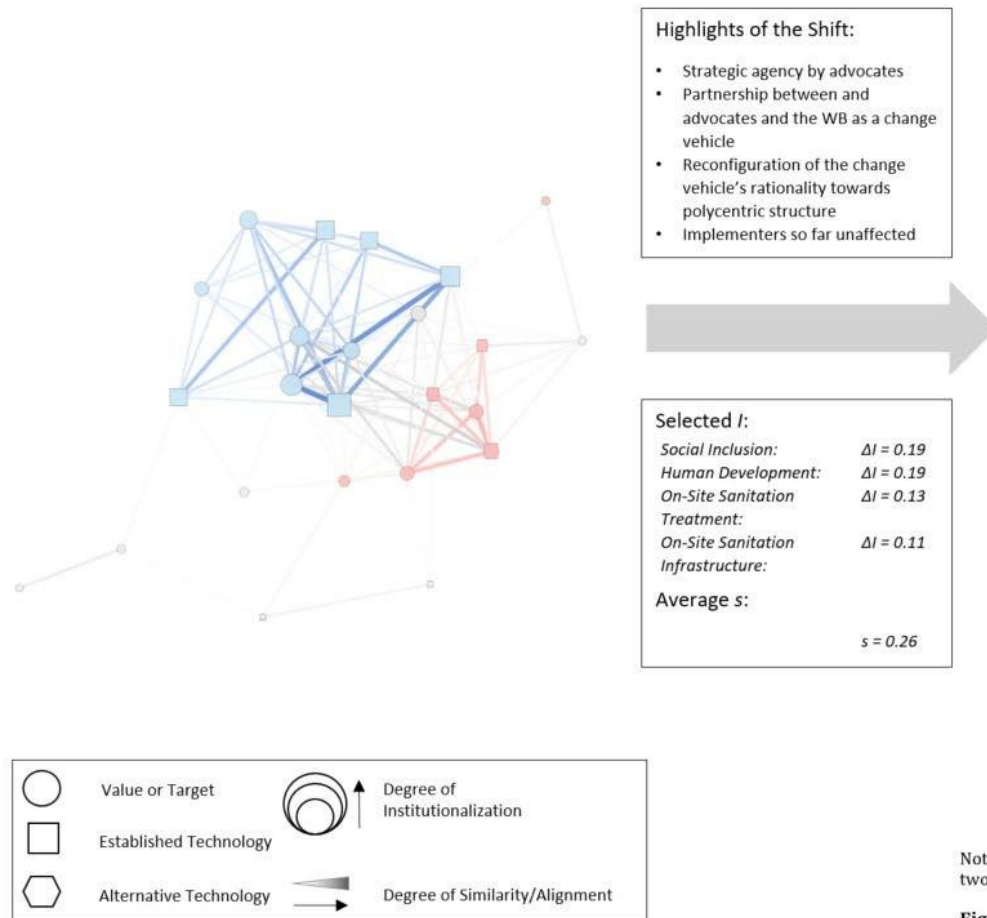
While the impact of SuSanA's advocacy was certainly important but more indirect in influencing the WB to promote on-site sanitation infrastructure, the new configurational template created by the coalition of advocates around BMGF had a major direct impact on the WB, as an examination of a second shift in the socio-technical configurations promoted by the WB will illustrate.

4.3. Shift 2 (2015-): The institutionalization of CWIS as a new guiding rationality with the WB becoming a change vehicle for an imminent transition

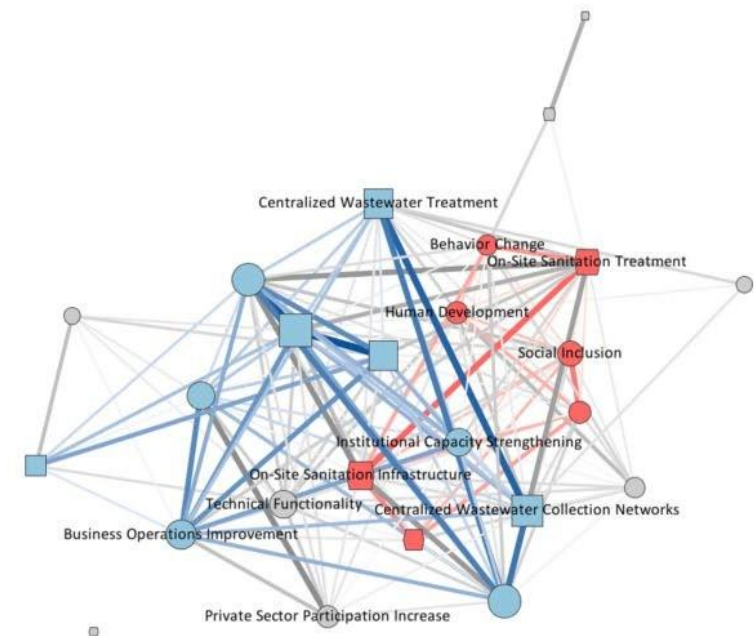
Results from the STCA

Comparing Network B and C in Fig. 7 shows that between 2010 and 2021 *I* increases considerably for various on-site cluster concepts and particularly for *social inclusion, human development* ($\Delta I = 0.19$), *on-site sanitation treatment* ($\Delta I = 0.13$), and *on-site sanitation infrastructure* ($\Delta I = 0.11$). In fact, on-site technologies are now mentioned almost as frequently as *centralized wastewater treatment* ($I = 0.52$) and *centralized wastewater collection networks* ($I = 0.61$). The overlap between the two clusters reflects the increase in *s* (averaging $s = 0.26$) between different concepts belonging to the centralized and on-site cluster. Most notable is an increasing alignment between on-site technologies and centralized wastewater technologies, jumping from $s = 0.09$ to $s = 0.4$ in the case of *on-site sanitation infrastructure* and *centralized wastewater treatment*. The picture of the largely co-existing centralized and on-site cluster thus changes radically towards a more polycentric structure, in which the WB promotes centralized and on-site solutions in a much more integrated manner.

Network B: 2010 - 2015



Network C: 2016 - 2021



Note: Illustration by the authors based on WB (2022) data. For better representation, links between two concepts connected by a Jaccard index smaller than 0.2 have been removed.

Figure 7 One-Mode Concept Network for the Period 2010 to 2015 (B) and 2016 to 2021 (C).

Insights from our interviews suggest that while the conference and Call to Action represented important initial institutionalization efforts by explicitly addressing on-site sanitation in urban contexts, more significant efforts followed. For example, shortly after the conference, the WB and BMGF entered into a partnership to promote work on CWIS (In5, 9). As noted earlier, the partnership between the two organizations was not a coincidence, but rather a rather direct and strategic attempt of an advocate (BMGF) to integrate its guiding vision (CWIS) in the strategies of a change vehicle (WB). An important step in establishing the CWIS vision at the WB was a BMGF grant of approximately US\$21 million to one of the WB's Multi-Donor Trust Funds.⁹ This grant enabled a small team of WB specialists to work exclusively on influencing the agenda for WB urban sanitation projects toward CWIS (In5; Gambrill et al., 2020). By organizing workshops and learning events, and supporting WB project managers and government officials with the presentation of best practices and standard terms of reference, the WB CWIS team quickly institutionalized the concept within the WB and relevant external expert circles (In5, 9, 12, 13, 14).

In addition to the growing realization among WB staff that conventional regime solutions had failed in various (low-income) parts of the world, it was the "small" investment by BMGF that succeeded in leveraging *"the whole WB institution [...] to promote this approach across the [...] 2 billion portfolio that [the WB] has annually in water and sanitation"* (In13). And indeed, the second shift illustrates that the WB's CWIS team was successful in its efforts to spread CWIS principles throughout WB projects. Of particular note is the increasing institutionalization of on-site solutions in investment streams targeting urban areas, as illustrated in Fig. B3 in Appendix B. The indicator s ($s = 0.26$) further demonstrates that on-site technologies are now being used to complement centralized infrastructure, making them subject to conventional, centralized concepts such as *institutional capacity strengthening, business operations improvement and private sector participation increase*. This results in the emergence of a polycentric configuration that unites two previously barely linked configurations under the CWIS umbrella, combining a hybrid market-community rationality.

In terms of the relationship between BMGF and the WB, advocate and change vehicle have played to each other's strengths in institutionalizing CWIS, or in the words of one interviewee:

"The WB is like an oil tanker in the sea, which takes a long time to change direction sometimes, and the Gates Foundation is more like a speedboat that can change direction very quickly, and can mobilize funding and fund things much more quickly (In5)."

Although BMGF is characterized by a significantly lower level of investment compared to other organizations active in the water and sanitation sector (OCED, 2022), they initiate transformative change through their unique network position. While BMGF is characterized by a typical advocate outsider position, it has comparatively high levels of resources (i.e. money) and prestige (i.e. through Bill Gates) that are flexibly and strategically deployed in various investments. As one BMGF specialist puts it:

"[W]e can exactly invest in these kinds of things, in convening people and doing trainings. [...] So we are a small fish, but I do think the ability to convene and the ability to think about who needs to learn from who and how we do this has been important (In9)."

Exemplary in this regard are other attempts of BMGF to leverage change vehicles, including BMGF's technical cooperation agreement with the Islamic Development Bank *"to embed and institutionalize CWIS"* (In8,) and financial support to a development bank working group hosted by the Asian Development Bank (In8, 9). As a result of these efforts, CWIS is already on the minds of various development actors and widely recognized as the way forward for international development assistance (In1, 2, 5, 6). Nevertheless, CWIS has not yet left the *"development realm"* and other change vehicles such as international consultancies, as well as large implementers including water MNCs and utilities, remain rather unaffected (In1, 2, 7).

"The concept is nowhere taken up except when it is funded (In7)".

While there is general agreement that much has happened in people's minds, not as much has found implementation in practice, and the first results of CWIS-inspired projects are only now becoming visible (In9, 10). According to a WB practitioner, the challenge will be to make CWIS *"less sexy and more mainstream"* (In13), so that standards and guidelines around CWIS will eventually find their way into material infrastructure and into various regulative, normative and cognitive institutions across the world. To this end, important efforts have been made by BMGF to engage non-development change vehicles and implementers. These include a BMGF-funded Consultant Capacity Development program aimed at familiarizing local and regional consulting firms (change vehicles) with the new paradigm, and funding for a UN Habitat initiative to integrate (sustainable) sanitation strategies into its global water operator partnership alliance (network of implementers) (In11).

In summary, our analysis reveals that the advocate coalition promoting CWIS had a transformative effect on how the WB (and other development banks and donors) frame and allocate their most recent investments, particularly in sanitation infrastructure. The shifts in the investment portfolios of these large change vehicles are a clear proxy for an imminent shift in the types of sanitation infrastructure that will be built in low - and middle-income countries in the

coming years. The central position of CWIS principles in WB projects will most likely also incentivize implementers such as large water MNCs or utilities to explore on-site solutions in more depth so as not to miss future development opportunities. Based on the analysis, we consider the global advocacy trajectory explored in this paper to be likely to lead to a sector transformation in the mid-term future, especially in low- and middle-income countries.

At the same time, it remains to be seen how widespread the new CWIS paradigm will become. One drawback is that the CWIS framing is rather polycentric, as it combines two infrastructure solutions that follow diverging institutional rationalities. Whether and how the resulting increase in institutional complexity in the water and sanitation sector can be managed in real-world implementations in different contexts remains an open question (Hacker and Binz, 2021). The jury is also still out on whether and how quickly the CWIS idea will travel from low- and middle-income contexts to high-income countries around the world.

5 Discussion

5.1 Distributed Global Agency

The analysis of the global advocacy trajectory has demonstrated that a coalition of advocates led by BMGF was particularly effective in institutionalizing a new infrastructure paradigm around CWIS at the global scale. The interaction between BMGF (an advocate) and the World Bank (a change vehicle) was repeatedly highlighted as one of the factors that enabled the rapid adoption of CWIS. In sectoral contexts such as water and sanitation, which are characterized by strong global regime structures (Fuenfschilling and Binz, 2018), a public-good character (Lieberherr and Fuenfschilling, 2016) and diverging regulatory responsibilities, rapid “vertical” interventions by advocates are bound to fail (Schertenleib et al., 2021). The reason for this is that it is practically impossible for advocates to gain direct access to implementers. Instead, the intermediate step of engaging change vehicles becomes a key condition for the success of global advocacy trajectories.

It is possible to draw parallels between our case and other global institutionalization processes in the area of global health. Here, the BMFG has invested relatively small resources to build platforms for soliciting funds directly from governments in collaboration with various IOs (e.g., GAVI Vaccine Alliance, Global Fund to Fight AIDS and Tuberculosis) (Matthews, 2020; Gates and Gates, 2020; KFF, 2022; KFF, 2021). Therefore, we reiterate that the foundation’s success relies more on building leverage through the flexible use of funds to build coalitions of actors from IOs and governments than on the provision of direct services (Matthews, 2020). While, we see the potential for other advocates to follow this strategy, the question is whether there are

comparable instances that are able to leverage change vehicles in the same way, and whether and how change vehicles can be leveraged without the extensive possession and use of own resources.

In addition to the importance of leveraging change vehicles, our study supports the recent finding by Runhaar et al. (2020) that change within a semi-coherent regime is facilitated when different configurations can be reconciled around a common boundary concept. In our STCA graphs, key boundary concepts largely correspond to the targets of the UN's MDG and SDG agenda, highlighting the performativity of those abstract goals for sectoral transformations. Moreover, our analysis has shown that the transformation of a semi-coherent regime is supported when two socio-technical configurations (e.g., centralized and decentralized sanitation) that are inherently incompatible under existing institutions and actor constellations are not only linked by individual boundary objects but combined under the umbrella of a smartly framed hybrid rationality (e.g., CWIS combining a market and community rationality).

5.2 Methodological Contributions

As this is (to our knowledge) the first study to apply STCA to project documents, we go beyond previous applications of STCA that have analyzed transformational dynamics based on actor statements (see e.g. Heiberg et al. (2022); Mörner et al. (2022a); Heiberg and Truffer (2022)) and make two important methodological contributions. First, we have demonstrated a way to identify socio-technical configurations that not only correspond to actors' perceptions, but are linked to concrete material and institutional activities in reality. Thus, we provide a more accurate picture of how a sector has developed in the past and might develop in the future. Second, we have illustrated how indicators for institutionalization (I) and alignment (s) of socio-technical configurations can be easily derived from project documents, which, unlike newspaper articles, also refer to "taken-for-granted" concepts.

However, some considerations need to be made when applying STCA to project documents. Since the approach relies on the voice of one or possibly a few stakeholders, it is advisable to determine their relevance to properly assess the impact of the changes they promote on the sector as a whole. Furthermore, project documents should be carefully selected, as there is a risk that an extensive use of buzzwords, commonly used to emphasize the societal relevance of projects, will distort the results. With this in mind, we recommend coding a specific section that follows the same structure across all documents and systematically addresses specific targets, proposed solutions, and underlying values. Finally, we recommend triangulating the analysis with other sources and supplementing it with insights from other stakeholders to provide a holistic picture. In this context, our analysis confirmed the usefulness of

combining STCA with interviews, in line with Miörner et al. (2022a).

6 Conclusion

In today's globalized knowledge economy, it is increasingly recognized that we need a better account of multi-scalar transition trajectories. While previous research on multi-scalar transition trajectories has pointed to the possibility that global actors may institutionalize an alternative socio-technical configuration directly within a sector's global regime, the question of which global actors are capable of doing so and how has not been adequately explored. In this paper, we propose that an examination of the distributed agency among three types of global actors (advocates, change vehicles and implementers) provides important new insights into how 'global advocacy' transition trajectories work.

Our analysis of a shift in socio-technical configurations promoted by the World Bank in its water and sanitation projects substantiates our conceptual argument. Global institutionalization processes rely on an interplay between advocates who create new configurational templates and change vehicles that translate them into principles, which in turn influence implementers who solidify novel configurational templates into intangible institutions and physical infrastructures around the world. In fact, we demonstrate that while several (coalitions) of advocates articulated different rationalities regarding alternative sanitation infrastructures, only one coalition, led by the Bill and Melinda Gates Foundation, managed to introduce a novel hybrid rationality potentially powerful enough to challenge the global regime by using the World Bank and other international organizations as change vehicles.

With our paper, we have made an important conceptual contributions to the study of multi-scalar transitions. First and foremost, we have developed a model for analyzing distributed agency in multi-scalar sustainability transitions. Therein, we have not only distinguished between different actor roles, but also elaborated the importance of an intermediary type of change agent in general and of (previously neglected) international organizations in particular (Kranke and Quitsch, 2021).

In addition, important policy implications emerge from our analysis. First, advocates could strategically join forces and pro-actively create 'global niches' in different sectors in the form of global intermediary organizations/networks, such as the Sustainable Sanitation Alliance in our case. Uniting diverse advocates with transformative ideas under one roof with sufficient long-term base funding could not only empower individual visionaries with extensive on-the-ground knowledge, but also facilitate the mobilization of change vehicles. Second, advocates could seek to influence the inner working and structures of potential change vehicles so that they become more open to the transformative ideas emanating from their networks. To this end, advocates should not

underestimate the potential of informal networks, as personal connections could be leveraged to, for example, establish regular knowledge exchange and engage in project activities of change vehicles. Given these implications, policy makers seeking to provide targeted support to niche innovations have the potential to support global sustainability transitions in two ways. First, by allocating more resources to creating advocate networks and convening different types of global actors, and second, by using their power as primary actors in, for example, IOs to introduce novel ways of working that facilitate exchanges between advocates and change vehicles.

The limitations of our analysis lead us to further lines of research. First, while we have characterized the different types of actors and analyzed the mechanisms of their distributed agency in global institutionalization processes, we have not further explored the variety of strategies advocates may use to approach change vehicles. In this context, we believe that it is promising to identify different types of advocates and change vehicles to create a typology specifying in more detail who should approach whom using which strategy. Second, since our empirical analysis focused primarily on the interplay between advocates and change vehicles, we encourage investigations into the interaction between change vehicles and implementers. For example, one could explore how to incentivize implementers to diffuse novel configurations by examining how advocate's visions and configuration templates are most effectively translated. Third, while our study has confirmed STCA as useful for examining changes in socio-technical systems, the proposed indicators remain at a rather rudimentary level. Future studies could therefore explore other document stocks and shed further light on the activities of global actors in different spatial and sectoral contexts.

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Appendix A

Derivation of the Indicators I and s

I is based on the column sum k ,

$$k(c_i) = \sum_j^n e_{ij}$$

of the two-mode binary project-concept matrix. While, k indicates the number of projects in which a concept was mentioned,

$$I_i = \frac{k_i}{n_i}$$

refers to the relative frequency with which a concept was included in a project in a given time i period taking into account the absolute number n of projects in a given time period i . I ranges accordingly from 0 to 1.

s is based on the Jaccard score, which is derived according to the following formula

$$s = \frac{a}{(a + b + c)}$$

where a represents the number of projects that use both concepts together, and the sum $(a+b+c)$ represents the number of projects that referred to both (a) and either one (b) or the other (c) of the two concepts (Heiberg et al., 2022). When $s = 1$, the numerator and denominator are equal, indicating that both concepts are always used together in a project., while s close to zero implies that the two concepts are rarely used together in a project.

Table A1 Overview of Interview Partners.

Interview	Person/Institution	Date
1	Academic researcher, Eawag	06.04.2022
2	Academic researcher, Eawag	12.04.2022
3	Sector expert	13.04.2022
4	Organization staff, GIZ	19.04.2022
5	Former organization staff, WB	20.04.2022
6	Consultancy staff, Aquaconsult	20.04.2022
7	Organization staff, IWA	21.04.2022
8	Organization staff, IsDB	22.04.2022
9	Organization staff, BMGF	24.04.2022
10	Academic Researcher, Eawag	26.04.2022
11	Organization staff, UN Habitat	26.04.2022
12	Organization staff, WB	28.04.2022
13	Organization staff, WB	03.05.2022
14	Organization staff, WB	11.05.2022

Appendix B

Table B1 Institutionalization Index for Concepts in the One-Mode Concept Networks.

	2000 - 2009		2010 - 2015		2016 - 2021	
Concept	k	I (n = 35)	k	I (n = 35)	k	I (n = 23)
Technical Functionality	2	0.06	4	0.11	11	0.48
Social Inclusion	4	0.11	7	0.20	9	0.39
Physical Well-being	15	0.43	12	0.34	6	0.26
Human Development	6	0.17	4	0.11	7	0.30
Financial Sustainability	29	0.83	11	0.31	11	0.48
Environmental Sustainability	7	0.20	4	0.11	4	0.17
Community Thinking	5	0.14	11	0.31	7	0.30
Small-Scale Water Supply Infrastructure	4	0.11	7	0.20	6	0.26
Small-Scale Wastewater Collection Infrastructure	2	0.06	2	0.06	1	0.04
On-Site Sanitation Treatment	5	0.14	9	0.26	9	0.39
On-Site Sanitation Infrastructure	6	0.17	13	0.37	11	0.48
Decentralized Water Supply Infrastructure	1	0.03	0	0.00	1	0.04
Decentralized Sanitation Infrastructure	1	0.03	2	0.06	2	0.09
Centralized Water Treatment	14	0.40	15	0.43	6	0.26
Centralized Water Supply Network Infrastructure	27	0.77	28	0.80	15	0.65
Centralized Water Production Infrastructure	16	0.46	20	0.57	12	0.52
Centralized Wastewater Treatment	27	0.77	16	0.46	12	0.52
Centralized Wastewater Collection Networks	30	0.86	18	0.51	14	0.61
Private Sector Participation Increase	9	0.26	5	0.14	7	0.30
Institutional Capacity Strengthening	12	0.34	15	0.43	11	0.48
Environmental Conditions Improvement	14	0.40	3	0.09	4	0.17
Business Operations Improvement	23	0.66	17	0.49	13	0.57
Behavior Change	6	0.17	10	0.29	6	0.26
Access to Water Supply	17	0.49	25	0.71	15	0.65
Access to Sanitation	16	0.46	21	0.60	16	0.70

Note: Calculations by the authors based on WB (2022) data

2000 - 2009										
	Financial Sustainability	Centralized Water Treatment	Centralized Water Supply Network Infrastructure	Centralized Water Production Infrastructure	Centralized Wastewater Treatment	Centralized Wastewater Collection Networks	Institutional Capacity Strengthening	Business Operations Improvement	Access to Water Supply	Access to Sanitation
Social Inclusion	0.10	0.13	0.07	0.11	0.07	0.10	0.23	0.08	0.11	0.11
Human Development	0.17	0.11	0.14	0.22	0.14	0.16	0.20	0.04	0.21	0.22
Community Thinking	0.13	0.12	0.19	0.24	0.07	0.09	0.06	0.12	0.29	0.31
Small-Scale Water Supply Infrastructure	0.06	0.06	0.15	0.11	0.03	0.10	0.14	0.04	0.24	0.25
On-Site Sanitation Treatment	0.13	0.12	0.19	0.17	0.19	0.17	0.00	0.17	0.16	0.17
On-Site Sanitation Infrastructure	0.09	0.18	0.22	0.22	0.10	0.16	0.20	0.12	0.35	0.38
Behavior Change	0.13	0.05	0.18	0.16	0.06	0.13	0.13	0.07	0.28	0.29
2010 - 2015										
	Financial Sustainability	Centralized Water Treatment	Centralized Water Supply Network Infrastructure	Centralized Water Production Infrastructure	Centralized Wastewater Treatment	Centralized Wastewater Collection Networks	Institutional Capacity Strengthening	Business Operations Improvement	Access to Water Supply	Access to Sanitation
Social Inclusion	0.06	0.10	0.21	0.13	0.10	0.19	0.22	0.14	0.23	0.22
Human Development	0.07	0.12	0.10	0.09	0.11	0.10	0.06	0.11	0.07	0.04
Community Thinking	0.10	0.08	0.30	0.29	0.08	0.12	0.24	0.04	0.38	0.45
Small-Scale Water Supply Infrastructure	0.06	0.05	0.21	0.23	0.05	0.04	0.10	0.09	0.28	0.27
On-Site Sanitation Treatment	0.05	0.20	0.32	0.38	0.09	0.13	0.20	0.08	0.36	0.36
On-Site Sanitation Infrastructure	0.14	0.17	0.37	0.27	0.12	0.15	0.27	0.11	0.46	0.55
Behavior Change	0.05	0.04	0.23	0.20	0.13	0.17	0.32	0.08	0.30	0.48
2016 - 2021										
	Financial Sustainability	Centralized Water Treatment	Centralized Water Supply Network Infrastructure	Centralized Water Production Infrastructure	Centralized Wastewater Treatment	Centralized Wastewater Collection Networks	Institutional Capacity Strengthening	Business Operations Improvement	Access to Water Supply	Access to Sanitation
Social Inclusion	0.05	0.15	0.33	0.24	0.24	0.28	0.25	0.10	0.41	0.32
Human Development	0.20	0.00	0.22	0.12	0.36	0.40	0.13	0.18	0.16	0.28
Community Thinking	0.06	0.00	0.22	0.12	0.27	0.31	0.20	0.18	0.29	0.35
Small-Scale Water Supply Infrastructure	0.13	0.09	0.24	0.20	0.06	0.18	0.13	0.27	0.31	0.29
On-Site Sanitation Treatment	0.18	0.07	0.50	0.40	0.40	0.35	0.33	0.38	0.60	0.56
On-Site Sanitation Infrastructure	0.22	0.06	0.44	0.35	0.28	0.32	0.38	0.41	0.63	0.59
Behavior Change	0.13	0.00	0.24	0.20	0.29	0.25	0.21	0.19	0.31	0.38

Note: Calculations by the authors based on WB (2022) data.

Figure B1: 2000 - 2009

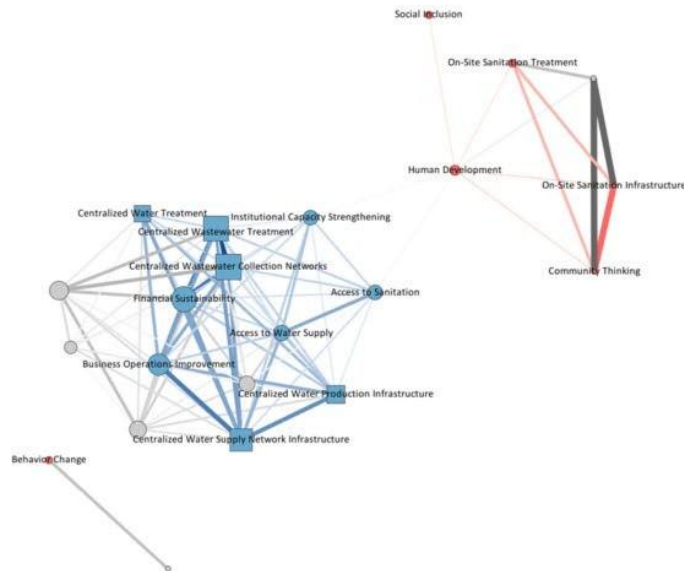


Figure B2: 2010 - 2015

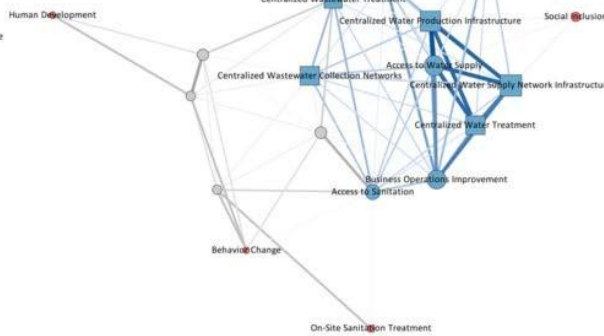
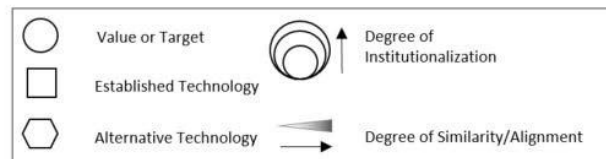
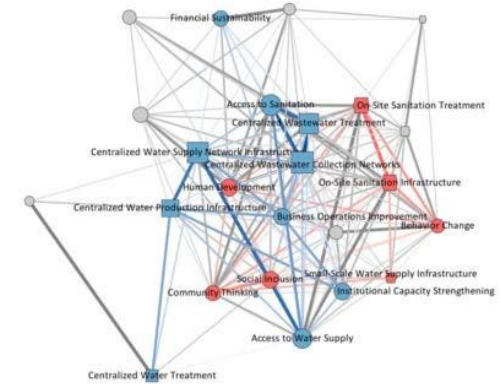


Figure B3: 2016 - 2021



Note: Illustration by the authors based on WB (2022) data. For better representation, links between two concepts connected by a Jaccard index smaller than 0.2 have been removed.

Figure B One-Mode Concept Network for Urban Projects in the Period 2000 -2009 (B1), 2010 to 2015 (B2) and 2016 to 2021 (B3).

Notes

¹ More specifically, we coded project appraisal documents. These are prepared once all project details have been negotiated and accepted by the governments and the WB. Although the project appraisal documents vary in scope, they follow the same outline, which facilitates structured coding of the identified concepts.

² US\$100 million was chosen as a suitable threshold, as it is assumed that cost-intensive projects also receive more attention within the WB and in the project countries thus being more decisive for sectoral development.

³ In the case that no project appraisal document was available, the project description section was coded in the corresponding project information document. This was the case 12 times, and mainly for additional financing commitments.

⁴ Particularly decisive are SDG 6.1, “By 2030, achieve universal and equitable access to safe and affordable drinking water for all”, and 6.2, “By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations” (UN, 2020).

⁵ For a comprehensive overview of I and S, see Table B1 and B2 in Appendix B.

⁶ The Water Supply and Sanitation Collaborative Council was established in 1990 as a global membership organization under the administration of the United Nations to promote cooperation between countries and development organizations in the field of water supply and sanitation.

⁷ These include, for example, the Water and Sanitation Program, a multi-donor partnership of various countries and organizations administered by the WB to promote safe access to water and sanitation (In4, 10)

⁸ The compendium of sanitation systems and technologies (Eawag, 2008).

⁹ The Global Water Security & Sanitation Partnership is the largest trust fund managed by the WB. It is situated within the WB’s Global Practice Water but is supported by a wide range of stakeholders. Its goal is to generate, collect, and disseminate knowledge and expertise by learning from and influencing WB water and sanitation projects (WB, n.d.).

Centrality and relatedness of environmental technologies in the industry and paths of technological diversification

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Abstract

The aim of this paper in progress is to identify at sectoral level how environmental technologies are related to the industrial knowledge bases and, if they are, in what extent relatedness represent a potential natural path of technological evolution in manufactures. To do that, the paper develops a taxonomy of industries according to their main environmental risk and indicators of relatedness and diversification to associate both phenomena. Our study found that: (i) centrality of environmental technologies in industry is related to its main environmental risk, which means that they are coherent; (ii) environmental technologies that involve costs reduction and private gains are more pervasive than those that involve positive externalities and social returns; (iii) relatedness of environmental technologies to core-competences of the industries does not drive the path of industrial diversification. The last two findings allow us to discuss about the different role of regulation and public policies to guide the rhythms and paths of ecoinnovations in the industries given the different proximity of the knowledge embedded in the ET that respond to their environmental risk to the industry core-competences.

Introduction

Ecoinnovation or Environmental *innovations* are defined by “the production, assimilation or exploitation of a product, production process, service, management, or business methods that are novel to the firm [or organization] and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use)” (Kemp and Pearson, 2007). The definition of ecoinnovation implicitly carries a conceptualization of environmental technologies (ET) according to the scope about what ‘environmental risk’ is. Concretely, we call the attention to two domains: one refers to acts of pollution and other to acts of use of resources including energy. These two domains allow us to characterize the environmental risk to which the innovative agent is more sensitive and the kind of environmental awareness he perceives that configure the focus of his technological trajectory like, for example, cost-saving efforts to reduce the consumption of raw materials, energy, and water or the design of ‘green products’ following the pressure from costumers and stakeholders for environmental-friendly practices.

Given the recent importance of ecoinnovation to avoid environmental risk in the modern societies, a question emerges: what determines the rhythms and paths of ET creation and adoption? As any other innovation, incentives to innovate in ET are given by the properties of the own technologies in terms of opportunity and appropriability; by the markets in terms of competition; and by the firms’ leadership in terms of competitiveness (efficiency, costs, etc.). However, unlike other technologies, the wide set of environmental issues, solutions and applications involves that ET have a strong transversal character in the above three dimensions. At technological level, they can refer to products, processes, and organization [even simultaneously]. At the industrial level, ET find

applications into a quite large number of production processes and products across the industries, and the intensity and degree of application is closely related to the way industries interact with the environment as contaminants. At the firm level, ET entails to transform the whole set of firms’ competences: productive, technological, and managerial. Additionally, ET are in the core of governments actions and institutions (rules) to achieve specific environmental goals. Environmental regulations, pollution taxes and requirements for public procurement are pointed out as important ecoinnovation drivers. (Horbach, Rammer and Rennings, 2012; Hojnik, Ruzzier, 2016).

As ET are transversal at the industrial level, they potentially can establish connections with a wide range of technologies in different industries representing paths of industrial knowledge base evolution, which becomes

more varied (diversified), related, and complex. The extent to which new technical fields are incorporated into an industrial knowledge base depends on how they are related to the old ones, that is, on how old and new knowledge complement each other to create new or improved technologies. In this sense, the aim of this paper is to identify at sectoral level how ET are related to the industrial knowledge bases and, if they are, in what extend relatedness represent a potential natural path of technological evolution in the manufacturing.

To answer those two questions has policy implications. If industries develop technological trajectories in ET according to the relatedness of those technologies with their industrial knowledge bases, public policy plays an important role in guiding the connections between technologies, for example, supporting environmental solutions for specific environmental problems in specific industries. Alternatively, if ET are not a natural path of industrial evolution, even been close related to the industrial knowledge bases, public policies must establish incentives to stimulate ET creation or adoption more compulsory.

To pursue our objective, we develop three exercises. First, we position the ET in the industrial knowledge bases according to their relatedness to the central technological domains. Second, we calculate a technological diversification index towards ET. Third, we identify if the path of diversification towards ET is associated to the relatedness between ET and the central technologies at industrial level.

1. The evolution of industrial knowledge bases.

Considering the nature of productive coherence and the bounded rationality and uncertainty associated to innovation processes, innovations are not only the result of pursuing the most profitable technologies, but the result of searching in specific knowledge domains that are complementary and interrelated. In this sense, innovation happens pushed by complementary knowledge [internal, external (subcontracting) or cooperation] (Bonte and Dienes, 2013). From this perspective, innovation in firms depends strongly on the technological coherence of the firms' technological domains related to their core activities and complementary assets (Chiu et al, 2008).

Because of the coherence among technological domains, technological diversification allows the firm to exploit the spillovers from one technology to another (cross-fertilization among related knowledge and technologies), to obtain gains from non-related technologies, to explore opportunities, to reduce the risks of searching, to capture more social benefits of their own

innovations, and to prevent negative lock-in of narrow specialization in one technology (Vega, 2006). The industrial bases of knowledge are *coherent* with the

scope of embedded technologies in products and processes on which firms produce, use and learn. Still, technological diversification uses to be wider than production diversification due to the technological interdependence (complexity and complementarity) between products and production processes (suppliers, materials, components, machinery, and equipment, etc.). Interdependence demands backward competences to identify, integrate and adapt technological changes in the production system. Additionally, a diversified base of knowledge allows to identify emerging technological opportunities that potentially means business opportunities. Emerging technologies can be marginal at the initial stages (like alternative energy production), but they can become more central as the firm identify and explore their potential in relation to the firm core business (Patel and Pavitt, 1997). However, there is a certain trade-off between technology specialization and diversification at the level of the firm. As much the firm diversify technologically, it loses economies of scale in learning processes and competitive advantages, as well as reduce capacity to transfer knowledge between its core competences and increase coordination costs (Yi-Chia Chiu, Hsien-Che Lai, Yi-Ching Liaw, Tai-Yu Lee, 2010). The trade-off between specialization -usually associated to path dependency- is associated with the technology diffusion cycle and the emergence of new paradigms (Lavarello, 2016). At the initial stages, the search for new solutions and applications pushes the firms to diversification. Along this process, firms develop a set of 'secondary' technological competences that complement 'core competences' that allows them to expand their technology portfolios and their knowledge base in a coherent way. Afterwards, they stabilize focusing their R&D and learning efforts on the existing knowledge.

At the sectoral level, technological coherence refers to the knowledge base hosted in the firms' productive, technological, and managerial competences that belong to the same industry. The sectoral knowledge base express, in aggregated terms, not only the technological core-competences of the firms that compose the industry, but also their complementary assets. Core-competences and complementary assets conform a variety of technical fields from which industry develop patterns of search (problems, methods, and solutions to specific problems) and of technological diversity, that is, technological micro-trajectories. Usually, technological competences are industry-specific, that is, industries are characterized by a set of common and dominant technologies labelled as 'core' highly persistent and path-dependent (Patel and Pavit, 1997). However, when new technological paradigms emerge, the cycle of technological diversification at the firm level cannot converge with the sectoral knowledge bases, which means a process of non-related diversification that progressively became related when came from internal learning (Lavarello, 2016; Krafft et al, 2011). If diversification came from external efforts by fusions and acquisitions to control complementary assets or to create barriers to entry, the result is 'conglomerate diversification' and coherence could

have no place. The 'long wave' view supposes that eventually new technological paradigms will affect all the industries (Fai and Von Tunzelmann, 2001). In addition, as much the technologies are pervasive -like environmental technologies-, innovation not only could take place in one specific industry, but also along the path of technological diversification of the set of industries whose bases of knowledge the innovation are related to (for example, innovation in medical equipment by pharma industry). As a result, a process of technological convergence between industries takes place.

Industrial knowledge base are composed by pieces of knowledge that combine in specific ways to resolve specific patterns of problems, heuristics and procedures. These pieces of knowledge are interconnected like in a network. Therefore, the hierarchical categorization of different types of knowledge at the sectoral level must consider at least two criteria: *centrality* and *relatedness*. The frequency and linkages of every single piece of knowledge used in an industry determine its *centrality*. On one side, frequency measures the relative importance of a piece of knowledge among the set of pieces of knowledge that compose the range of technological competences of the industry. On the other side, linkages measure how any piece of knowledge is related to the central technological domains. In this sense, one piece of knowledge can be central not only by its frequency, but also by its relatedness to the central technological domains at sectoral level. Therefore, the more frequent the links among pieces of knowledge are, the more *related* those pieces of knowledge will be into the industrial base of knowledge. Therefore, relatedness indicates the specific way through which an industry combines knowledge to solve problems, extending and thickening towards connected technical fields. Centrality and relatedness of the technological domains in an industry reveal the technological coherence of the industrial knowledge base. Using both, one can observe how the structure of the industrial knowledge base evolved in terms of variety, using new pieces of knowledge, connections or both.

From the above considerations, we can elaborate three hypotheses:

H1: *Environmental technologies acquire more centrality according to the sensibility of core competences in the industry to environmental risk.*

H2: *Environmental technologies are more related to the core competences of an industry according to the sensibility of the industry to the environmental risk.*

H3: *Relatedness of environmental technologies with core-competences of the industry determines the path of technological diversification towards environmental technologies.*

2. Database.

To measure competences and build industrial knowledge bases, we use a patent database (OECD, 2009; Patel and Pavitt, 1997; Krafft et al, 2011). Patents represent results of formal or informal innovation efforts and provide detailed data in a regular and long time series grouped by firm, country, geographic location, and technical field, which makes them appropriate to analyze technological competences at the firm level and at industrial level (Patel and Pavitt 1991). Nonetheless, there are some limitations of patents as an indicator of competences. In the first place, measuring technological specialization to develop specific products and industries can involve a classification of technological fields that do not respond to the usual ones in patent classifications. Therefore, additional criteria for product aggregation could be necessary. Second, some technological competences can be underestimated when they are built on non-patentable technologies or on technologies that are not protected by patents. Furthermore, the option of patenting a particular object depends, among others, on firms' strategies, the features of the object, and the intellectual property system of the country. Not every effort involved in processes of technological change will necessarily result in patenting, and the propensity to patent varies according to the country, sector, and size of the firms (Cohen et al., 2002; Arundel, 2001; Levin et al., 1987; Nagaoka, Motohashi and Goto, 2010; Hall 2009). Third, patents do not capture some categories of ET (Oltra, Kemp, & De Vries, 2010). These are relative to methods linked to marketing strategies, organizational and management changes, and institutional arrangements to promote ET. Patents applications statistics do not evaluate the environmental impact of any adopted technology.

Four significant methodological aspects are worth to be noted concerning the treatment given to the information contained in the patent database. First, patents are the only source of information that synthesize national R&D efforts with the potential for innovation by technical field. Second, the database for industry knowledge base includes patents filed only by companies and excludes patents filed by other applicants, such as government agencies, universities, and individuals¹ or that have an unknown NACE code. Third, one patent represents a technology that combines different pieces of knowledge. For this reason, a patent can correspond to more than one technical field.

The analysis uses patents applications filed at the EPO between 1969 and 2016. Data were extracted using the EPO PATSTAT Global - 2020 Spring Edition (EPO, 2020). EPO database in EPO PATSTAT represents the best source of information for international comparisons for several reasons. Firstly, because a simple patent is extensible to all Munich Convention member countries, which reduces country bias of the domestic effect. Secondly, fee applications are relatively higher, which excludes from the database patents of low industrial value. Thirdly, EPO publishes grants and deposits of patents eighteen months

after the application (by mean), while other bases are more delayed [for example, UPSTO only publishes after two years (by mean)] (Grupp and Schmoch, 1999; Le Bas and Sierra, 2002; van Zeebroeck et al., 2006).

Table 2 - Environmental technical fields

Technical fields	Description
ALTERNATIVE ENERGY PRODUCTION	Bio-fuels, Integrated gasification combined cycle (IGCC), Fuel cells, Pyrolysis or gasification of biomass, Harnessing energy from manmadewaste, Hydro energy, Ocean thermal energy conversion (OTEC), Windenergy, Solar energy, Geothermal energy, Other production or use of heat, not derived from combustion, e.g., natural heat, Using waste heat, Devices for producing mechanical power from muscle energy
TRANSPORTATION	Vehicles in general, Vehicles other than rail vehicles, Rail vehicles, Marine vessel propulsion, Cosmonautic vehicles using solar energy
ENERGY CONSERVATION	Storage of electrical energy, Power supply circuitry, Measurement of electricity consumption, Storage of thermal energy, Low energy lighting, Thermal building insulation, in general, Recovering mechanical energy
WASTE MANAGEMENT	Waste disposal, Treatment of waste, Consuming waste by combustion, Reuse of waste materials, Pollution control
AGRICULTURE/ FORESTRY	Forestry techniques, Alternative irrigation techniques, Pesticidealternatives, Soil improvement

Source: WIPO – IPC Green Inventory –

<https://www.wipo.int/classifications/ipc/green-inventory/home>

The classification of patents applications by technical fields was based on Schmoch (2008). For the ET, we use the following five categories based on the “IPC Green Inventory” developed by the WIPO according to environmental technologies listed by United Nations Framework Convention on Climate Change (UNFCCC): Alternative Energy Production, Transportation, Energy Conservation, Waste Management and Agriculture / Forestry (table 2).

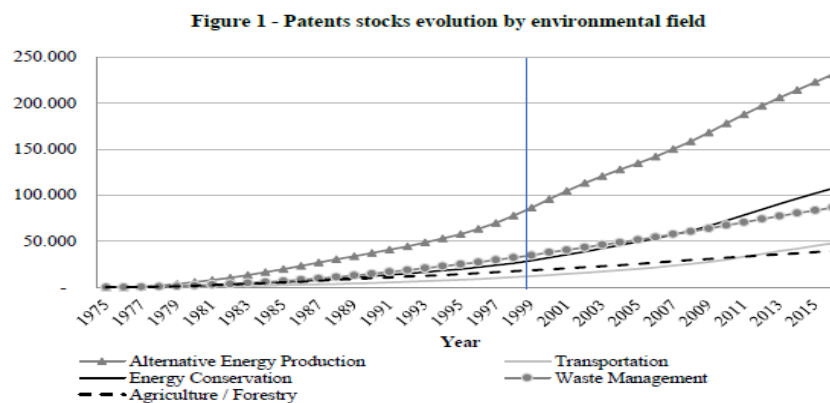
EPO database recorded 3,493,409 applications between 1969 and 2016; 1,768,628 patents were filed by industrial companies (50.6%); 455,858 patents were identified as ET, with a huge concentration in the energy technical fields

(Alternative energy production and Energy conservation (Table 3). The contribution of the manufacturing industries for environmental technologies was about 45.5%, with higher participation in the Energy conservation (52.8%), Agriculture/Forestry (50.6%) and Transportation (49.7%).

Technical fields	Total (a)	Manufacturing Industries (b)	Industry contribution 100*(b)/(a)
Environmental Technologies	455,858	207,570	45.5
Alternative energy production	231,132	97,065	42.0
Transportation	47,744	23,707	49.7
Energy conservation	107,324	56,673	52.8
Waste management	86,483	34,613	40.0
Agriculture / forestry	39,218	19,840	50.6
Other technologies	3,037,551	1,561,058	51.4
Total	3,493,409	1,768,628	50.6

Source: Own elaboration using EPO PATSTAT / EPO (2020) and Orbis/BvD (2016).

The predominance of energy technical fields in the ET's patent stock is verified along all period of analysis (Figure 1). The number of patents for Energy Alternative Production was already bigger at the beginning of 1980. Then, the stock of patents grew the most during the period 1980- 2016. The moment of greatest expansion was after 1995 until the beginning of the 2000s, then it remained at a stable growth rate. That was coincident with the period of greatest expansion for Energy Conservation and Transportation. After 2005, the transportation patents had the greatest expansion cycle, intensified between 2009 and 2011. Energy conservation also had the second stronger growth after 2005. The growth rates in Agriculture/Forestry remained low in the 2000s and reduced after 2010.



3. The centrality of environmental technologies in industrial knowledge bases.

3.1. Environmental technologies and industrial environmental risk.

Environmental technologies usually refer to a set of technologies that resolve traditional environmental issues recently focused on the main environmental challenges in the millennium goals of climate change: reducing carbon emissions, treating waste in soil and water, and exploring alternative and low-impact energy sources. Carbon emissions and waste management represents social costs and, economically, they present externality problems with elevated social costs. Alternative and low-impact energy sources have also positive externalities, but they represent directly private returns and cost reductions as they became cheaper.

In general terms, the environmental problems are transversal to all industries. However, specific environmental technologies should be developed in industries directly involved in specific environmental risks. Therefore, the centrality of environmental technologies in each industry depends on how environmental issues are representative in their products and productive processes. To get a better approach on the specificities of environmental issues by industry, we elaborated the Figure 1 distinguishing the three millennium goals of climate change affecting products and process as well as the environmental technology associated. Table 1 allow us to cluster industries in five categories.

1) Pollutant industries by GHG gases and Wastes in process; 2) Pollutant industries by GHG gases by their products; 3) Pollutant industries by Wastes in products; (4) High intensity energy consumers; and (5) Low contaminant industries. This taxonomy differentiates between high polluting industries (wastes and GHG gases) and high energy consumers. Both environmental micro-paradigms have different implications in terms of social and private returns.

Figure 1 – Most important environmental issues by industry.

	Polluting (gases)	Wastes	High intensity Polluting (gases)
Processes	Textiles Paper and paper products Coke and refined petroleum products Fabricated metal products, exc. m. & eq.	Textiles Tobacco products Leather and related products Paper and paper products Fabricated metal products, exc. m. & eq. Basic pharmaceutical products and pharmaceutical preparations - Machinery & equipment.	Other non-metallic mineral products* Basic metals** Paper and paper products Chemicals and chemical products Food products Beverages Coke and refined

			petroleum products
Products	· Motor vehicles, trailers and semi-trailers · Other transport equipment	· Computer, electronic and optical products · Basic pharmaceutical products and pharmaceutical preparations · Chemicals and chemical products · Rubber and plastic products · Electrical equipment · Wearing apparel · Food products · Beverages	
Low Pollutant	Wood and of products of wood and cork, except furniture; Articles of straw and plaiting materials • Printing and reproduction of recorded media • Furniture • Other manufacturing • Repair and installation of machinery and equipment		
Associated technology	Transportation conservation	Waste Management	Alternative Energy Production Energy
	Pollutant industries by GHG emissions in products Pollutant industries by GHG emissions and waste in process Pollutant industries by waste in products High intensity energy consumers Low pollutant industries		

Source: Own elaboration

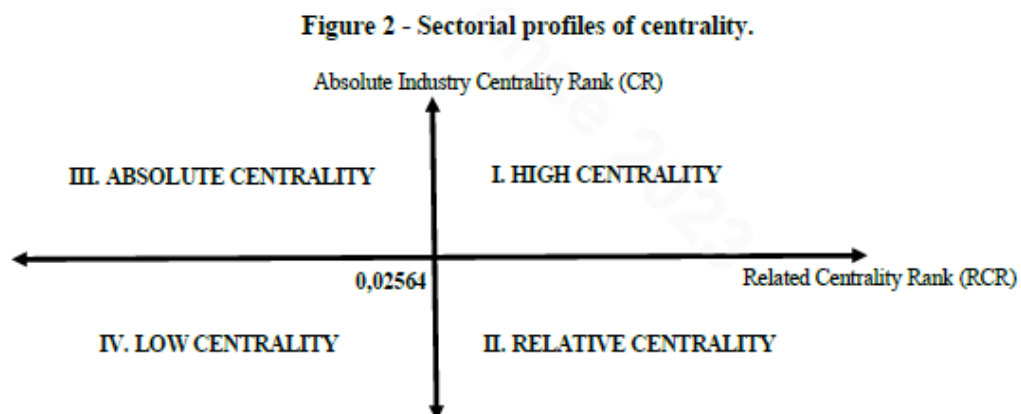
3.2. The centrality of ET in the industry.

In order to classify ET according to their centrality, we developed a methodology inspired in the Patel and Pavitt's (1997) work, but with a different conceptualization and with some additional methodological considerations. First, technical fields by IPC classification at any level of aggregation represent technologies referred to a restricted space of heuristics, this is, of problems, methods, procedures, and solutions. Therefore, IPC codes represent the nodes in the knowledge base at the sectoral level. Second, as technological efforts in ET are low in relation to other technologies, measures based on frequency -as the created by Patel and Pavitt (1997)- would underestimate the importance of

ET inside the technology competences profiles. In this sense, we adapted the Patel and Pavitt's methodology using analysis of networks, which includes not only the frequency of use of each technology, but also their links and interactions. Third, the way the nodes are connected to each other varies from one industry to another. Thus, the centrality indicator must consider not only the frequency, but also the number of relations each node is linked in the industry knowledge base. The more connected a node is to others in the base of knowledge, the higher its centrality.

The nodes are technical fields or IPC codes assigned to each patent. As it is usual that a patent registers more than one IPC code, the co-occurrence of different nodes in the same patent register measures the linkages between nodes. The co-occurrence network has three components: the nodes; the edges, which link nodes when co-occur on the same patent; and the co-occurrence frequencies of pairs of nodes as weights for the edges. The more frequent two nodes are linked in, the stronger their relationship. The co-occurrence network forms an undirected and weighted graph.

The centrality of a node in the co-occurrence matrix that represents each industrial base of knowledge is measured by the Absolute centrality rank (ACR) calculated using the PageRank algorithm. PageRank is a graph-based ranking algorithm that approximates the importance [centrality] of a node by considering both its inbound and outbound links (Perra & Fortunato, 2008; Ding, 2009). Nodes with more links and higher weights will get high PageRank scores. From this, nodes that co-occur with many other nodes [which indicates "more links"] and co-occur many times with these nodes [which indicates "high weights"] will get higher PageRank scores. Also, nodes linked with central nodes will get higher PageRank scores.²



The Absolute centrality rank (ACR) is calculated in each one of the 24 manufacturing industries aggregated for 39 nodes of which 5 correspond to

environmental technical fields (ET) and 34 other technical fields (OT). Similarly, to Patel and Pavitt's taxonomy, we need relative values for the ACR. For that, considering the number of nodes (39) and the PageRank algorithm, we calculate a reference value using a hypothetical base of knowledge where all the nodes had the same participation, that is, all have equal rank values. The value of the centrality rank of reference is 0.02564. The distinguished nodes in an industry are those whose Related Centrality Rank (RCR) is higher than 1, that is, the centrality rank in the industry (ACR) is higher than the centrality rank of reference. With these two indicators, ACR and RCR, a node x , can belong to four possible

classifications (Figure 2). When $ACR^i > 0.02564$ and $RCR^i > 1$ in industry i , it represents a 'high

x x

central' technology, that is, the technology has a rank above the mean in its industry and above the

whole base of knowledge. When $ACR^i > 0.02564$ and $RCR^i < 1$ then the node x is an 'absolute

x x

central' technology in the knowledge base of industry i , that is, the technology has a rank above the mean in its industry but below the mean of the whole base of knowledge. The third possibility is that

$ACR^i < 0.02564$ and $RCR^i > 1$, which represents a 'relative central' technology in industry i , that is,

x x

it is ranked below the mean in the industrial knowledge base but above the mean in the whole base of knowledge. Finally, when $ACR^i < 0.02564$ and $RCR^i < 1$ the technology is considered "low central".

x x

Table 4 shows the evolution of the ET centrality between 1969-1999 and 2000-2016. The total of cases is 120, that is, 5 ET in 24 industries. The values in the diagonal represent the stability of the centrality or the number of ET in by sector that remain in the same centrality level between periods. In terms of centrality there is no hierarchy between relative and absolute centrality, so movements between those categories are considered also stability. The rest of the cells in the matrix represent centrality gains or losses. Considering the hierarchical importance of the categories, from no competences to high centrality, the sum of the values below the diagonal represents centrality gains, while the sum of the values above the diagonal represents centrality losses.

The first observation from the table 4 is the stability of the ET centrality. The relative frequency of the stability was 73.3% (the sum of the diagonal gray area values which is 88 on the total 120 cases). The stability is more

characterized by the low centrality of environmental technologies (relative frequency of 61.4%), which is compatible with its novelty as path to explore new business opportunities. However, there is some evidence that these technologies are gaining centrality. The sum of the values below the diagonal is 21, which means that there was a gain of centrality in a 17.5% of the cases. Alternatively, the sum of the values above the diagonal was 11, that is, there was loss of centrality in 9.2% of the cases.

Table 4– The evolution of ETcentrality

		2000-2016					
		High	Relative	Absolute	Low	No competences	Total
1969-1999	High	19	2	0	4	0	25
	Relative	4	9	1	3	0	17
	Absolute	5	0	4	1	0	10
	Low	2	2	6	54	1	65
	No competences	0	0	0	2	1	3
Total		30	13	11	64	2	120
	Stability						
	Gains/Losses of centrality						

*'No competences' cases also included

Source: Author calculations based on data from EPO PATSTAT / EPO (2020), Orbis/BvD (2016).

Table 5. The centrality* of environmental technologies in the industry by environmental risk

	N° industries	1969-1999					2000-2016				
		Alternative Energy Production	Energy Conservation	Waste Management	Agriculture / Forestry	Transportation	Alternative Energy Production	Energy Conservation	Waste Management	Agriculture / Forestry	Transportation
GHG and Wastes in processes	7	5	1	4	2	1	6	3	3	1	1
High intensity consumer of energy	7	6	1	5	2	-	7	3	6	3	-
GHG in products	2	1	2	2	0	2	2	1	2	0	2
Waste in products	8	6	2	2	3	1	7	2	2	4	1
Low-Pollutant	6	4	4	4	1	2	5	3	2	1	2
Total	24	17	10	14	5	6	21	11	11	5	6

(*) Number of industries in each group where ET have high, absolute, or relative centrality.

Source: Author calculations based on data from EPO PATSTAT / EPO (2020), Orbis / BvD (2016).

Table 5 tests the H1 by reporting the number of manufacturing industries grouped by environmental risk where the 5 ET reported high, absolute or relative centrality in 1969-1999 and 2000-2016 in 24. There are two observations, one transversal and one temporal. The transversal observation confirms that ET tend to acquire some centrality in industries according to the relative relevance of the environmental risk, and this propensity tend to be stable between periods. For example, Waste Management, which includes technologies to reduce GHG emissions, and Transportation are central in the two industries of the GHG pollutant in products (transport industries). This is also the case of Alternative Energy Production in the group of High intensity consumers. The other ETs, Energy Conservation, Agriculture/Forestry and Transportation, acquire a low propensity to remain central in each group, which means that those are environmental technologies associated with environmental risk that affect specific industries. A second observation is the pervasive character of the Alternative Energy Production, that is, no matter what the main environmental issue is, the propensity to be central in the industry is quite high. A third observation is a different pattern by product and processes, that is, the centrality of ET tends to rise between periods when they affect production efficiency (costs reduction) like Alternative Energy Production.

The temporal observation shows the stability of the ET centrality between periods. Nevertheless, some interesting facts emerge. The pervasiveness of the Alternative Energy Production and Energy Conservation centrality grows, especially in the industrial groups where the environmental risk is referred to processes; and whatever the environmental risk is, Alternative Energy Production gains centrality in the industry strongly. There are also some interesting movements of the ET centrality between periods. Waste Management loses centrality in industries pollutant in GHG and Wastes in processes, that become more focused in the energy issue, but also in the Low pollutant industries.

In sum, the centrality analysis seems to confirm the H1. In general terms, ET tend to be more central when the environmental risk affects more to the reduction of production costs than to the reduction of social costs or negative externalities.

4. The relatedness of ET to the industrial central competences and the paths of technological diversification.

The H2 establishes that Environmental technologies are more related to the core competences of an industry according to the sensibility of the industry to the environmental risks. The indicator used for relatedness between two nodes a and b in period t ($R_{a,b,t}$) is the *cosine index* (Breschi et al., 2003); Yan & Luo, 2017). The cosine index captures similarities between vectors representing the relations of a node to each other in the co-occurrence matrix that represents the global knowledgebase, that is, the base of knowledge built including all kinds of applicant and not only firms. (see Appendix A).

$$R_{a,b,t} = \frac{\sum_j CO_{a,j,t} CO_{b,j,t}}{\sqrt{\sum_j CO_{a,j,t}^2} \sqrt{\sum_j CO_{b,j,t}^2}}$$

where $CO_{a,j,t}$ is the edge size or the co-occurrence frequency of the pairs a -node and j -node in the t -period co-occurrence network.

After finding the relatedness between all pairs of technical fields, the relatedness between each ET and the central technologies (CT) set of the industry h in period t ($R_{C,et,t}^h$) is calculated as:

$$R_{C,et,t}^h = \frac{\sum_{j \in C^h} R_{et,j,t} O_{j,t}^h}{\sum_{j \in C^h} O_{j,t}^h}$$

where C^h is the CT set of the h -industry and $O^h_{j,t}$ is the number of occurrences of the j -node in the h -industrial-knowledge-base in the t -period. This indicator measures how similar the CT and ET in a specific industry, that is, when they co-occur with the same nodes. If CT and ET are similar, then we say that both are indirectly related.

Table 6 presents the relatedness index by ET and by industry grouped according to the main characteristic environmental risk. In general terms, the H2 seem to be confirmed. The relatedness of ET to CT is stronger than other technologies in those ET that are more closely related to the environmental risk that affect the industry. In the group of pollutant industries by GHC emissions in processes, the relatedness index of ET-Waste Management to CT is superior to other technologies in Paper products, Coke and refined petroleum products and Metal products. Only in Textiles is inferior. This relatedness of Waste Management technology is stable between period and only there is a loss of relatedness in the second period in Paper products.

Table 6 - Relatedness index by ET and industry grouped by environmental risk. (Mean of R^h by industry)

														$C_{et,t}$			
1978-1999														2000-2016			
	Tech FSIR (Average)	Alternative Energy Production	Energy Conservation	Waste Management	Agriculture / Forestry	Transportation ET (average)		Tech FSIR	Alternative Energy Production	Energy Conservation	Waste Management	Agriculture / Forestry	Transportation ET (average)	Diversification			
GHG emissions in processes																	
Textiles	0,47	0,36	0,47	0,45	0,37	0,26	0,42	0,45	0,39	0,41	0,45	0,40	0,28	0,41	RD		
Paper and paper products	0,47	0,39	0,47	0,47	0,36	0,27	0,42	0,46	0,43	0,41	0,44	0,39	0,27	0,42	RD		
Coke and refined petroleum products	0,37	0,40	0,33	0,47	0,58	0,15	0,45	0,37	0,38	0,35	0,40	0,50	0,23	0,41	RD		
Fabricated metal products, exc. m. & eq.	0,44	0,28	0,51	0,45	0,23	0,49	0,37	0,43	0,35	0,46	0,45	0,25	0,47	0,38	RC		
Wastes ind processes																	
Textiles	0,47	0,36	0,47	0,45	0,37	0,26	0,42	0,45	0,39	0,41	0,45	0,40	0,28	0,41	RD		
Tobacco products	0,41	0,35	0,42	0,43	0,37	0,26	0,39	0,42	0,37	0,37	0,40	0,36	0,27	0,38	R		
Leather and related products	0,47	0,28	0,52	0,41	0,26	0,37	0,37	0,45	0,34	0,41	0,41	0,29	0,31	0,36	R		
Paper and paper products	0,47	0,39	0,47	0,47	0,36	0,27	0,42	0,46	0,43	0,41	0,44	0,39	0,27	0,42	RD		
Machinery and equipment n.e.c.	0,42	0,25	0,37	0,55	0,36	0,21	0,35	0,4	0,37	0,43	0,48	0,44	0,24	0,39	RD		
Fabricated metal products, exc. m. & eq.	0,44	0,28	0,51	0,45	0,23	0,49	0,37	0,43	0,35	0,46	0,45	0,25	0,47	0,38	RC		
Basic pharmaceutical products and pharmaceutical preparations	0,28	0,56	0,23	0,43	0,60	0,10	0,46	0,25	0,53	0,21	0,31	0,55	0,09	0,40	R		
High intensity consumers of energy (resources)																	
Other non-metallic mineral products	0,45	0,35	0,48	0,48	0,34	0,36	0,41	0,43	0,40	0,44	0,46	0,38	0,36	0,42	RC		
Basic metals	0,46	0,35	0,56	0,52	0,33	0,34	0,44	0,44	0,40	0,50	0,52	0,34	0,38	0,44	RD		
Paper and paper products	0,47	0,39	0,47	0,47	0,36	0,27	0,42	0,46	0,43	0,41	0,44	0,39	0,27	0,42	RD		
Chemicals and chemical products	0,38	0,47	0,34	0,49	0,51	0,15	0,45	0,37	0,43	0,37	0,41	0,52	0,21	0,43	RC		
Food products	0,35	0,55	0,28	0,46	0,57	0,14	0,47	0,31	0,53	0,25	0,37	0,59	0,13	0,43	RD		
Beverages	0,37	0,44	0,36	0,44	0,45	0,21	0,42	0,36	0,47	0,31	0,39	0,47	0,20	0,41	R		
Coke and refined petroleum products	0,37	0,40	0,33	0,47	0,58	0,15	0,45	0,37	0,38	0,35	0,40	0,50	0,23	0,41	RD		

(*) remarqued squares indicate the environmental technology more adequately addressed to the environmental risk associated with the industry. Source: EPO PatStat and Orbis. Author's calculation.

Table 6 - Relatedness index by ET and industry grouped by environmental risk. (Mean of R^h $C_{et,t}$ by industry). (Continuation)

1978-1999

GHG emissions in processes

Textiles	0,47	0,36	0,47	0,45	0,37	0,26	0,42	0,45	0,39	0,41	0,45	0,40	0,28	0,41	RD
Paper and paper products	0,47	0,39	0,47	0,47	0,36	0,27	0,42	0,46	0,43	0,41	0,44	0,39	0,27	0,42	RD
Coke and refined petroleum products	0,37	0,40	0,33	0,47	0,58	0,15	0,45	0,37	0,38	0,35	0,40	0,50	0,23	0,41	RD
Fabricated metal products, exc. m. & eq.	0,44	0,28	0,51	0,45	0,23	0,49	0,37	0,43	0,35	0,46	0,45	0,25	0,47	0,38	RC

Wastes ind processes

Textiles	0,47	0,36	0,47	0,45	0,37	0,26	0,42	0,45	0,39	0,41	0,45	0,40	0,28	0,41	RD
Tobacco products	0,41	0,35	0,42	0,43	0,37	0,26	0,39	0,42	0,37	0,37	0,40	0,36	0,27	0,38	R
Leather and related products	0,47	0,28	0,52	0,41	0,26	0,37	0,37	0,45	0,34	0,41	0,41	0,29	0,31	0,36	R
Paper and paper products	0,47	0,39	0,47	0,47	0,36	0,27	0,42	0,46	0,43	0,41	0,44	0,39	0,27	0,42	RD
Machinery and equipment n.e.c.	0,42	0,25	0,37	0,55	0,36	0,21	0,35	0,4	0,37	0,43	0,48	0,44	0,24	0,39	RD
Fabricated metal products, exc. m. & eq.	0,44	0,28	0,51	0,45	0,23	0,49	0,37	0,43	0,35	0,46	0,45	0,25	0,47	0,38	RC
Basic pharmaceutical products and pharmaceutical preparations	0,28	0,56	0,23	0,43	0,60	0,10	0,46	0,25	0,53	0,21	0,31	0,55	0,09	0,40	R

High intensity consumers of energy (resources)

Other non-metallic mineral products	0,45	0,35	0,48	0,48	0,34	0,36	0,41	0,43	0,40	0,44	0,46	0,38	0,36	0,42	RC
Basic metals	0,46	0,35	0,56	0,52	0,33	0,34	0,44	0,44	0,40	0,50	0,52	0,34	0,38	0,44	RD
Paper and paper products	0,47	0,39	0,47	0,47	0,36	0,27	0,42	0,46	0,43	0,41	0,44	0,39	0,27	0,42	RD
Chemicals and chemical products	0,38	0,47	0,34	0,49	0,51	0,15	0,45	0,37	0,43	0,37	0,41	0,52	0,21	0,43	RC
Food products	0,35	0,55	0,28	0,46	0,57	0,14	0,47	0,31	0,53	0,25	0,37	0,59	0,13	0,43	RD
Beverages	0,37	0,44	0,36	0,44	0,45	0,21	0,42	0,36	0,47	0,31	0,39	0,47	0,20	0,41	R
Coke and refined petroleum products	0,37	0,40	0,33	0,47	0,58	0,15	0,45	0,37	0,38	0,35	0,40	0,50	0,23	0,41	RD

(RD), Relative Diversification; (RC) Relative Concentration; (R), Importance reduced.

(*) remarked squares indicate the environmental technology more adequately addressed to the environmental risk associated with the industry. Source: EPO PatStat and Orbis. Author's calculation.

In the group of industries characterized by be pollutant in Wastes in process, 5 of the 7 industries report a relatedness index of Waste Management to their core- competencies: Tobacco, Paper products, Machinery and equipment, Metal products and pharmaceutical products. Once again, this pattern remains between periods with two exceptions. Waste management is an ET that increase its relatedness index in the Textileindustry in second period, bur losses relatedness in the Tobacco industry.

Industries that are high intensity consumers of energy and resources should develop competences in Alternative energy production and Energy conservation. The relatedness index of this ET to the CT should be higher in these industries than the averagerelatedness index in other kind of technologies, and thy really are. All de seven industriesin this group show that result in the two periods with this pattern: in Other non-metallic mineral products, Basic metals and Paper products, the relatedness index is superior in Energy conservation, while in Chemical products, Food, Beverages and Coke and refinedpetroleum products, the relatedness index is superior in Alternative energy production. We call the attention also to the relativeness index of Agriculture/Forestry to central competences in the Coke and refined petroleum products, which is quite relatively superior to the relativeness index of other technologies. This is due to the exploration of biofuels technologies, which once more confirm what we expected in H2.

The group of pollutant in the products they produce only contemplates two industries: Motor vehicles and Other transport equipment. Industries in this group is expected to be more sensitive to Energy conservation and Transportation technologies, and the relativeness indexes for both technologies confirms that they really are. In both industries and in both periods, the relativeness index of this technologies to the core competences of the industries is quite superior to the relativeness index for the rest of technologies.

Lastly, industries characterize by be pollutant generating wastes in their productsshould be more sensitive to Waste management technologies and show a relatedness index to their core competences in this ET superior to the average relatedness index in other technologies. The results shows that this expectation really happens in 7 of the 9 industries clustered: Pharmaceuticals, Chemical products, Rubber and plastic products, Wearing apparel, Food and Beverages. This pattern remains between periods. Only in Wearing apparel the relatedness index loss their relative importance. We call also the attention to the elevated values of the relatedness index in Agriculture and Forestry technologies in Pharmaceuticals and Chemicals products, which are also expected given that in both industries there is a strong association between Pharma industry and Forestry resources, on one side, and between Chemical products applications to Agriculture, by the other side.

Once it was identified the relatedness of environmental technologies with core- competences of the industry, we can test the H3 about how is associated this relatedness to the path of technological diversification towards environmental

technologies. Initially, it implies that when $R^h C_{et,t}$ is relatively higher, the ET potentially constitutes a coherent path of diversification by knowledge interdependencies in the h -industry. Alternatively, relative low $R^h C_{et,t}$, means that ETs relatedness is dissimilar to the CT relatedness in the h -industrial-knowledge-base and, therefore, the ET does not constitute a *natural* path of diversification in the firms.

We define that a industry show a path of diversification towards ET whensimultaneously occur two conditions:

- (1) the share of ET occurrences grows in the h -industrial knowledge base between periods $t-1$ and t (ΔET^h) such as,

$$\Delta ET^h = \frac{\sum_{j \in ET} s_{j,t}^h}{\sum_{j \in ET} s_{j,t-1}^h} > 1, \text{ where } s_{j,t}^h = \frac{c_{j,t}^h}{\sum_j o_{j,t}^h}$$

- (2) the share of ET is more diversified, that is, contributes to a higher diversification and variety in the industrial knowledge base, when the diversification index among ET increases more than the diversification index among all the other nodes (technologies) in the industrial knowledge base. The adjusted Theil Entropy index (TE) measures the diversification:

$$TE_{K,t}^h = \frac{-1}{\ln(n)} \sum_{j \in K} s_{j,t}^h * \ln(s_{j,t}^h)$$

where n is the number of nodes in the observed knowledge base, K . When calculating TE for the entire knowledge base (*Total-KB*) $n=39$ and when measuring diversification among ET, $n=4$ (*ET-KB*), as there is only 4 ET. The adjusted version of this diversification index varies between 0 [the hypothetical case that the h -industrial knowledge is composed of only one node], and 1 [the hypothetical case that the h - industrial knowledge is composed of all the 39 technical fields with the same weight].

The diversification towards ET in period t occurs when the diversification index among ET (TE^h_{ET-KB}) grows at least equal to diversification in the entire knowledge base:

$$\frac{TE_{ET-KB,t}^h}{TE_{ET-KB,t-1}^h} \geq \frac{TE_{Total-KB,t}^h}{TE_{Total-KB,t-1}^h}$$

Considering the above two conditions, three diversification scenarios are possible for ET: relative diversification, relative concentration, and importance reduction (Figure 3). If the participation of ET in the industry knowledge base increases and the industry diversifies in ET at least as it diversifies in the other technologies, we say that industry is diversifying in the direction of ET [relative diversification towards ET]. If the participation of ET in the industry knowledge base increases and the industry diversifies in ET less than it diversifies in the other technologies,

we say that industry concentrate towards ET [relative concentration towards ET]. Finally, if the participation of ET in the industry knowledge base decreases, we say simply that ET reduced their importance in the industry knowledge base [ET importance reduction].

Figure 3 - Scenarios of diversification towards ET in the industrial knowledge base.

		Contribution of E-UTK to industry diversification	
		$\frac{TE^h_{-KB,t}}{TE^h_{otal-KB,t}}$	$\frac{TE^h_{-KB,t}}{TE^h_{otal-KB,t}}$
		$\frac{ET}{Total-KB,t-1}$	$\frac{ET}{Total-KB,t-1}$
		$\frac{ET}{Total-KB,t-1} < \frac{ET}{Total-KB,t-1}$	$\frac{ET}{Total-KB,t-1} \geq \frac{ET}{Total-KB,t-1}$
Evolution of ET participation in the industrial knowledge base between 1968-1999 and 2000-2016	↑	Relative Concentration towards ET	Relative Diversification towards ET
	↓	ET importance reduction	

The sectors where the diversification towards ET occurs is presented in table 7. The ET reduced its importance in the industrial knowledge bases in some sectors between 1968-1999 and 2000-2016 periods. However, in more than half of the industries, ET not only increased its participation, but also contributed to the diversification of industrial competences. This last scenario took place in GHG pollutant sectors, pollutant sectors by waste, and in high intense energy consumer industries, such as chemicals, textile, motor vehicles, and coke and petroleum; but also in low pollutants sectors, reinforcing the ET transversal character.

According to the H3, the relative diversification towards ET should be associated with higher relatedness between ET and the industry central competences in the period before ($RhC_{et,t-1}$), as it would constitute a coherent diversification path. Last column of table 6 show the path followed by the industries in terms of technological diversification. The relative diversification was the most frequent path in industries, but it seems associated to relatedness just in some specific industries, like in Coke and refined petroleum products, Machinery and equipment, Basic Metals, Paper products, Motor vehicles, Other Transport equipment and Rubber and plastics. In other cases, superior relatedness indexes are associated with concentration in ET, like in the cases of Metal products, Other non-metallic mineral products, Chemical products, and Foods. Finally, there are cases where the relatedness index is as expected according to the environmental risk and still ET lost importance. These are the cases of Pharmaceutical products

and Beverages.

Table 7 – Industries and relatedness index (mean of $R_{C,ET,t}^h$ by industry) according to scenarios of diversification towards E-UTK

Scenario	Industry	$R_{C,ET,t}^h$ (1968-1999)
Relative Diversification towards ET	Food products	0.38
	Textiles	
	Wearing apparel	
	Wood and of products of wood and cork, except furniture; Articles of straw and plaiting materials	
	Paper and paper products	
	Coke and refined petroleum products	
	Chemicals and chemical products	
	Rubber and plastic products	
	Basic metals	
	Computer, electronic and optical products	
	Machinery and equipment n.e.c.	
	Motor vehicles, trailers, and semi-trailers	
	Other transport equipment	
	Repair and installation of machinery and equipment	
	Printing and reproduction of recorded media	
Relative Concentration towards ET	Other non-metallic mineral products	0.36
	Fabricated metal products, exc. m. & eq.	
	Electrical equipment	
ET importance reduction	Beverages	0.38
	Tobacco products	
	Leather and related products	
	Basic pharmaceutical products and pharmaceutical preparations	
	Furniture	
	Other manufacturing	

Source: EPO PatStat and Orbis. Author's calculation.

The last question is if the diversification towards ET verified in 2000-2016 is associated with the relatedness observed in the period before [1968-1999]. The results do not demonstrate a clear association that confirms the importance of technological coherence to explain paths of diversification and variety in the industrial knowledge base. The relatedness between ET and CT (index mean) in the group of sectors where relative diversification towards ET occurred [0,38] was like the one verified in the group where ET reduced its importance (Table 7). Besides that, relative diversification towards ET occurred in cases of low relatedness index, which means that ET represent paths of diversification driven by other forces beyond the complementarities of knowledge into the industrial knowledge base, like complementary assets, reduction costs or environmental policy requirements. An example is Computer, electronic and optical products that presents the lowest relatedness between ET and CT among all sectors, 0.26 (Table

6). At the same time, ET reduced its importance in the knowledge base of industries whose CT were close related to ET, what indicates gaps of technological coherence in the new competences development process. This happened in other manufacturing, and Basic pharmaceutical products and pharmaceutical preparations, the last one a pollutant industry by its processes and products.

5. Conclusions and discussion

This paper aimed to test whether environmental technologies constitute a natural path of technological diversification in the industry, considering their relatedness to the core competences in each industry. To do that, the paper enounced three hypotheses: (1) on the coherence of ET in relation to the main environmental risk of the industry; (2) on the pervasiveness of the ET considering that environmental risks affect can involve, on one hand, developing energy costs reducing ET that provide private returns; and on the other hand, developing managing wastes ET, which involves social returns; (3) on the association between diversification towards ET and its relatedness to the core competences of the industry.

In relation to the first and second hypotheses, the paper shows, as expected, that ET are mainly marginal and stable between periods (1969-1999 and 2000-2016). However, a non-negligible part of the ET has a representative centrality in the industry and, even more, ET tend to gain centrality between periods. In addition, ETs use to be coherent (more central) in industry according to the main environmental risk, but gains of centrality are more relevant when ET provides private returns (case of alternative energy production and energy conservation). ET that provides social returns, those are the related to Waste management, does not reveal significant gains of centrality. This result is a first indication about the source of the motivation in the industry to invest in eco-innovation. As much as ET provide cost reduction, there is a motivation to innovate. However, there is low motivation in the industry to innovate in ET that provides social returns, especially technologies to resolve issues like the Waste generation in products (like in computers, pharma, chemicals, rubber and plastics, electrical equipment, wearing products, food, and beverages). In these cases, regulation and policy incentives must to stimulate eco-innovations in the industry. Respecting on the third hypothesis, the results reveal that the relatedness of environmental technologies to the core-competences of the industries does not drive the path of technological diversification in industry. This result is another indication that regulation and public policies are necessary to guide the rhythms and paths of eco-innovations in industry. It does not seem clear that ET represent a natural path of technological diversification, excepting maybe in the alternative energy paradigm.

Finally, the gaps of technological coherence observed in other manufacturing, and Basic pharmaceutical products and pharmaceutical preparations [the last one a pollutant industry by its processes and products] highlight cases that deserve more investigation and could contribute to understanding the role played by other factors pointed out in the literature as determinants for the development of new environmental competences and not considered in this paper, such as cost reduction and reputation. Additionally, it involves some relevant insights from an environmental policy perspective, as it draws attention to sectors where regulation and other instruments could be more important to foster eco-innovations more directly.

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Notes

¹ As a reference for the nature of the applicant, it was used the classification available on ORBIS - Bvd for stakeholder and affiliate types, and the following applicant categories were disregarded: Foundation/Research Institute, Employees/Managers/Officers, Individuals/Families, Public Authorities/State/Government, or Not Identified. As for the industry sectors in which each firm acts, it was used the classification created by ORBIS - Bvd based on the revised Statistical Classification of Economic Activities in the European Community (NACE Rev.2), and were included only the companies listed in sections A to L.

² Package igraph for R was the software used to calculate the Page Rank.

Galvanizing System Change through youth-led Digital Innovation: The Case of Kenya

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Abstract

Science, Technology and Innovation (STI) is recognized globally as a key strategy in meeting the sustainable development goals by 2030. It has therefore attracted significant investments by countries in the Global South and North (UN IATT, 2022; African Union, 2019) although in unequal measures. Despite these significant investments, developing countries still lag behind in innovation due to factors referred to as weak framework conditions which include poor ICT infrastructure and a looming skills gap (Kraemer-Mbula & Wamae, 2010).

In the eve of the fourth industrial revolution (4IR), frontier technologies that include digital technologies such as artificial intelligence, cloud computing among others are taking center stage in the international development agenda especially among developed countries. Developing countries are also developing elaborate plans to provide a roadmap on the innovative application of digital technologies to economic growth (MOIYA, 2022). Experts recommend that in order to reduce the inequality gap between Global North and South, developing countries will need to increase their capabilities in the already existing technologies that will include adoption, usage, policy and infrastructure development, and R&D (UNCTAD, 2021).

The growing youth population in developing countries is considered a key asset in revolutionizing digital innovation in a highly dynamic environment. However, in the Kenyan context specifically, the absence of a coordinated approach to addressing the youth skills gap and the weak system dynamics of the digital innovation ecosystem present as barriers to youth inclusion. The government initiatives have realized some achievements (MOIYA, 2022) however, their focus purely on digital literacy is inadequate for the achievement of the desired digital

transformation (this proposed research refers to a conceptualization of digital innovation by Weisbock (2018) where he describes it as a result of 2 key processes, i.e., digitalization and digital transformation). There is also heavy focus on technical skills whereas digital transformation requires for one to have the dynamic capabilities of sensing, seizing and transforming. Digital inclusion policies also need to be strengthened.

The proposed research will apply the technological innovation system (TIS) framework and the dynamic capabilities approach to develop a novel approach to youth-led digital innovation. The result will be theory-led assessment framework for youth capabilities in digital innovations by focusing on the Kenyan context. Nairobi and Kisumu counties will be the sites for the study as the two provide unique contextual considerations. A concurrent mixed methods design will be employed among youth 18-34 years and key informants in Nairobi and Kisumu counties.

Comparative case studies will be applied to explain how the contexts in Nairobi and Kisumu influence youth-led digital innovations. Multiple regression analysis will be used to analyze quantitative data and validated using analysis of variance. Content analysis will be used for qualitative data. This proposed research will provide education policy leaders, ICT industry leaders as well as government policy makers with useful information in reviewing existing initiatives and policies to be more conducive to youth-led digital innovations.

1. Introduction

1.1. Background Information

Innovation is defined as “a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)” (OECD/Eurostat, 2018). Innovation is critical in the social and economic growth of both developing and developed nations in the 21st Century. The product innovation is characterized by technological and digital advancements, which have penetrated various sectors that include banking, transportation, economics, and most of all in education (Sharma & Chaudhary, 2020). Science Technology and Innovation (STI) have for a long time driven economic growth with little attention being given to its impact on sustainable development (Walsh et.al., 2020). The UN, recognizing the potential for STI to deliver the ambitious targets of the sustainable development goals (SDGs) has placed STI as a central tool for implementing the SDGs (UN IATT, 2022)

The African Union (AU) also acknowledges STI as a key driver of the 20 goals of the AU2063. Thus, the continent has made significant progress in institutionalizing innovation by creating an enabling environment, establishing institutions to implement and monitor the STI agenda, developing policies. In addition, funding has been secured from various agencies and governments to support higher education and specific programs that include emerging technologies such as artificial intelligence, micro-grids among others (African Union, 2019).

However, despite the significant investments made in research and development (R&D), African countries still reported low innovation output in the Global Innovation Index 2020 (Cornell University, INSEAD, WIPO, 2020). Kraemer-Mbula & Wamae (2010) refer to weak framework conditions for innovation such as unstable economic and social environments, weak governance mechanisms, unaffordable higher education systems and skills reserve, poor Information and Communication Technology (ICT) infrastructure among others, as affecting the output of innovation in developing countries.

With frontier technologies (that include digital, nanotechnology, new materials and biotechnology) taking center stage in the international development agenda in the eve of the fourth industrial revolution (4IR)¹, especially among developed countries, the developing nations are said to be operating below the average of technology adoption and use, with low levels of human capital (Goedhuys et al., 2008). UNCTAD (2021) reports Sub-Saharan Africa as having the majority of countries that are the least ready for frontier technologies with a score of

approximately 0.18 out of a total score of 1, which is below the world average of around 0.45. The score was based on a *Frontiers Technology Readiness Index* that focuses on the following 5 building blocks: ICT deployment, skills, research and development (R&D) activity, industry activity and access to finance.

In order to reduce the inequality gap between developed and developing countries, that will increase from the new technologies, developing countries will need to focus on improving the scores of the Frontiers Technologies Readiness Index. Since technologies build on each other, developing countries will need to first build their capabilities in the existing technologies that will include adoption, usage, policy and infrastructure development, and R&D (UNCTAD, 2021).

¹ The 4IR is defined as a “Revolution that is blurring the lines between the physical, the digital, and the biological worlds. Massive advances in artificial intelligence (AI), Internet of Things (IoT), robotics, 3D printing, quantum computing, genetic engineering, and various other technologies (Schwab, 2016)

According to the United Nations Inter-Agency Task Team on Science, Technology and Innovation for the SDGs and European Union (2021), these technologies present several opportunities and challenges for developing countries in meeting the SDGs. While they present significant potential for developing countries to meet the SDG targets, they also present the developing countries with the potential risk of lower labour exports as well as increased job loss as most work done by humans will be taken over by the new technologies. Developing countries also lack the necessary human capital as well as infrastructure necessary for the advanced technologies. They should strengthen their STI capabilities and use their entrepreneurial potential to take advantage of the opportunities presented by the frontier technologies, while anticipating and building capacity to respond to the challenges. They should also develop their own technological capacity to build resilience to the challenges in the long term (UNDESA, 2018).

In addition, the developing countries, especially African countries need to take advantage of the growing population which is predominantly youthful. It is estimated that by 2050, Africa’s youthful population will double to over 830 million making up the larger population of the continent’s workforce, which will be a quarter of the world’s workforce (UNECA, 2017). In Africa, it is expected that about 11 million young Africans will join the labour market every year for the next decade. This youth bulge can be turned into a demographic dividend that can fuel social and economic growth through the acquisition of skills necessary for the 21st Century innovation landscape, specifically, building youth capacities to adopt, use and innovate ICTs in readiness for the frontier technologies.

This proposed research will therefore examine how youth in developing countries can play an integral role in the socio-economic development of their countries through youth-led digital innovations by looking at the Kenyan context. Specifically, it will seek to establish a framework by which youth can be engaged by assessing their individual capabilities in developing digital innovations and the system dynamics that influence the development and diffusion of youth-led digital innovations.

Digital innovation being a new concept, but becoming more popular especially with the advent of COVID-19 has been conceptualized differently by many scholars. This proposed research will however apply the conceptualization by Nambisan et al. (2017) and Weisbock (2018). According to Nambisan et al. (2017) digital innovation is “the creation of (and consequent change in) market offerings, business processes, or models that result from the use of digital technology”. Weisbock (2018) goes further to describe digital innovation as a result of 2 key processes, i.e., digitalization and digital transformation. He defines digitalization as “the identification, adoption, adaptation, development, and management of innovative digital technologies while digital transformation is the transformative impact of digital technologies in organizations”. The digital technologies may include what he refers to as SMAC technologies, i.e., social, mobile, analytics, and cloud computing. Reference will also be made to the expansion by Gartner (2018) who sees digitalization as the use of digital technologies in business/organizational processes with the *supreme intention of innovatively adding value* by developing new business models or generating revenue.

1.1.1. A Synopsis of Kenya’s Digital Innovation Ecosystem

Kenya’s digital ecosystem has evolved significantly since the arrival of the undersea fibre optic cable in 2009. The IEA (2021) report sheds light on the 20-year transformation that has seen the development and review of policies that aim at improving access to affordable information through the use of new applications, policies that protect the consumer, advanced infrastructure development and opening the telecommunications ecosystem to multiple actors in the public and private sectors. Digitization has now become a new way of life and a major part of development that is entrenched in almost every sector of the country that include but not limited to health, finance, agriculture and education (IEA, 2021). The country now needs to strengthen the digital innovation ecosystem to create value out of the digitization process.

Despite the reasonably expanding ICT activity in Kenya, the sector’s contribution to the GDP stagnated at an average of 2.6% between 2016 and 2020 (KNBS, 2021),

an indication that the value added from ICT services is still low. Some of the key reasons identified as leading to the minimal performance in ICT innovation are a lack of technical and research skills to drive innovation in the sector, with majority of graduates opting to move into corporate jobs (ITU, 2019). In Kenya, doctorate students account for approximately 0.71% of a total ICT student base of 36,452 at public and private universities (The Commission for University Education, 2019), an indication of a low transition rate from Bachelors degrees to PhDs. In addition, youth ICT enterprises are not sustainable and hence cannot innovate. Studies allude to either a lack of business/entrepreneurial, technical skills or, innovation skills (ITU, 2019). The Kenya government has therefore launched the Kenya Digital Masterplan 2022-2032 to guide in rolling out the interventions required to advance the country's digital transformation agenda. The masterplan's 5 flagship programs are: improving the digital infrastructure; digital services, products and data management; digital skills; digital enterprises, innovation and businesses; policy, legal and regulatory. This information will be important for the proposed research, especially in analyzing the system dynamics that influence the capabilities of youth to develop digital innovations for sustainable development. It has attempted to address issues that are of interest to this proposed research such as digital inclusion of youth and women, digital innovation capabilities (especially among youth), and system dynamics.

1.2. Statement of the Problem

While the potential of youth to create, innovate and adopt new technology is alluded to in studies (Grzeslo, 2020) and policy documents (MOIYA, 2019), in the current digital economy that is considered constantly disruptive and evolving (Nambisan, 2017), their true potential to drive digital innovations for sustainable development remains unclear. As the country looks upon the youth to spur digital innovation, a clear framework on how youth are expected to do this is required – their capabilities to develop digital innovations need to be assessed and enhanced, inclusive policies that support youth involvement in digital innovation also need to be developed.

The government initiatives have realized some achievements (MOIYA, 2022) however, their focus purely on digital literacy is inadequate for the achievement of the desired digital transformation. The initiatives are fragmented with each institution/organization in the digital innovation space running its own program. There is also a heavy focus on digital technical skills whereas digital transformation requires for one to have the dynamic capabilities of sensing, seizing and transforming. Digital inclusion policies also need to be strengthened.

The proposed research will therefore assess the potential of youth to develop digital innovations for development presently, with the existing technologies, and in anticipation of frontier technologies by looking at their capabilities to innovate, and assessing system dynamics of the local context in relation to youth digital innovation.

1.3. Objectives

The **main objective** will be to contribute to the development of an integrated framework for youth-led digital innovation that galvanizes system change. The **specific objectives** will be:

1. To determine the system dynamics of the youth-led digital innovation in the Kenyan context
2. To assess the inclusiveness of the youth-led innovations in the digital innovation ecosystem
3. To evaluate the individual – level dynamic capabilities of youth to develop digital innovations

1.4. Research Questions

1. What are the system dynamics for youth-led digital innovation and how do they influence the youth performance in the digital innovation space?
2. What aspects of inclusiveness are youth-led innovations in the digital innovation ecosystem?
3. What forms of individual – level dynamic capabilities do youth have/or require to develop digital innovations?

1.5. Significance of the Study

The proposed study will add to new knowledge in the area of ICT innovations for development and research. It will provide significant information that will help in developing a novel approach to exploring youth-led digital innovations in the local innovation ecosystem – a theory

led assessment framework for youth capabilities in digital innovations. The information will also be useful in bridging the disconnect between digital entrepreneurship and sustainable development in the Kenyan context. The proposed study will also contribute to new knowledge that will help establish a critical mass of future innovation leaders and provide lessons that can be replicated in other developing countries. To education policy leaders, ICT industry leaders as well as and government policy makers, this proposed research will

provide them with useful information in reviewing existing policies to be more conducive to digital innovations by youth. Lastly, it will also contribute to tackling youth unemployment in Kenya which is at 10.8% (KIPPRA, 2020). The significance of Kenya as the context of the research lies in its strategic position as East Africa's Digital Hub with 48 tech hubs (Shapshak, 2022).

2 LITERATURE REVIEW

2.1.1 ICT in the Context of Developing Countries

Technology, particularly ICTs has permeated different sectors globally and is a major topic among academics and policy makers especially in relation to economic growth and sustainable development. Despite the on-going discourse regarding the importance of ICT in economic growth and sustainable development, no standard definition exists for ICT. A literature review conducted by Zuppo (2012) showed a lack of consensus in the definition of ICT among the economic, education and business sectors, a position also held by May et al (2014). The authors further explain this ambiguity by introducing 2 arguments used to define ICTs. In their research, they have found that some scholars define ICTs in terms of new technologies such as computers and internet while ignoring the old ones such as phones and radios, while others define them by the set of tasks they perform such as a phone being both a radio and a mini-computer. ICT has also been used interchangeably with the term digital technologies in several literatures (see for example Abdel-Aziz et.al., 2015; Korunka & Vartiainen, 2017) with each author defining them differently, although there is consensus on the core roles of the digital technologies and ICTs, which are to process, store, retrieve data or information.

In the African context, like in several other developing countries, an understanding of ICT goes beyond the technical aspects. It is seen as an enabler of development and has been adopted into health, climate change, education, agriculture and government services although in limited degrees. Paradoxically, it also presents as a new source of social exclusion, a situation that may be as a result of the limited research hence inadequate knowledge on ICT in developing countries. Solomon & Klyton (2020) also attribute the limited adoption of ICT to inadequate skills and infrastructure, and unaffordability of digital devices and technologies.

2.2. Determinants of Digital innovations in developing countries

The strength of digital innovations in any particular country is measured by assessing the strength of the overall ICT sector. This strength is measured by the strength of inputs that include financing, technical skills, size of the ICT sector, demand for digital innovations and international competitiveness of digital innovations. Components of digital innovation systems that include technologies, actors, institutions, mechanisms of interaction and infrastructure are also measured and so is the impact of innovations (Wintjes, 2016; ITU, 2019).

ICT innovations are influenced by different factors in developed and developing countries. Based on a comparative analysis between a developed country, Sweden and developing country, Sri Lanka, Wijesinghe et.al., (2021) found that education and mindset, a risk-taking environment, embracing failures, digitalization and collaboration are the critical determinants of ICT innovations in Sweden contrary to the generally weak innovation systems, technological capabilities at individual, firm and government levels in developing countries. They proposed that the lessons learned from Sweden could be contextualized and used to strengthen Sri Lanka's ICT innovation system.

A study by Satalkina & Steiner (2020) draws some similarities with the study by Wijesinghe et.al., (2021) although they are more specific to digital entrepreneurship. They suggest that digital entrepreneurship is essential for the innovation process. Through a literature review, the authors grouped digital entrepreneurship into 3 core categories: entrepreneur (personal attitudes and intentions to start a business and digital competencies), entrepreneurial process (adaptability to digital platforms, digital capabilities), and ecosystem (digital business environment, infrastructure, collaboration and social values).

The generally weak environment for innovations in developing countries characterized by low education levels, low incentives for entrepreneurship, weak ICT infrastructure make the ICT innovation system weak (Aubert, 2004). This is evident in the poor documentation of ICT innovations in developing countries (Nielsen, 2017). In addition, some authors observe that the technological innovation system in developing countries tend to be more incremental other than radical as a result of path dependency and lock-in (Dosi, 1982; Frantzeskaki and Loorbach, 2010; Markard and Truffer, 2006). Markarda et.al. (2012) suggest that radical changes to technology will provide the much needed solutions to complex sustainability issues as opposed to incremental changes.

Africa's ability to catch-up on the other hand is most significantly hindered by poor infrastructure, relatively poor business environment, and lack of human development (Dasa & Drine, 2019). The authors suggest that for African countries to realize sustainable growth, they will need to improve outcomes on the hinderances in addition to improved policies and good governance.

2.3. Innovation Systems and Digital Innovation

The concept of innovation has evolved over several decades increasing in scope and depth as depicted by Rossetto et al., (2017). The four authors analyze the structure and evolution of innovation research in four periods between 1956 and 2016, with more diversification in the innovation topics noted from 1986, making the concept more complex. In the first three periods, from 1956 to 2000, technological adoption and diffusion as well as technology change were dominant topics in innovation discussions. In the last period under study, i.e., from 2001 to 2016, new approaches to innovation emerged that included social innovation, innovation in emerging markets, knowledge transfer, triple helix models, systems of innovation, disruptive innovation, new product development process and portfolio management. Some of those approaches such as the systems of innovation absorbed technology.

Information systems (IS) scholars insist on isolating the area of technology so as to develop a comprehensive definition of digital innovation. The topic has only gained traction in the last 10 years with nearly 744 publications identified (out of 793 identified since 1983) through a literature review conducted by Kaczmarek et al (2022). Majority of the publications identified (507) came from Europe and most of those publications (514) covered topics from engineering sciences, i.e., computer sciences, engineering and mechanical science. Although various definitions were proposed in the different publications, they commonly refer to the production of new products and services using digital innovations.

Nambisan et al., (2017) conceptualize an inter-disciplinary perspective of digital innovation with the view that digital innovation requires the input of various actors. In this sense, it compares well with Systems of Innovation theory which recognizes the importance of different actors in the innovation process. However, the authors attempt to draw a difference between innovation management and digital innovation in that while innovation management describes innovation outcomes and processes that are well "bounded" or in other words, fixed, the outcomes and processes of digital innovations are dynamic and non-linear. This means that they evolve continuously even after an innovation has been

implemented and ideas emerge from different sources. In a nutshell, Nambisan et al. (2017) therefore conceptualize digital innovation as “the creation of (and consequent change in) market offerings, business processes, or models that result from the use of digital technology”.

The definition of digital innovations by Weisbock (2018) is not far from that by Nambisan et al (2017). However, he introduces the concepts of digitalization and digital transformation where he suggests that digital innovation is a result of the two concepts in addition to what he refers to as digital artifacts which are innovative digital technologies, innovative digital solutions, and innovative digital business concepts. The author describes digitalization as “the identification, adoption, adaptation, development, and management of innovative digital technologies while digital transformation is the transformative impact of digital technologies in organizations”. These digital technologies include what he refers to as SMAC technologies, i.e., social, mobile, analytics, and cloud computing. Vigren et al., (2022) define digitalization as “sociotechnical innovation processes of invention, development and implementation of new ideas, in which both technological and organizational aspects are considered”. Schmitt et al., (2020), in defining digital innovations introduce the concepts of exploration and exploitation. They describe exploration as the identification of opportunities to produce new offerings and exploitation the execution of identified opportunities.

With this backdrop therefore, one can conclude that digital innovations require capabilities in digitalization and digital transformation, i.e., the innovator needs to be able to identify gaps, innovatively use different digital technologies to develop new processes, products and market opportunities that have the potential for significant change.

2.4. Youth and Digital Innovations

Youth all over the world demonstrated their ability to utilize digital technologies to improve their societies during the COVID-19 pandemic, their resilience to overcome socio-economic challenges such as unemployment and mental instability by applying their skills in ICT to run their businesses and network with other youth. Pietilä et al (2021) found that digitality helped Finnish youth, more so, those skilled in ICT, cope with various societal challenges as they were able to access content and useful information for coping, thereby promoting inequality among youth and furthering the digital divide. They suggest that for equality to be enhanced, there's need to ensure that all youth are well equipped with digital skills and competencies. In Africa, youth with access to digital technologies saw the opportunity for business, enhancing access to the Internet by using their mobile

phones as hotspot at a fee (Pinet et al., 2021).

Youth are digitally excluded in use and access to digital technologies. Skills, gender and language barriers further inhibits the potential of youth to participate in digital innovations (Pinet et al., 2021). In Africa, over 70% of the youth is offline (AU, 2020) and the rural-urban trajectory cannot be ignored as youth in the urban areas are more likely to be engaged with digital technologies as compared to their counterparts in the rural areas due to infrastructure developments and access to skills development and opportunities to explore digital technologies. With regards to gender inequality, Schmitt et al (2020) note that more women are concerned with utilizing technology than technology innovation thereby suggesting that digital innovation potentials for women remain untapped.

IEA (2021) reported that despite equal access to connectivity between males and females in the Kenyan context, the adoption and utilization rate of digital technologies among males is higher than females. The report also shows that the youth population (especially 25-34 years olds) has the highest mobile phone ownership among the different age segments at approximately 80% however, only half of that population use the internet and just over 10% bought or ordered goods online at the time of the study. In addition, very few use desktop computers/laptops or tablets. Some factors that contribute to the digital exclusion of this population are for example: cost of access, inadequate skills, lack of content, poor connectivity, information gaps among other factors. OECD (2004, 2012) suggest that digitalization, being an important first step in ensuring successful digital innovation therefore requires that the workforce possesses digital skills, the Information Communication Technology (ICT) infrastructure needs to be in place and there needs to be internet connectivity and utilization.

2.5. ICT Innovation Theories

Theories regarding ICT Innovation for developed and developing countries have been discussed in several literatures, revealing notable differences. Avgerou (2008, 2010), who has delved into ICT innovations theories for developing countries discusses 3 perspectives in this context of developing countries; the transfer and diffusion theory (technologies are transferred and adapted to the contexts of the developing countries), social embeddedness theory (locally appropriate innovations) and transformative techno-organizational intervention (IS innovation as transforming the social, economic, and political conditions). Nielsen (2017) through a literature review introduces the concept of inclusive innovation. He argues out the importance of involving developing countries as active participants in innovations as opposed to passive participants to conduct data entry and

digitization of documents through impact sourcing conducted by developed countries.

Digital innovations are defined as either products or processes, i.e., digital innovations as technology used to develop new products or business processes, and digital innovations as outcomes of the innovations processes (Karabulut, 2020; Khin & Ho, 2018; Nambisan et al., 2017; Henfridsson et al., 2009) which may be digital or non-digital (Karabulut, 2020). Both concepts will be applied in this proposed research.

2.6 .Theoretical Framework

The proposed research will use elements of the Technological Innovation System (TIS) by Carlsson & Stankiewicz (1991) as the main analytical framework. A few elements from the dynamic capabilities framework by Teece et al (1997) will also be applied due to the limitations of TIS in capturing individual-level digital innovation capabilities among the actors (the youth). The output of the integration of the two frameworks will be a novel approach of assessing youth- led digital innovation (see figure 1). The specific elements are highlighted in detail in the next sections under each framework. Although the focus of the proposed research is primarily on system dynamics and youth capabilities, youth inclusion and factors influencing their choices (conversion factors described by Sen (1992)) are exigent and will therefore be addressed under the TIS framework.

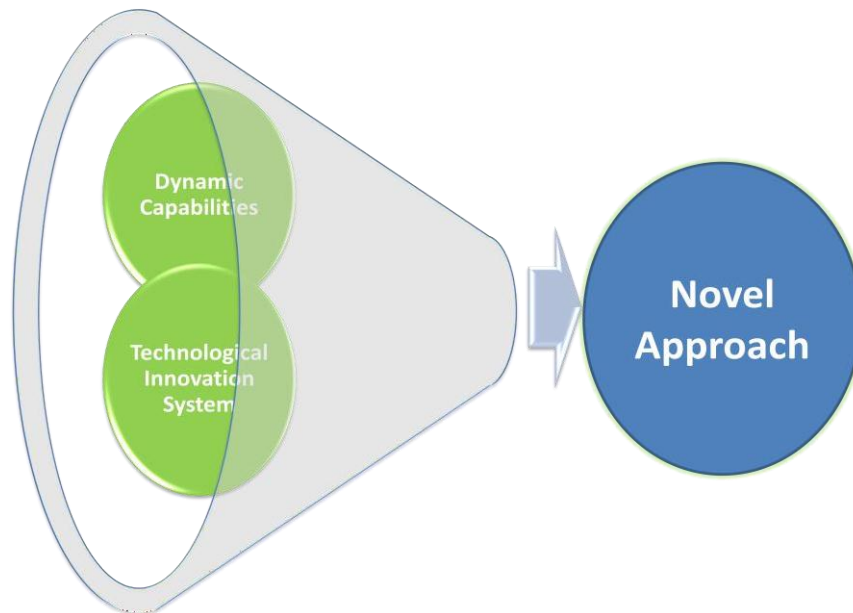


Figure 1: Integration of Frameworks (Dynamic Capabilities and Technological Innovation System)

2.6.1. Technological Innovation Systems (TIS) Framework

The TIS emerged from the National Innovation System (NIS) concept, which was inspired by the systems of innovation (SI) theory. The SI theory promotes an innovation process that is non-linear and one that involves interactive learning among actors (Edquist, 2001). The NIS is important in innovation studies as it emphasizes the complexity or non-linearity of the innovation process. The NIS concept also highlights the importance of context in innovation – systems are different and so innovation processes are unique in different contexts. In addition, interactions among people, institutions and enterprises are important in fostering innovation in the NIS (Chaminade, Lundvall, & Haneef, 2018).

Carlsson & Stankiewicz (1991) introduced the TIS as a framework to study the effects of emerging new technologies on inter-organizational associations. They defined it as a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology. The authors pointed to a possible extension of the TIS beyond the National Innovation Systems (NIS) geographical borders as new technologies emerge. The TIS may also be smaller than the NIS, that is, local or regional systems. According to Carlsson & Stankiewicz (1991), economic competence, clustering of resources, and institutional infrastructure were at the core of the TIS. The authors later expanded the scope of the TIS to include a description of actors and relationships between the actors, boundaries, levels of analysis and performance of the system (Carlsson et al., 2002). In essence, they tried to make the system more practical in this second study of the TIS. The framework is often used to analyse system dynamics to guide policy development and overall system performance (Alkemade et al., 2011; Jacobsson & Karltorp, 2013; Weber and Rohrer, 2012; Wieczorek & Hekkert, 2012) in the energy and transport sectors (Markard et al., 2015). There is also empirical evidence of its use in the analysis of system dynamics, diffusion and adoption of digital innovations in other sectors such as the financial, healthcare and mining (see for example, Kingiri & Fu, 2019; Apell & Eriksson, 2020; Gruenhagen & Parker, 2022).

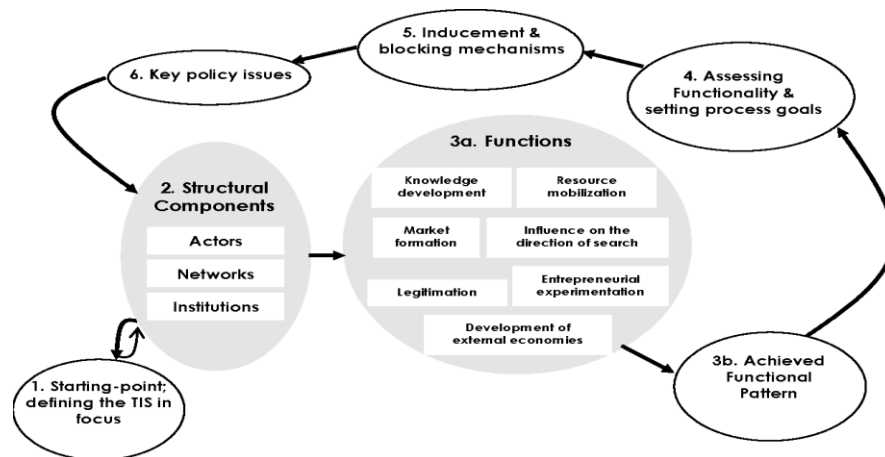
Promoters of this framework propose a functional based approach to analyze the performance of activities and processes in a system. Bergek et al (2008) discuss key processes at functional and structural level in the context of the energy sector. Their research findings demonstrate how new technologies in the energy sector can be strengthened at the meso and micro level to hasten the rate of generation, diffusion, and utilization. They propose 7 functions of the TIS based on literature

review and empirical studies as follows: knowledge development and diffusion (learning), influence on the direction of search, entrepreneurial experimentation, market formation, resource mobilization, legitimation, development of positive externalities or free utilities. They suggest that the functions approach can help unearth system weaknesses and provide a basis on which the entrepreneurs and policy makers can develop systems building activities that counteract the negative effects within the system that lead to a possible dysfunction. Markard et al.(2015) suggest that the TIS framework has the potential to evolve from the original view as new technologies emerge for different socio-technical purposes.

The framework has however been criticized for being inward-oriented, meaning it ignores the external influences on the TIS; lack of a properly defined boundary (system delineation); context or geographical background not covered adequately; its usefulness in analyzing transitions has been questioned; inadequate focus on political influence; and policy recommendations (Markard et al., 2015). One such critique of the framework is Edsand (2019) who proposed an extension to the TIS by adding functions and landscape (contextual) factors to suit the context of developing countries. These functions added included creating adaptive capacity, resource mobilization, creation of legitimacy/advocacy of coalition function. The landscape factors included but not limited to environmental awareness and economic growth. The author's proposal was informed by a literature review and an assessment of the Multi-Level Perspective (MLP) framework, in the context of an empirical study of wind energy transition in Colombia. However, according to Markard et al (2015), TIS, through the functional approach, is capable of providing generalizable insights into the range of gaps identified under the criticisms.

Bergek et al (2008b, p9) propose 6 steps in TIS scheme of analysis as illustrated in figure 2 below.

Figure 2: The Scheme of analysis (Source: Bergek et al., 2008)



In the proposed research, steps 1-3a have already been established - the focus of the TIS is youth-led digital innovation while the actors are youth. Institutions that are likely to influence youth-led digital innovations are both legal and regulatory institutions, financial institutions, relevant ministries (ICT and Youth Affairs). Learning networks will include technology/innovation hubs managed by private and public entities and higher education institutions (HEI). The proposed research will apply 4 of the 7 functions (see table 1) of the TIS framework as defined by Bergek et al (2008a) to determine the system dynamics of the youth-led digital innovation in the Kenyan context, i.e., the youth operate within a space that has several dynamics that influence their digital innovation activities. Steps 3b-6 will be established after the research is conducted and results are analyzed.

Table 1: Selected TIS functions for proposed research

	Function	Description
1	Knowledge development and diffusion	Absorptive capacity and technical learning
2	Influence on the direction of search	Factors influencing the development of a TIS
3	Resource Mobilization	Human and financial capital as well as other resources
4	Entrepreneurial experiment*	Product/service/market testing and development

**merged with market formation*

2.6.2. Dynamic Capabilities

As alluded to in the introduction of this section, the proposed research will apply sections of the dynamic capabilities framework due to the limitations of the TIS in capturing the individual- level dynamic capabilities among the actors (the youth).The word “capabilities” is one that is often used by scholars and professionals from different spheres of life but often with different meanings. As a result, different theoretical frameworks have evolved over time.

Amartya Sen, a welfare economist, originally used the capabilities approach (CA) to analyse and understand famine and poverty. According to the CA, what a person succeeds to do with their wealth or a commodity at hand at a particular time and context is what produces a desired outcome (Sen, 1993). In other words, the availability of wealth alone is insignificant without human intervention. Sen went on to add that for individuals to be successful, they need to have the

freedoms or real opportunities to choose the kind of life they want to live. He equated capabilities with freedoms or real opportunities available to an individual that would help them turn the commodity at hand to what he termed as a functioning, or what the individual can be or do. These functionings according to Sen include being well nourished, being healthy, not suffering from a lack of self-respect, taking part in social life, and so on. The freedoms or real opportunities do not operate in a vacuum but depend on individual, social, and environmental factors. Due to growing interest in the approach, scholars have applied it in different contexts such as in innovation/ICT studies (Odooyo & Liyala, 2018; Hoque, 2020), moreso in the area of ICT4D (ICT for development). Proponents of the CA approach in ICT4D give prominence to the role of humans in creating change using available ICT resources and infrastructure unlike the mainstream ICT4D which merely attributes its impact to resource distribution (Oosterlaken, 2012; Hoque, 2020).

Further to the capabilities framework was the development of the dynamic capabilities by Teece & Pisano (1994) who first defined it as “the firm’s ability to integrate, build and reconfigure internal and external competences to address rapidly changing environments to sustain a competitive advantage” (Teece & Pisano, 1994; Teece et al., 1997). Teece D. J. (2017) later expanded it to include the aspect of ordinary capabilities which he described as less superior forms of capabilities as compared to the dynamic capabilities.

Digital innovations, being transformative in nature require the application of digitalization and digital transformation capabilities which enable firms and individuals to sense new opportunities, seize them, and use them in a way that will change the business processes of a firm (Wiesböck & Hess, 2018). Through a co-citation analysis of antecedents, conceptualization and consequences of digitalization capabilities (digital transformation), Annarelli et al. (2021) found them to be higher order capabilities also similar to dynamic capabilities when applied to the capability- based conceptual model for digitalization capability (see figure 2 below).

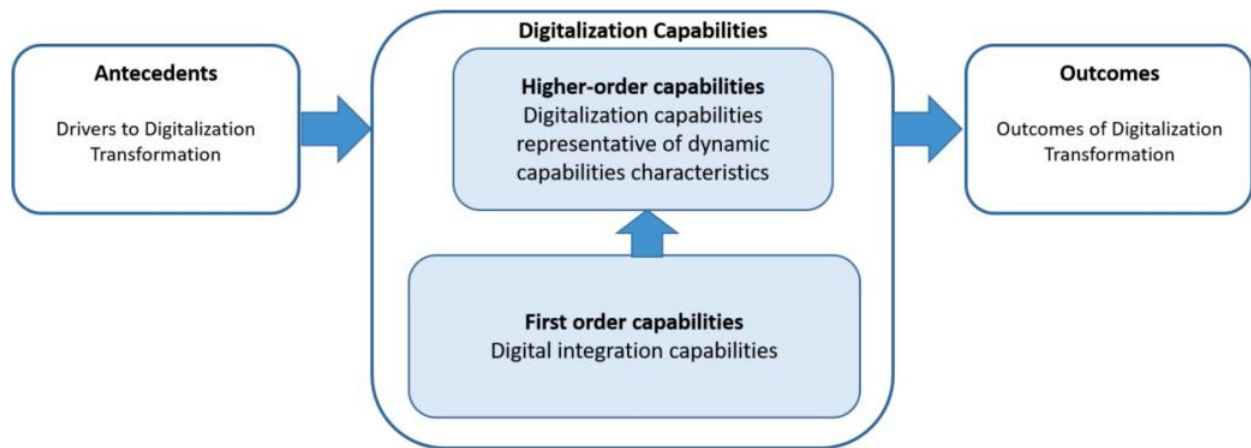


Figure 2: Capability-based conceptual model for digitalization capability.

The dynamic capabilities framework has had several criticisms especially regarding a lack of consensus on its functions, benefits, and environmental context, mostly attributed to its application in a diverse range of disciplines that include information technology, marketing, strategic management and entrepreneurship (Kay et al., 2018) . It's neglect of the employee in the organization has also been noted by (Fallon-Byrne & Harney, 2017 and Kurtmollaiev, 2020). These criticisms have led to the emergence of other concepts that include the micro foundations movement and multi-level approach. Kurtmollaiev (2020) advanced the individual-level dynamic capabilities based on the micro-foundations movement which according to Foss (2010), advocates for reductionism, i.e., analyzing a phenomenon from the smallest level/unit to understand interactions that lead to the outcomes at the macro level in social sciences. Although many have argued that the firm-level should be the smallest unit of analysis since the individual- level is too time consuming, Fallon-Byrne & Harney (2017) and Kurtmollaiev (2020) suggest that the focus on the individual-level helps to eliminate the somewhat ambiguity of the framework. The authors assert that the view on firm-level and senior-level employees of an organization alone is not accurate as the dynamic capabilities framework focusses on human behaviour and motivations such as routines, path dependencies and organisational learning.

According to the authors, the outcomes at the organizational level can be better explained by the activities at the micro level, i.e., the agency or, individual level. Supporters of the multi-level study of dynamic capabilities on the other hand view the individual as part of an ecosystem and argue that they should be analyzed within the context of a larger system to understand the systemic dynamics that affect the micro and macro levels and their interdependencies (Paukku et al., 2010).

They suggest that the environment within which the individual operates influences their innovative capabilities, i.e., their capabilities in sensing changes in the environment, seizing the available opportunities and transforming the opportunities into innovative ideas. Thus they view the individual-level dynamic capabilities as being entrepreneurial in nature. Mudalige et.al. (2019), also proponents of the multi-level approach to dynamic capabilities refer to individual-level dynamic capabilities as “Owner Specific Dynamic Capabilities (OSDC)”. They suggest the importance of an individual being able to sense entrepreneurial opportunities (EO) within their network, thus the importance of having a strong and big social capital (SC) in which the entrepreneur can sense and seize the EOs and lastly the significance of a good and strong human capital (HC), mainly the previous experience, which is important in transforming.

While Sen’s capability approach centers more on the individual-level capabilities, Teece’s dynamic capabilities framework focuses on firm-level capabilities. Although both approaches focus on building capabilities, they are based on different theoretical backgrounds, have different perspectives, and serve different purposes. Sen’s capabilities approach which stems from welfare economic theories is used to understand different phenomena especially in human development such as inequality and poverty alleviation (Paukku et al., 2010) whereas Teece’s dynamic capabilities stems from organizational economics theories and focuses on creating a competitive advantage in a rapidly changing environment. Both approaches are multi- dimensional in nature (Krishnakumar, 2014), however, the dynamic capabilities approach will be most applicable in understanding individual youth capabilities in developing digital innovations in a highly disruptive digital innovation space operating within an unpredictable environment. Sen capabilities approach will on the other hand be useful in understanding the kinds of choices that youth make and factors that influence their choice of digital innovation to develop, whether individual, social, or environmental. Generally, researchers have found that social variables such as peer support or pressure, shared values and mentors influenced the youth’s choices regarding the adoption of innovations and technologies, as is the case with Facebook (Mustaffa et.al., 2011). This is a significant point as adoption of new innovations and technologies is one of the significant capabilities in digital innovation (Nasiri et.al., 2020).

3 METHODOLOGY

3.1. Locational/Site of the Study

Kisumu and Nairobi Counties will be the locations of the study. The two cities have different contexts within which digital innovations are developed owing to

their population structure, ICT infrastructure, economic activities among others. Context is important in innovation since systems are different and so innovation processes are unique in different contexts (Chaminade, Lundvall, & Haneef, 2018). A comparison of data collected from the two cities will therefore shed light on the extent to which context affects youth-led digital innovation. Reports also indicate a need to expand digital innovations beyond Nairobi County to sufficiently address developmental needs in the country.

Kisumu, being an intermediary city that is expanding rapidly is a significant location of the proposed research having being elevated to City status in the year 2001. It is also strategically positioned as an East African economic and transport hub owing to the vibrant Kisumu International Airport and the newly renovated Kisumu Port at the Lake Victoria. The county is also part of the Lake Basin Economic Bloc, which leverages the economies of scale of the 13 member counties for economic development (Deloitte, 2014). In addition, Kisumu County is host to 3 universities, 5 university colleges, 1 medical training college (MTC), 1 National Polytechnic and several commercial private colleges (Council of Governors, 2017) as well as several public and private secondary schools that churn out approximately 130,656 youth to the labour force yearly (KNBS, 2019). Finally, its ICT policy development is also currently underway (County Government of Kisumu, 2021) making this an opportune time to conduct this study in the county. Nairobi City County, being the capital City of Kenya is home to approximately 97% of tech start-ups in Kenya (Disrupt Africa, 2022) with a total of 48 tech hubs, giving it prominence as among the top 15 tech cities in Africa (Giuliani & Ajadi, 2019). The ICT sector in Nairobi county is also well established as compared to other counties: It has an ICT policy (Nairobi City County Assembly, 2016), leads in access and usage of ICT devices and services (KNBS, 2010). These qualities, together with its high youth population joining the job market yearly, and the high number of higher education institutions make Nairobi City County a rich learning site.

3.2. Research Design

The proposed research will employ concurrent mixed methods research (CMMR) design and comparative case study design. The purpose for choosing mixed methods is to develop an in- depth understanding of the findings of this proposed research through qualitative and quantitative methods (Schoonenboom & Johnson, 2017). In addition, employing the CMMR design will help in assuring validity of findings through triangulation, where data collected qualitatively and quantitatively will be checked for similarity. The point of integration for the two methods in this proposed research will therefore be at the data analysis stage.

The case study design will be employed by comparing data collected from the two study locations, Kisumu and Nairobi with the aim of understanding the similarities and differences in the two contexts to promote replicability.

3.3. Population

The proposed research will target a population drawn from among six essential stakeholder groups as defined by ITU (2019) that are important in ensuring that the ICT centric innovation ecosystem runs well. These include entrepreneurs, public sector actors, financial actors, academics, private sector actors, and entrepreneurial support networks. The youth population will be drawn from among the entrepreneurial support networks (tech hubs) in addition to institutions of higher learning in the 2 counties, i.e., universities and TVET institutions.

3.4. Sampling Procedure and Sample Size

The proposed research will employ 2 sampling methods, i.e., purposive and simple random sampling.

Purposive sampling:

Purposive sampling method will be used to select participants who will provide expert knowledge and in depth information on the influence of the prevailing system dynamics on youth-led digital innovations, as well as provide recommendations for improvement. These will be drawn from among the leadership of the technology/innovation hubs or centers, representatives of county-level ICT departments, academics from ICT departments of select higher education institutions (HEI). Youth respondents agreeing to participate in focus group discussions will also be selected purposively.

The selection of technology/innovation hubs or centers will also be done purposively. These will be typically information-rich centers that record a high population of youth engaged in technology innovations and a good number of technology start-ups established through them.

Simple random sampling:

Once the technology/innovation hubs or centers are selected purposively, simple random sampling method will be applied to select youth participants 18-35 years from within the technology/innovation hubs or centers to ensure an equal chance. Clustering them within technology/innovation hubs or centers makes it more cost-

effective and easier to identify and reach them.

Sample Size:

The sample-to-item ratio will be used to determine the sample size. It is recommended that the ratio should not be less than 5:1 (Gorsuch, 1983; Hatcher, 1994; Suhr, 2006). Other recommended and commonly used ratios are 15:1 and 20:1. The sample-to-item ratio has been applied in several studies not limited to (Brown & Greene, 2006; Liao, So, & Lam, 2015; Forsberg & Rantala, 2020). For this particular proposed research, a ratio of 5:1 will be used to generate a sample of 190 respondents for a questionnaire with a total of 38 items or questions.

The sample size for key informants will be 15 participants while that of the 2 focus group discussions (1 in Kisumu and 1 in Nairobi) will be 10 participants each.

3.5. Instruments/Questionnaire/Interviews

The proposed research will employ 2 instruments – a semi-structured questionnaire and an interview guide. The semi-structured questionnaire will be used to explore the capabilities of youth to develop digital innovations while the interview guide will be used to get in-depth information regarding the topic. The semi-structured questionnaire will specifically assess the dynamic capabilities of youth, which according to IS literature, are the capabilities necessary for digital innovations. The semi-structured questionnaire will be divided into 2 main sections: Part A will be close-ended based on the measures of the individual level dynamic capabilities adopted from different scholars and reviewed to suit the context under research. The 15 independent variables will be ranked on a 5-point likert scale under the following sub-topics:

- 1) Entrepreneurial orientation (EO) scale developed by Bolton & Lane (2011)
- 2) Social Capital (SC) developed by Senik et al (2010)
- 3) Human Capital (HC) scale developed by Cizewski-Mlinary (2003)

Part B that will consist of 16 open-ended questions that will be used to capture more detail on the topic.

An interview guide consisting of 7 questions will also be used to engage key informants in in-depth discussions on the system dynamics that influence youth-led digital innovations. A guide for focus group discussions will also be developed

3.6. Piloting/preliminary research

The pilot study will be conducted to ensure reliability and validity of the research instruments.

3.6.1 Reliability

Reliability of instruments will be conducted to ensure that the results are consistent when administered to different respondents at different times. Reliability test will be checked for consistency (Cronbach's Alpha reliability) and stability (test-retest).

3.6.2. Validity

The validity of the instruments used will be assured by conducting content validity, where the questions will be checked for relevance, clarity and simplicity by experts in the field of ICT (Zohrabi, 2013).

3.7. Data Collection

Qualitative and quantitative data will be collected concurrently, in a single phase through the use of an interview guide and semi-structured questionnaires respectively. This means that the data collected from both methods will be independent of each other. Key informant interviews (KIIs) targeting county level policy makers, managers of innovation/tech hubs and academics will be conducted using an interview guide through face-to-face interviews while the semi-structured questionnaires will be administered to youth selected from the tech hubs through a survey via google forms. Consenting survey respondents will also be invited for focus group discussions to probe their responses further. Secondary data will be gathered from studies published in journals and other relevant reports. Data quality checks will be conducted at the end of the day.

3.8. Data Analysis

In this proposed research, qualitative and quantitative data will be analysed independently however, the inferences drawn from both data will be integrated into meta-inferences (Schoonenboom, 2022). Descriptive statistics will be used to organize and summarize both qualitative and quantitative data while multiple linear regression analysis will be used to draw inferences to the quantitative data and validated using analysis of variance. Content analysis will be used to draw inferences to the qualitative data.

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Notes

¹ The 4IR is defined as a “Revolution that is blurring the lines between the physical, the digital, and the biological worlds. Massive advances in artificial intelligence (AI), Internet of Things (IoT), robotics, 3D printing, quantum computing, genetic engineering, and various other technologies (Schwab, 2016)

The Decision to Import Material Inputs: Firm level evidence from Uganda

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Abstract

The aim of this study was to investigate the determinants of imports of material inputs by Ugandan manufacturing firms. The study built on previous studies by including learning variables, productivity, factor intensity variables and the specific characteristics of the individual firm that are associated with fixed costs of importing material inputs, in one integrative model to investigate the determinants of imports of material inputs using to bit and probit estimation procedures. The econometric results showed that capital labour ratio, foreign ownership, being a chemical firm, being a textile firm, being a plastic firm, being a paper firm, being a printing and publishing firm, being a construction firm and import experience were consistently associated with the propensity to import material inputs. Several policy implications arise from these findings.

Key words: Import, material inputs and manufacturing firms

1.0 Introduction

This study investigated the determinants of imports of material inputs by Ugandan manufacturing firms. World trade in material inputs represents nearly 50% of overall trade flows in goods (Markusen, 1989). Hummels et al. (2001) and Yeats (2001) show that international trade has grown faster in components than in final goods. Theory and evidence suggests a number of channels through which the use of foreign inputs could contribute to firm performance. Foreign technology embodied in imported relative to domestic material inputs allows firms to become more competitive (Kasahara, 2007; Goldberg et al., 2009; and Bas and Berthou, 2012). There is also empirical evidence of a positive relationship between imported inputs and firm productivity (see Bernard et al. 2005, Elliot et al. 2019; Schor, 2004; Broda and Weinstein, 2006; Amiti and Konings, 2007; Kasahara and Rodrigue, 2008; Topalova and Khandelwal, 2011; Halpern et al., 2015; Edwards et al., 2018; and Bas 2009). Interestingly, although the availability of firm-level data has led to a great deal of studies of export behavior (as surveyed by Bernard et al. 2007; Mayer and Ottaviano 2007; Niringiye and Tuyiragize 2007), much less effort has been spent on understanding import behavior in African manufacturing firms.

The existing literature on firm-level imports shows that access to foreign intermediate material inputs (or semi-finished goods) improves firm performance via variety, quality and learning effects. Specifically, the use of imported inputs raises firm productivity (Amiti and Konings, 2007; Augier et al., 2013; Halpern et al., 2005; Kasahara and Rodrigue, 2008), increases the introduction of new products for both domestic markets (Colantonea and Crino, 2014; Goldberg et al., 2010) and increases the probability of exporting and the range of countries exported to (Aristei et al., 2013; Bas, 2012; Bas and Strauss-Kahn, 2014; Fugazza and McLaren, 2014). Imported inputs may allow firms to upgrade product quality, due to the introduction of more sophisticated inputs in the production process (Puga and Trefler, 2010), but could also allow firms to introduce higher quality goods for the export market (see Kugler and Verhoogen, 2009 and Fan et al., 2015). According to Smeets and Warzynski (2010) and Bas and Strauss-Kahn (2011), developing countries are able to profit more than developed countries from the benefits of importing intermediate inputs, which they cannot always produce due to the existence of supply side restrictions. Recent empirical evidence suggests that the use of foreign material inputs may be important for the growth and development of both firms and the wider economy (Amiti and Konings 2007; Bernard et al. 2007; Seker 2012; Vogel and Wagner 2010). This could be because imported inputs are of

higher quality due to embedded foreign technology, and certain other foreign or domestic inputs may be imperfect substitutes (Halpern et al. 2009; Gibson and Graciano 2011). On the other hand importation of material inputs may lead to loss of domestic input suppliers and potential linkages (Halpern et al, 2015). This is more likely in situations where the material inputs could be sourced locally.

Firms are increasingly outsourcing and offshoring in order to achieve lower costs and higher quality inputs and, therefore, improve their competitiveness (OECD, 2010). One of the benefits of imports of material inputs in a low-income context such as Uganda is to obtain access to higher technology and/or higher quality inputs. Part of the reason why this has been important to exporters is that in order for goods to succeed on the export market, these goods need to be of high quality. Evidence has been documented that most of the firms that export also engage in importing activities. Empirical analyses have found that these two-way traders are larger, more productive, more capital- and skill-intensive than firms that only export or only import and those that do not trade (Amin et al, 2014; Edwards et al, 2018; Koren and Szeidl, 2015; Aristei et al., 2013; Seker, 2012; Bernard et al., 2005, 2007; Kasahara and Rodrigue, 2008; Muuls and Pisu, 2009).

Liyun (2014), Edwards et al (2018) and Manova and Zhang (2012) show that importing raises exports, especially if inputs are sourced from advanced economies. Similarly, access to lower cost imported inputs has been shown to boost export revenue (Bas and Strauss-Kahn, 2014; Feng et al., 2016; Edwards et al., 2018). Using Belgium firm-level data, Muuls and Pisu (2009) show a positive and significant coefficient of lagged import status, indicating previous experience in importing inputs raises the probability of exporting in the current period. In contrast, Elliot et al (2019) show that previous export experience is found to reduce the likelihood to import. Many of the existing studies on the determinants of import behaviour of manufacturing firms were conducted in developed countries and focus on determinants of intra trade in multinational companies. The few studies in Sub Saharan studies also focus on the relationship between material inputs imports and firm performance (see Edwards et al, 2018). Given the predominant role of materials inputs in international trade and its impact on productivity and competitiveness of firms, the study of the determinants of firms' import decisions or characterization of firms' importing behavior is crucial.

Uganda has used several trade policy measures towards strengthening the competitiveness of the domestic economy (Jaimovich and Kamuganga, 2010). The key hallmark of the trade reform process has been reduction and harmonization of tariffs, removal of quantitative trade barriers and acceding to trade liberalizing agreements (Gaalya, 2015). In addition to the COMESA trade agreement in 1985 and EAC trade agreement in 2001, Uganda acceded to the WTO

agreement in 1995 and other bilateral and unilateral liberalization arrangements(Gaalya,2015). East African Community (EAC) partner states adopted a three-tiered duty structure for imports from outside the East Africa Customs Union (EACU) under the terms of the Protocol on the establishment of the EAC Customs Union, which became fully operational in 2010.

Most finished products are subject to a 25 percent duty, while intermediate products face a 10 percent levy. Raw materials (excluding food stuffs) enter the country duty free. Tariffs on raw materials were completely abolished to encourage manufacturing within the country to supply the domestic and international markets (Gaalya, 2015). The Uganda Industrial policy which is currently under review encourage the use of locally available raw materials in value adding industrial processes to enhance market opportunities for supplying sectors. The Uganda content policy is still under formulation.

Globalization has led to a steady increase volume of imports for the last two decades. In Uganda, the overall imports bill rose from US\$ 4,730.8 in 2010 to US\$ 5,592 million in 2015 and 6,789 million in 2018. Table 1 show that the Asian continent remained the leading source of Uganda's imports from 2011 to 2018. Its imports share stood at 45.4 percent in 2011, and then rose to 53.2percent in 2015 and declined to 43.7percent in 2018. Uganda's main trading partners in the Asian continent were India, China, Japan and Indonesia whose market shares were estimated at 12 percent, 17.4 percent, 4.7 percent and 3.1 percent in 2018 respectively. The African continent ranked second with an import bill increased from US \$ 1,144 million in 2014 to US\$ 1,444 million in 2018. The main African trading partners included Kenya with a market share of 8.0 percent, followed by South Africa (4.6 percent) and Tanzania (3.9 percent) in 2018. The market share for the European Union bloc decreased from 12.6 percent in 2011 to 8.8 percent in 2018(see Table 1).

Table 1: Uganda's Imports percentage shares by region

Region	2011	2012	2013	2014	2015	2016	2017	2018
COMESA	14	12.4	11.9	12.7	13.1	12.4	11.3	11.3
Other African Countries	6.2	6.6	5.4	6.0	6.2	6.2	6.8	10
Asia	45.4	48.9	55.3	55.0	53.2	50.9	48.1	43.7
EU	12.6	10.7	11.7	10.3	11.4	11.3	9.3	8.8
Middle East	14.8	15.1	10.2	11..7	12.4	15.1	19.3	21.6
Other Countries	7	6.3	5.7	4.3	3.7	4.1	5.3	4.6
Total	100	100	100	100	100	100	100	100

Source: UBOS (2019)

Imports of material inputs by Uganda grew by 56 percent between 2011 and 2018 compared to a growth rate of 5 percent of other imported goods during the same period (see Table 2). Imports of raw materials and intermediate goods as a percentage of total imports increased from 4 percent and 24 percent in 2011 to 4.4% and 31.8% in 2018 respectively. This growing share of raw materials and intermediate goods in total imports is consistent with government trade policy that supports import of material inputs with the aim of encouraging manufacturing within the country to supply the domestic and international markets.

Table 2: Uganda's Imports of Raw and Intermediate Goods (Millions US\$)

Imports	2011	2012	2013	2014	2015	2016	2017	2018
Raw materials	224.1	75.5	116.3	251.3	215.0	226.3	317.3	296.5
Intermediate goods	1334.8	1278.9	1320.7	1424.2	1434.4	1318.5	1493.1	2141.8
Total Imports	5630.9	6044.1	5817.5	6073.5	5528.1	4829.5	5595.9	6729.4

Source: World Bank, WITS

Around 38 percent of the manufacturing firms which are primarily formal with at least 5 employees in Uganda use imported material inputs (including direct and indirect imported material inputs) compared to an average of 69 % of the firms in Sub Saharan Africa(see Table3). In contrast, only 14 percent of the firms export (directly or indirectly) some or all of their final output compared to 11 percent of the firms in Sub Saharan Africa in 2014. The proportion of total domestic inputs that are used by manufacturing firms that are of foreign origin is 28 percent compared to 4 percent of total sales that are exported directly and indirectly. There is a significant amount of indirect importing with 59 percent of the firms using imported goods which they have not imported directly, but rather purchased from wholesalers or retailers in 2014. The proportion of firms importing and exporting in Uganda, Sub Saharan Africa and low income countries is shown in Table 3 below.

Table 3: Proportion of Firms Participating in Trade

	Small firms(1-19 employees)	Medium firms(20-99 employees)	Large firms (100+employees)	Uganda	Sub Saharan	Low Income countries
% of firms that use imported materials inputs	38.8	51.2	36.9	38	69	65.8
% of firms exporting	10.4	30.2	23.5	14.3	10.7	12.5
Average time of clearing imports from customs (days)	14.2	33.1	19	24.1	18.1	16.4

Source: Enterprise Survey (2014)

From a policy point of view, it is important to know what determines a firm's level of material imports. However, little is known about what determine the levels of firm imports of material inputs and what would be the appropriate policies to increase the levels of imports of material inputs? Important theoretical insights have been derived on crucial determinants of international trade transactions that are done internally to the firm (intra-firm trade) and those which are done outside the boundaries of the firm (outsourcing)(McLaren, 2000; Antràs 2003, 2005; Antràs and Helpman,2004 and Grossman and Helpman, 2005; Acemoglu et al. 2006; Feenstra and Spencer, 2005; Tomiura, 2005; and Corcos et al. 2012). While the theoretical literature has been expanding rapidly, it focuses on multinational firms and the empirical evidence on these dimensions has been more limited and mainly focuses on developed countries.

Studies on determinants of imports at firm level are still fairly limited compared to the number of studies on determinants of exports at firm level. The characteristics of importing firms tend to be similar to those in the exporting firms literature which is to say that importing firms are larger (generally larger than exporters), more productive and more capital-intensive than non-importing firms. Among a few empirical studies on firm importing behaviour, Tomiura (2005) shows how Japanese firms tend to outsource more of their activities overseas when their productivity is higher, when their products are more labor- intensive and when they are R&D-intensive. Defever and Toubal (2007) using data on French imports in 1999, show that the likelihood of sourcing from an independent

supplier is increasing in the final producer's total factor productivity. In addition, using French firm-level data, Corcos et al. (2012) showed that capital-intensive firms tend to source labor-intensive goods from labor-abundant countries and complex inputs are more likely to be produced within firm boundaries, particularly for capital-intensive firms.

Several empirical works also show evidence on a positive impact of firm productivity and capital intensity on its import decision (See Kasahara and Lapham, 2013; Bernard et al. 2005; Bas and Berthou 2012; and Bas 2009). In addition, importers have been shown to perform better in terms of sales, skilled and capital intensity than firms sourcing their goods from the domestic market (See Biscourp and Kramarz, 2007; Bernard et al., 2005 and Kasahara, 2007). In terms of productivity, a positive and significant productivity differential between importing and non-importing firms has been found by Halpern et al. (2005) and Andersson et al. (2008). Bas and Berthou (2012) also showed using Indian firm data that firms with a lower leverage and a higher liquidity have a higher probability of being an importer. Using the sample of manufacturing firms across 83 developing countries for which data are available, (Amin and Islam (2014) find that large firms imports as 44 percent of all material inputs, compared with 33 percent for small firms. Acemoglu et al. (2005) also show with data from U.K. industry that outsourcing is more likely when the producing industry is less technology intensive.

Studies that investigate the direction of causality between productivity and importing, include: Liyun(2014); Vogel and Wagner (2010); and Augier et al. (2013). Liyun(2014) show evidence of a bi-directional causal relationship between importing and productivity. Although importing firms tend to be more productive before entering the import market, once they start importing firms appear to experience significant productivity gains for up to two years following entry. Augier et al. (2013) study Spanish firms and find an insignificant productivity effect of switching to importing, although when firms both import and have a large share of skilled labour there is some evidence of a learning effect from the use of imported intermediates suggesting an absorptive capacity effect. Vogel and Wagner (2010) use German manufacturing firm data and find some evidence for self-selection of more productive firms into importing but no support for the learning effect of importing on productivity.

Central to our investigation, is whether more productive firms decide to import (self-selection hypothesis) or whether learning influences a firm's decision to import (learning-by-doing hypothesis). Both the learning by exporting and the self-selection hypotheses predict that importing firms ought to be more productive than non-importing firms. The self-selection hypothesis argues that firms that want

to start importing have to incur sunk costs which include the costs associated with the search for information on possible inputs (Andersson et al., 2008; Castellani et al., 2010). Additional fixed costs may include transport costs incurred by importers (Andersson et al., 2008; Kasahara and Lapham, 2013). The self-selection hypothesis assumes that relatively more productive firms may self-select into the import of material inputs because they expect the future returns to be greater than the entry costs (Clerides et al., 1998).

In contrast, the learning-by-doing hypothesis argues that it is the very act of engaging in export markets that firms learn to navigate often complex customs procedures and having to understand tax and trade credit regulations (Andersson et al., 2008; Castellani et al., 2010). Liyun (2014) has shown that past export experience has a significant effect on firms' decision to import. In addition, if market forces sort out unproductive firms, then older firms will tend to be more competitive in the world markets as a result of learning by doing (Roberts and Tybout, 1997).

This study is a contribution to this recent and growing strand of the literature by focusing on the Sub Saharan region using Ugandan manufacturing firm level data. Our main research questions are on the relationship between productivity (more productive firms self-select into import markets), learning by doing (whether learning increases the chances of a firm to enter into imports markets), firm size (whether large firms are more likely to import material inputs than small firms as predicted by self-selection models) and importing of material inputs by Uganda manufacturing firms. Little micro-evidence has been provided so far on the determinants of imports of material inputs at firm level in Sub Saharan Africa.

Do Sub Saharan African firms that are more productive, experienced in exporting and old more likely to import their material inputs from foreign markets? A firm-level data analysis is needed to answer this question, and no such analysis is available at this point in time. To the best of our knowledge, this is the first work that investigates the determinants of imports of material inputs in Sub Saharan Africa. Taking advantage of a RPED dataset that was collected by World Bank in 2013 that documented firm characteristics and imports of material inputs by Ugandan firms, this study aimed at identifying the determinants of the imports of material inputs at the firm level. We did this by building on existing models regarding determinants of level of imports by firms and tested the model empirically.

1.1 Statement of the problem

Given the important role of material inputs, there is a need to understand which factors determine their imports in African manufacturing firms. There are no studies to the best of our knowledge that show what determines the levels of imports of material inputs at firm level in the Sub Saharan Africa. Little is therefore known about the determinants of the level of imports of material inputs in African manufacturing firms. Many of the studies on the determinants of import behaviour of manufacturing firms in developed countries that currently exist focus on determinants of intra trade in multinational companies. Therefore, policy formulation in Sub Saharan Africa has been hampered by a lack of timely relevant empirical studies at firm level. The policy question that arises is: What determines a firm's level of imports of material inputs and the decision to import from different regions? The purpose of this study was therefore to investigate the factors that determine the level of imports of manufacturing firm's material inputs and those that influences importation of material inputs from different regions because importation of material inputs involves both fixed and variable costs that may depend on the distance from the source.

1.2 Objectives

The general motivation of the study was to investigate the determinants of imports of material inputs by Ugandan manufacturing firms. The specific objectives of the study are:

- To investigate the significant factors of the propensity to import material inputs among Uganda manufacturing firms.
- To identify the determinants that influences importation of material inputs from different regions.

1.3 Hypotheses

On the basis of the specific objectives of the study, the following null hypotheses were tested:

- Firms' productivity is positively related to importation of material inputs as predicted by self- selection models
- Past export and import experience, have a positive effect on firms' importation of material inputs as predicted by learning models.
- Large firms are more likely to import material inputs than small firms as predicted by self- selection models.

2. Theoretical Framework

The standard theoretical models of international trade such as the Ricardian, Heckscher-Ohlin-Samuelson (HOS) and specific factor models, suggests factor intensities and technical innovations as the standard determinants of trade structure. If the comparative advantage model is correct then firms producing commodities that make intensive use of the country's abundant factor should have a lower probability of being importers than firms using a scarce factor intensively. However, observed pattern of trade, even at the most disaggregated level, show significant intra-industry trade so that countries appear to export as well as import the same commodity. Moreover, countries with similar factor endowments trade more with each other than with countries which had very different factor endowments. The development of the so called new trade theory in the 1980s, by introducing economies of scale at the firm level and consumer preference for consumption of different varieties of the same commodity provided a theory of intra- industry trade (i.e. trade in differentiated products of the same industry) and also a motive for trade between countries with similar factor endowments.

A firm may choose to buy an input in the home country or in a foreign country. When it buys the input at home, it engages in domestic sourcing and when it buys it abroad, it engages in foreign outsourcing. To address issues that arise from the choice of foreign outsourcing versus domestic sourcing, we need a theoretical framework in which firms make endogenous organizational decisions.

The transaction costs theory of the firm initially explicated in Coase (1937) and later developed by Williamson (1985) and Grossman and Hart (1986), show that activities take place wherever transaction costs are minimized. Specifically, when transaction costs are high, internalizing the transaction within a hierarchy is the appropriate decision. Conversely, when transaction costs are low, buying the good or service on the market (domestic or international) is the preferred option.

The firm's decision about where to outsource has recently been formalized by the incomplete contract theory. For example, in the model by Grossman and Helpman (2005), producers of differentiated final goods must go outside the firm for material inputs. Search is costly and firms choose whether to conduct it in one national market or in outside markets. If a firm finds a potential partner with suitable expertise, the supplier must customize the input for the final producer's use with a relation-specific investment, governed by an incomplete contract. The contracting legal environment may vary across national markets. An improvement in the contracting possibilities in a country raises the relative profitability of outsourcing there, given the numbers of component producers in each country and the relative

wage. However, the model cannot be used to study the make-or-buy decision that is a central issue in the organization of a firm (Grossman and Helpman, 2005).

In this study, we adopted a fixed costs of importing framework that has become a common feature of international trade models following Melitz (2003). To explain why most manufacturing firms do not import any material inputs and why those that do are relatively large and productive, Melitz (2003), in widely cited work, develops a model with firm heterogeneity and fixed import costs. Fixed costs of importing include; search costs for foreign suppliers, inspection of goods, negotiation, contract formulation, learning customs procedures, greater informational asymmetries associated with imperfect monitoring of the purchased goods quality and cost of transferring the technology embedded into it (Altomonte and Bekes, 2009).

It is assumed that fixed costs of outsourcing increase in distance and are lower for countries with a common language and trade agreements (Antràs et al., 2017). Additional assumption include among others, that the firm's fixed cost substantially reduces if the firm has already had business experiences in foreign countries and reduces with quantity of yearly imports and are likely to be higher for more complex goods (Altomonte and Bekes, 2010). According to Melitz (2003) general equilibrium model there is substantial heterogeneity of firms within narrow industry borders in terms of productivity, firm size, factor use, foreign and domestic intermediate input use, and other plant-specific fixed costs, generating rich trade patterns, on the aggregate and the firm level alike.

The implication of firm heterogeneity and fixed import costs is that only the most productive firms self select into importing from international markets. Therefore, only the firms surpassing some threshold level of productivity can make positive profits in international markets. Self selection hypothesis builds on the observation that due to fixed costs of importing, only the firms above some productivity threshold could import their material inputs from the outside markets while low productivity firms limit themselves to sourcing from domestic markets (Dalgic et al., 2015). There is a vast empirical evidence supporting self selection mechanism of importing (Vogel and Wagner, 2010; Eriksson et al. 2009; Smeets and Warzynski, 2010; Kasahara and Rodrigue, 2008; and Altomonte and Bekes, 2010).

3. Methodology

Firm specific characteristics can be integrated into new trade theory in the production at the firm level. In cross-industry regressions, firm specific characteristics would just add an extra element to residual variance. In the model, fixed costs of importing determines which firms import material inputs implying

that all variables included in the model are proxies of fixed costs. Import activity of an individual firm is therefore influenced by a combination of productivity, learning variables, factor intensity variables and the specific characteristics of the individual firm that are associated with fixed costs of importing material inputs. The import activity M_{ij} of firm i in sector j will then be a function of total factor productivity, P_{ij} , learning variables, L_{ij} , factor intensity variables, F_{ij} , and other firm characteristics that capture a firm's ability to deal with fixed costs, C_{ij} .

$$M_{ij} = f(P_{ij}, L_{ij}, F_{ij}, C_{ij})$$

Total factor productivity were estimated using past period total factor productivity. The learning variables include firm age, export and import experience. The factor intensity variables that we analyzed are the standard ones suggested by new trade theory; they include human capital intensity, capital intensity and technical innovation. The inclusion of technical innovations reflects the technology gap theory of trade originally suggested by Posner (1961) and formalized by Krugman (1979) amongst others, together with the product theory of Hirsh (1965). Both these theories assign a crucial role to technological innovation in the structure of trade. There is now an established body of literature that points to the overwhelming importance of other firm characteristics that capture a firm's ability to deal with fixed costs such as firm size, ownership, and sector effects.

3.1 The Model

Our model rely partially on the assumption that the fixed cost of importing material inputs is higher than the fixed cost of sourcing from the domestic economy. We used total factor productivity, specific firm characteristics, learning variables and factor intensity variables as proxies for sunk costs following previous studies (Roberts and Tybout, 1997; Aiteken et al. 1997). This suggests a basic model of the form:

$$M_{ij} = a + \alpha P_{ij}(t-1) + \gamma L_{ij}(t-1) + \beta F_{ij} + \delta C_{ij} + \epsilon$$

where M_{ij} is the import propensity (i.e., share of imported inputs in total inputs) of firm i in sector j ; $P_{ij}(t-1)$ is the previous period total factor productivity, C_{ij} is the set of other control variables (ownership, firm size, sector dummies), L_{ij} is a vector of learning variables (export experience, import experience and age of the firm) and F_{ij} is a vector of factor intensity variables (human capital intensity, capital intensity, education of the manager). a is a constant, α , γ and β are vectors of parameter estimates, and ϵ is an error term.

3.2 Description of the Variables to be used in the Empirical Analysis

Dependent Variable

The dependent variable is the level of imports of inputs that was measured by the ratio of imported materials inputs to total materials used by a firm. The chosen specification of the dependent variable is preferable because it will help predict not only whether a firm imports but also how much.

Independent variables

Human capital or skill intensity. We included the ratio of white collar to total employees, which was used as a proxy for the measure of human capital intensity in a given firm following previous studies (Wood and Jordan, 2000, Niringiye and Tuyiragize, 2007). We expected a positive association between skill intensity and import participation since Uganda is endowed with relatively more unskilled labour compared with its trading partners.

Capital intensity. The ratio of capital to labour was used as a measure of capital intensity. Capital is defined as the replacement cost of existing machinery and other equipment used in the production process, multiplied by the degree of capacity utilization. Factor intensity data suggest that intermediate manufacturers are on average significantly more capital intensive than final goods (Markusen and Melvin, 1984). According to Antràs (2003), capital intensive goods are imported from countries that are relatively abundant in capital. In addition, capital-intensive firms can engage in foreign outsourcing because they can overcome high fixed entry costs for foreign outsourcing. The trade theory predicts that the coefficient on capital intensity is positively associated with import participation.

R&D. R&D intensity was used as a proxy for the technological innovation. R&D was measured by the amount of new machinery purchased in the last two years as a ratio of the value of capital stock. R&D intensity proxy has already been used for similar purposes (e.g. Acemoglu et al., 2005). The theory predicts that the coefficient on R&D intensity should be positive.

Total Factor Productivity. The Total Factor Productivity of firm was estimated as the residual (plus the constant) of a log-linearized three-factor Cobb-Douglas production function with labor, capital and material inputs as inputs. Since the fixed cost under foreign sourcing is higher than under domestic sourcing, only the most productive final good producer will be able to cover the fixed cost associated to foreign outsourcing. The likelihood of sourcing inputs from foreign source increases with the productivity of the firm. We expect firms' previous period productivity to be positively related to the decision to import material inputs as

predicted by self-selection models(see Antras and Helpman, 2003 and Tomiura, 2005).

Export and import experience: Past export and import experience has been found to have a highly significant effect on firms' decision to enter imports market of material inputs in previous studies (Liyun, 2014). Firms that have imported previously are more likely to import in the current period because they do not need to incur the sunk entry costs again for market research, foreign regulation, etc. Lagged export (including direct and indirect exports) and import (including direct and indirect imports) experience were included in the model to capture trade experience. The coefficient of the lagged dependent variable is interpreted as a measure of sunk costs. We used the actual number of years firms from when they started importing material inputs in Uganda until the time of the survey. We expected firms' past import experience, to have positive impact on the propensity to import by Ugandan manufacturing firms.

Education of the manager. We also included the education of the manager as a proxy for organizational resources. Managers with university degrees might be more likely to have contacts abroad, especially if they obtained their degrees outside their home countries, or might be willing to overcome bureaucratic barriers to importing. We categorized the education levels of the manager into three; graduates, those with vocational training and secondary and levels of education, and those with primary education and lower levels of education. We used the number of schooling years completed by the manager.

Ownership. A sizable body of research has focused on the role of multinationals and ownership more generally, in cross border trade. The structure of ownership may be important for the cost to access foreign markets. The importance of foreign ownership reflects the advantages of proprietary information(Berry, 1992). We used the foreign ownership ratio to capture these ownership effects.

Firm age. A firm's maturity may lead to stronger international linkages and greater international sourcing of material inputs. Firm age may capture the extent of a firm's learning experience (Graner and Isaksson,2002).Mature firms may have accumulated considerable knowledge stocks (Baldwin, 1998). On the other hand, core capabilities can become core rigidities or competence traps (Leonard-Barton, 1992). We included age and age squared in order to capture potential changes in the quality of the firm, as models of learning suggest (Javanovic, 1982; Hopenhayn, 1992). We used the actual ages of firms from when they started operating in Uganda until the time of the survey. We expected older firms to be more likely to import material inputs than young firms as predicted by productivity learning models.

Firm size. Larger sized firms are more able to afford large sunk cost, and thus more likely to enter the import market(see Antràs and Helpman, 2004; Grossman et al., 2005). The economies of production may benefit larger firms disproportionately. Scale may be important in overcoming such initial cost barriers as gathering information or uncertainty of a foreign market. For the descriptive statistics we categorized firms into three groups of firm sizes (that is, small if $5 < 50$ employees, medium if 50-100 employees, and large if 100+ employees)(see Niringiye,2014; World Bank, 2004, for similar categorization of firms).We expected to find a positive relationship between firm size and propensity to import material inputs.

Sector dummies. Import behaviour is likely to vary across sectors. Sector dummies were included to capture unobserved sector specific characteristics that might be correlated with firms import decision. For example, some products might be more difficult to transport than others, thus limiting import potential. We grouped firms and used dummy variables under the following sectors: agro-industry and food processing, textiles, garments and leather, wood products and furniture, metal work and machinery, chemicals and paints, others (including plastics, construction, and paper, printing and publishing). The agro-industry and food processing sector was used as our base category.

Access to credit. Studies show that credit constraints are a key factor to explain firms' decision to source their goods from foreign countries because importing foreign goods is costly and requires the use of internal or external financial resources (see Bas and Berthou, 2012). Only those firms that have enough internal or external liquidity to undertake the fixed investment costs of importing will be able to source their goods from abroad. Access to credit was proxied by leverage constraints and we expected leverage to be negatively associated with propensity to import from abroad as some previous studies have shown.

Computer connection. Computer network connection is crucial in facilitating search of materials inputs and communicating with suppliers. Computer network connection should be positively related with the likelihood of importing from abroad, since it reduces search costs and facilitates business-to-business matching. Business environment factors such as customs delays were not analyzed in this study because previous studies have shown weak support for business environment factors in affecting firm performance because they may be affecting all firms more or less equally and thus may not predict the variation between firms as far as propensity to export or import material inputs (Niringiye and Tuyiragize, 2007).

3.3 Estimation strategy

If the propensity to import of material inputs is used as an indication of import behaviour, it varies by definition between zero and one. As a result, OLS regression may not be the most suitable estimation procedure, as it can give estimates that imply predictions of the propensity to import outside the feasible range. Since the dependent variable is continuous but likely to be bounded between zero and one, we instead used a w estimation procedure for this analysis. The tobit model assumes that any variable that increases the probability of positive imports must also increase the average volume of imports of the importing firms. The tobit model incorporates the decision of whether or not to import and the level of imports relative to total material inputs in one model, that is, it imposes the same coefficients on the explanatory factors for the two decisions. The Tobit model assumes that the decision to import and the level of imports of inputs are made jointly and the factors affecting each decision are the same. The tobit model is also appropriate for censored data. In addition, we used a binary import/non import specification for probit regressions that is typical of the literature on firm specific effects on import activity. Furthermore, we established the determinants that influences the decision to import from different regions, ie, Africa, Europe, and Asia.

Although some questions from the RPED study ask for information pertaining earlier years, we are not convinced of the reliability of the data. Since we had only one year of observations, we neglected the panel dimension of the sample and did not estimate a fixed or random effect model. It could be argued that rational firms will always estimate their input needs taking into account their size for example. This could lead to reverse causality. Moreover, some unobserved effects, such as foreign network, can affect firms' size and also impact on the decision to import. Such unobserved heterogeneity is also a source of endogeneity. There is, for example, a potential endogeneity between the importing inputs decision and exporting experience, importing experience, capital intensity and average wage. The instrumental variables (IV) and general method of moments (GMM) estimators are traditionally applied to deal with endogeneity concerns of this type. There is no data on these variables dated t-3 and earlier that can be used as instruments in the first-differenced equations and first-differences of these same variables lagged once that can be used as additional instruments in the level equations. Previous studies have shown the difference to be marginal when control for potential endogeneity of some explanatory variables is undertaken and when there is no such control (see Graner and Isaksson, 2002). We used the STATA13 computer package in our analysis.

3.4 Data sources

Primary data was taken from Enterprise Survey of 378 manufacturing firms in Uganda in 2013(World Bank, 2014). The manufacturing firms are comprised of 118 food related firms, 54 textile and leather firms and 206 firms from other manufacturing sectors. There is a significant amount of indirect importing with 59 percent of the firms using imported goods which they have not imported directly, but rather purchased from wholesalers or retailers. Uganda Bureau of Statistics database was used as a sampling frame that consisted of formal manufacturing firms with 5 or more employees in the 2001/02 Census of Business Establishments (UBOS, 2002). A stratified random sample was drawn with geographic region, size and sector as the stratification dimensions. Size stratification was defined following the standardized definition for the Enterprise Surveys: small (5 to 19 employees), medium (20 to 99 employees), and large (more than 99 employees). Industry stratification was stratified into three manufacturing industry (food, textiles and garments, other manufacturing including chemicals, furniture, metals), Regional stratification for the Uganda ES was defined in six regions (city and the surrounding business area): Jinja, Kampala, Lira, Mbale, Mbarara, and Wakiso. The enterprise data include three weighting variables (wstrict, wmedian, wwweak) to solve for the stratification bias. The relevant sample included all firms that have complete data on all variables of our interest which include both importing and non-importing manufacturing firms. The survey collected information on firm's sales, imports, plant age, the first year of importing, countries of origin of imports, employment, and ownership, along with the experience, education and skills of workers among other details. The data is reliable and of reasonably good quality because it is collected by World Bank following the standard methodology that allows for better comparisons' across 148 countries. The data is reliable and of reasonably good quality because it goes through extensive quality assurance with discrete checks for validity and reliability.

3. DISCUSSION OF RESULTS

3.1 Descriptive Results

Summary statistics of major variables used in the study are presented in Table4. Table 4 provides the summary statistics of the dependent and the explanatory continuous variables. It reports the overall mean, standard deviations, and unit of measurement. A multivariate test for equality of means yielded a p value of 0.000 meaning that the results are significant. The standard deviations of most variables are larger than the means, indicating a wide spread around the means. The average level of education by the top manager of manufacturing firms in Uganda is vocational training. The average age of the manufacturing firms is 13.7 years, not

far from the median age of 14.9 years, implying that most of the firms are young. In addition, the average firm size is 71 employees. Importing of input materials as a percentage of firms total inputs was 29 percent of the manufacturing firms in Uganda which is comparable to the average of 37 percent across countries, with a low of 2 percent in Indonesia and 74 percent in Albania (Amin et al, 2014).

Table 4: Summary Statistics of all the Variables

Variable	All	Importers	Non Importers	Min	Max	Unit of Measurement
Ratio of imported material inputs	.29(.42)	.73(.34)	0	0	100	Ratio
Firm Size	71.1(267)	125.1(435)	36.3(142.3)	5	3500	No. of permanent workers
Micro firms(<10 workers)	41	7	34			% age
Small size firms (10-49 workers)	40	18	22			% age
Medium firms (50-99 workers)	8	5	3			% age
Large firms (100+ workers)	11	7	5			% age
Firm Age	13.7(14.9)	16.2(16.7)	12.1(13.4)	1	93	Years
Export Experience	1.1(4.2)	1.3(4.5)	0.9(4.0)	0	40	Years
R&D	0.9(0.2)	0.10(.24)	0.08(.22)	0	1.48	Ratio
Education of the manager	12.9(4.0)	13.7(4.6)	12.1(13.4)	0	18	Years of Education
Managers with education University level	38	8	30			% age
Managers with education equal secondary and vocational level	52	13	39			% age
Managers with education equal and below primary level	10	5	5			% age

Skill Intensity	.64(.34)	.65(.32)	.64(.36)	0	100	Ratio
Capital Labor ratio	6.5(1.0)	6.9(.86)	6.2(1.0)	2.47	8.76	Log
Total factor Productivity	7.9(1.1)	8.4(1.1)	6.2(1.0)	5.58	11.03	Log
Foreign ownership	18.2(37.4)	34.1(45.9)	8.2(26.7)	0	100	% age
Foreign-ownership (=>50%)	18	14	4			% age
Foreign owned ship (<50%)	82	25	57			% age
Import experience	1.8(5.2)	4.6(7.5)	0(0)	0	40	Years
Sector						
Agriculture sector	42	13	29			% age
Chemicals sector	6	5	1			% age
Textiles sector	5	4	1			% age
Metals sector	7	1	6			% age
Furniture sector	17	2	15			% age
Other sectors	22	12	10			% age
Observations	241	94	147			No of firms
Share of total	100%	39%	61%			% age

Notes. Reported are the means of variables with standard deviations in parentheses and number of firms. Source: Author's own calculation from Investment Climate Survey data, 2014

Table 4 represents the proportion of importers of materials inputs by sector, size and ownership, education level of the top manager, export experience, and number of the firms. The number of materials inputs importing firms was used to measure the propensity to import materials inputs with respect to different firm characteristics.

All the firms can be classified into one of five sectors, with 42 percent of the firms in the agricultural sector, 17 percent of the firms in the furniture and wood sector, 6 percent of the firms in the chemical and paints sector, 5 percent of the firms in the textile and leather sector, 7 percent of the firms in the metals sector and 22 percent of the firms under other sectors (plastics; construction; and paper, printing and publication).

The proportion of firms using foreign inputs was 39 percent compared to the lowest in the world of 5 percent (Indonesia) and a highest of 100 percent (Samoa) (Amin et al, 2014). From the descriptive results, foreign ownership seems to be an important factor in determining the propensity to import materials inputs: 77% of

firms with some high percentage of foreign owned firms are importers compared with only 30% of firms with high percentage of domestic ownership. The education of the manager seem to matter but not as predicted by existing empirical literature; for example, 50% of the firms have a manager with primary education import material inputs, compared to 25% and 21% of firms with managers with secondary and vocational education, and University education respectively.

Sector effects seem to be significant in some sectors; for example, the chemical sector, textile sector and other sector(plastic; construction; and paper, printing and publication), have over 55% of their firms importing material inputs compared to less than 30% in agriculture sector, metals sector and furniture and woods sector (see Table 4). The size of the firm – more especially being large – appears to be important as has been shown in previous studies: 64% of large firms are importers of materials inputs compared with 63%, 45% and 17% of medium, small and micro firms, respectively (Table 4). This finding is comparable to a study that used the sample of manufacturing firms across 83 developing countries for which data are available, that found that large firms imports as 44 percent of all material inputs, compared with 33 percent for small firms(Amin et al., 2014). We proceed next by analyzing these mechanisms using econometric methods.

3.2 Regression Results

Table 6 presents marginal effects of variables that determine the propensity to import material inputs among Uganda manufacturing firms. A step-wise regression analysis was used on a sample of firms, adding one more explanatory variable to the model to identify the primary determinants of imports of material inputs. The inclusion of control variables does not change the sign and statistical significance of the significant variables (see Table 5).

The model is correctly specified, as indicated by the p-values. To facilitate interpretation, we report marginal effects for continuous variables (capital labour ratio, firm size, firm age, import experience,

export experience, education of the manager, export experience, R&D, skill intensity, total factor productivity, foreign ownership) and for sectors, ICT usage, access to credit dummy variables, the discrete change in estimated propensities to import material inputs as the dummy changes from 0 to 1. The direction of causality may go both ways for some of the determinants of propensity to import material inputs. The estimated marginal effects, for this reason, should be interpreted as the nature of association, rather than causation, between the determinants and import of material inputs.

Table 5: Determinants of import of material inputs: Tobit estimates for equations 1-9 dependent variable; Import of Material inputs ratio

Variable	1	2	3	4	5	6	7	8	9
Constant	-1.462 (-2.7)***	-1.642 (-2.7)***	-1.378 (-2.5)**	-1.317 (-2.9)***	-1.315 (-3.0)***	-1.461 (-2.5)**	-1.340 (-3.1)***	-1.336 (-3.1)***	-1.165 (-2.7)***
Capital Labor ratio	0.154 (2.4)**	0.152 (2.1)**	0.159 (2.5)**	0.145 (2.1)**	0.153 (2.4)**	0.130 (2.0)**	0.158 (2.5)**	0.165 (2.6)***	0.171 (2.6)**
Foreign ownership	0.003 (2.3)**	.003 (2.0)**	0.002 (1.7)*	0.003 (2.4)**	0.003 (3.0)***	0.003 (1.8)*	0.004 (3.2)***	0.004 (2.5)**	0.004 (2.5)***
Import experience	0.033 (3.2)***	0.040 (3.5)***	0.031 (3.1)***	0.036 (3.4)***	0.033 (3.4)***	0.0314 (3.1)***	0.038 (3.6)***	0.032 (3.3)***	0.033 (3.4)***
Furniture sector		-0.608 (-2.4)**	-0.483 (-2.5)**	-0.527 (-2.3)**	-0.506 (-2.4)**	-0.643 (-2.8)***	-0.519 (-2.5)**	-0.506 (-2.4)**	-0.494 (-2.3)**
Metals sector		-0.306 (-1.1)	-0.274 (-1.0)	-0.306 (-1.1)	-0.303 (-1.1)	-0.308 (-1.2)	-0.345 (-1.3)	-0.389 (-1.2)	-0.239 (-0.9)
Chemicals sector		0.513 (2.3)**	0.548 (2.5)**	0.485 (2.2)**	0.494 (2.3)**	0.495 (2.3)**	0.446 (2.1)**	0.466 (2.1)**	0.345 (2.5)**
Textiles sector		0.606 (2.5)**	0.439 (1.9)*	0.466 (1.9)*	0.410 (1.8)*	0.406 (1.8)*	0.599 (1.7)*	0.437 (1.9)*	0.488 (2.1)**
Other sectors		0.412 (2.7)***	0.379 (2.7)***	0.355 (2.5)**	0.348 (2.5)**	0.340 (2.5)**	0.335 (2.4)**	0.339 (2.5)**	0.415 (2.9)***
Firm size	.0002(1.5)	0.0003 (1.7)*	0.0002 (1.4)						
Skill Intensity	.0004(0.4)	.0006(0.6)		.0003(.15)					
Firm age	0.001(0.2)	0.001(.3)			.0002(.05)				
Total factor productivity	0.06 (0.8)	0.083 (1.1)				0.040 (0.6)			
Export experience	-0.024 (-1.5)	-0.026 (-1.7)*					-0.021 (-1.4)		
Access to credit		-0.243 (-1.5)						-0.177 (-1.2)	
Education of the manager		-.030 (-1.9)*							-0.024 (-1.6)
R&D		0.148(0.4)							
ICT usage		.003(0.7)							
log	-158.6	-151.33	-168.0	-161.1	-166.9	-162.3	-165.9	-166.2	-165.6

likelihood									
Pseudo R ²	0.20	0.25	0.20	0.20	0.20	0.21	0.20	0.20	0.21
No.of observations	236	236	236	236	236	236	236	236	236

Note: Reported values are marginal effects and the values in parentheses are the t-statistics. ***, ** and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Capital labour ratio, foreign ownership, import experience, being a chemical firm, being a textile firms, being a plastics firm, being a construction firm and being a paper, printing and publishing firm, were found to be consistently associated with the propensity to import material inputs. Other factors found to be associated with propensity to import include total factor productivity and firm size although the association was weak. Skill intensity, firm age, R&D, ICT usage, and access to credit were shown not to be significantly associated with the propensity to import material inputs.

The estimated positive and significant marginal effects of log capital-labour ratio across all specifications suggest that the marginal effect of importing material inputs increases with the capital intensity. This finding of positive association between capital intensity and propensity to import material inputs confirms our expectation and this may suggest that capital-intensive firms can engage in foreign outsourcing because they can overcome high fixed entry costs for foreign outsourcing. This finding is consistent empirical works which also show evidence on a positive impact of firm capital intensity on its import decision (see Kasahara and Lapham, 2013; Bernard et al., 2005; Bas and Berthou, 2012; and Bas, 2009).

As expected, the import experience coefficient is positive and significant across all specifications. Past import experience has also been found to have a highly significant effect on firms' decision to enter imports market of material inputs in previous studies (Liyun, 2014; Elliot et al., 2019). Firms with import experience are more likely to import in the current period because they do not need to incur the sunk entry costs again for market research, foreign regulation, etc.

Foreign ownership was found to play a significant role in the decision to import across all specifications: foreign owned manufacturing firms are about .2 percent to .4 percent more likely to import material inputs than domestically owned manufacturing firms. This finding is in line with the existing literature and is explained by foreign owned firms being able to make use of their foreign networks to enter the imports market, have more extensive know-how about foreign goods, and may face lower transactions costs (Berry, 1992; Elliot et al., 2019; and Tomiura, 2005).

Total factor productivity (TFP) has the expected positive effect on the propensity to import, but the coefficient is rather insignificant. Several empirical works show evidence on a positive impact of firm productivity on its import decision (See Kasahara and Lapham, 2013; Bernard et al., 2005; Bas and Berthou, 2012; Antras and Helpman, 2003; Seker, 2012 and Bas, 2009). The self-selection hypothesis assumes that relatively more productive may self-select into the import of material market because they expect the future returns to be greater than the entry costs (Clerides et al., 1998).

Access to credit was shown to be negatively associated with propensity to import from abroad as some previous studies (see Bas and Berthou, 2012) have shown although the association was not statistically significant. This may suggest that past firm borrowing or indebtedness adversely affects present import of material inputs if such borrowing increases the probability of bankruptcy.

Firm size is shown to be positively associated with propensity to import materials inputs but the association is weak as firm size loses its significance under different model specifications. This result was not surprising since the high fixed costs of importing make it difficult for small firms to enter import of material inputs markets. This finding is consistent with that of Elliot et al. (2019) that show sunk costs of importing are considerably smaller than those of exporting. Our result thus supports the existing theory of sunk costs of entering into the import of material inputs market.

The results also show that importing material inputs is most likely in textile firms, chemical firms, plastics firms, construction firms and paper, printing and publication firms and less likely in furniture firms, all factors held constant. Quantitatively, the effects are large. This finding is consistent with existing evidence (Andersson et al., 2008; and Kasahara and Lapham, 2013) that show that firms with lower transportation costs are more likely to import material inputs than firms with higher transportation costs. The less orientation of firms in furniture than in other manufacturing sectors seems more likely a result of transport costs thus limiting import potential and more likelihood of using local inputs compared to firms in chemical sector, plastics sector, paper, printing and publishing sector.

Firm age has a positive but insignificant effect on the import of material inputs decision suggesting that on average younger and older firms have equal propensities to import material inputs. This finding provides no evidence for the theory predicting that older firms are more efficient than younger ones as a result of a self-selection process taking place.

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Skill intensity was shown to be insignificantly associated with the propensity to import material inputs. This finding is consistent with Vogel and Wagner (2010) who used German manufacturing firm data and found some evidence for self-selection of more productive firms into importing but no support for the learning effect of importing on productivity. A large share of skilled labour would be expected to lead to a learning effect or absorptive capacity effect from the use of imported material inputs but this is not reflected in Ugandan manufacturing firms data set.

The finding of a negative effect of export experience on firms' decision to import although the significance is rather weak, contradicts the results from the learning-from-importing literature (Liyun, 2014). This result may suggest that firms experiment with either importing or exporting and that one does not necessarily lead to the other at least initially. This finding is consistent with findings by Elliot et al. (2019) and Aristei et al. (2013) that also show that previous export experience is found to reduce the likelihood to import material inputs. The negative effect of export experience may be explained by the fact that exporting involves sunk-entry costs, search costs and adjustment costs which may make importing less likely as firms may not have sufficient funds to invest in importing immediately (Elliot et al., 2019). In addition, firms that have export experience would face a degree of uncertainty and information asymmetry and in order to keep good control of the risks they may delay their decision to import until they have gained more international experience (Alessie et al., 2004). Another explanation is that the learning-from-exporting effect takes time and depends on their absorptive capability of the manufacturing firms more especially those considered to be far from the technological frontier (Augier et al., 2013). The education of the manager coefficient was negative but weak. Although variables such as ICT usage and R&D variables exhibited the expected signs, the coefficients were insignificant. The education of the manager coefficient was also insignificant

To establish the determinants that influence the decision to import materials inputs or not, which is determined by the magnitude of sunk costs, we estimated an additional model as also a robustness check. We analyzed the factors explaining this decision using probit regression. The marginal effects from the probit regressions are presented in Table 6.

Table 6: Determinants of import of material inputs: Probit estimates for equations 1-7 dependent variable; Import of Material inputs dummy

Variable	1	2	3	4	5	6	7
Constant	-2.083 (2.4)**	-2.782 (2.3)**	-2.064(-2.7)***	-2.075 (-2.7)***	-2.395 (-2.2)**	-2.072 (-2.7)***	-2.091 (2.8)**
Capital Labor ratio	0.278 (2.2)**	0.274 (2.1)**	0.280 (2.4)**	0.273 (2.3)**	0.226 (1.9)*	0.277 (2.3)**	0.282 (2.5)**
Foreign ownership	0.008 (2.3)**	0.008 (2.1)**	0.007 (2.1)**	0.008 (2.7)**	0.008 (2.3)**	0.009 (2.8)***	0.010 (2.9)***
Import experience	0.462 (4.2)***	0.449 (4.1)***	0.470 (4.2)***	0.470 (4.1)***	0.459 (4.0)***	0.466 (4.2)***	0.464 (4.2)***
Furniture sector		-0.693 (-1.6)	-0.432 (-1.3)	-0.441 (-1.3)	-0.616 (-1.6)	-0.522 (-1.5)	-0.505 (-1.5)
Metals sector		-1.19 (-1.8)*	-0.989 (-1.6)	-1.050 (-1.7)*	-1.003 (-1.7)*	-1.086 (-1.8)*	-1.093 (-1.8)*
Chemicals sector		0.430 (0.7)	0.501 (0.8)	0.473 (0.8)	0.471 (0.8)	0.334 (0.6)	0.326 (0.5)
Textiles sector		1.1 (2.2)**	1.001 (2.1)**	0.977 (2.1)**	0.960 (2.0)**	0.904 (1.9)*	1.025 (2.2)**
Other sectors		0.571 (2.0)**	0.692 (2.6)***	0.650 (2.5)*	0.665 (2.5)**	0.587 (2.2)**	0.622 (2.4)**
Education of the manager		-0.051 (-1.7)*	-0.055 (-1.8)*	-0.053 (-1.7)*	-0.055 (-1.9)*	-0.041 (-1.4)	-0.043 (-1.5)
Firm size	0.0005 (1.2)	0.0006 (1.3)	0.0004 (1.0)				
Firm age	0.004 (0.6)	0.002 (0.3)		0.007 (1.0)			
Total factor productivity	0.104 (0.8)	0.116 (0.8)			0.097 (0.8)		
Export experience	-0.082 (-1.2)	-0.106 (-1.4)				-0.061 (-1.1)	
Access to credit		-.421(1.3)					-.348(-1.2)
R&D		0.244(0.6)					
ICT usage		0.11(1.1)					
Skill Intensity	-.003(-.8)	-.002(-.5)					
log likelihood	94.8	88.1	96.1	96.7	93.7	95.8	96.0
Pseudo R ²	.39	.42	.39	.39	.40	.40	.40
No. of observations	235	235	235	235	235	235	235

Note: Reported values are marginal effects and the values in parentheses are the t-statistics. ***, ** and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Regarding the decision to import material inputs is concerned, capital labour ratio, import experience, and foreign ownership ratio, being a chemical firm, being a textile firm and belonging to other sectors(plastics; construction; and paper, printing and publication) are the only variables that are consistently shown to be statistically significant. Other variables were insignificant except the education level of the manager which showed a negative relationship with import of material inputs.

Import from different regions

We also explored the determinants that influence the decision to import materials inputs or not from different destinations. We identified three major import of material input sources: Africa (with 49 firms), Asian(central, middle east and other Asian countries)(37 firms) and Western world(West Europe, Canada and USA)(23 firms).Only 33 firms were importing from East Africa (Kenya and Tanzania) with 29 firms importing from Kenya only, 2 firms importing from Tanzania only and 2 firms importing from both Kenya and Tanzania. The average percent of value of imports of material inputs from Kenya and Tanzania was 46 percent for firms importing from Kenya and Tanzania.

Our regression results on the determinants that influence the decision to import materials inputs or not from different destinations are shown in Table 7. The variables that were positively associated with the decision to import materials inputs or not from Western world were import experience and total factor productivity. The variables that were positively associated with the decision to import materials inputs or not from East Africa and Africa region included foreign ownership, capital labor ratio, total factor productivity, and import experience. The variables that were positively associated with the decision to import materials inputs or not from Asia included skill intensity, total factor productivity, education level of the manager and import experience.

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Table 7: Determinants of import of materials inputs: Probit estimates;

Dependent variable: Import of Material inputs dummy

Variable	East Africa	Africa	Asia	Western World
Constant	-6.262(2.9)***	-12.380(-4.0)***	-10.243(-3.9)***	-7.696 (-3.5)***
Capital Labor ratio	.379(1.7)*	0.637(2.4)**	0.160(0.7)	0.240(1.0)
Foreign ownership	.010(2.5)**	.008(1.9)*	0.002(0.6)	0.008(0.2)
Import experience	.138(3.8)***	0.198(4.4)***	0.084(3.4)***	0.095(3.2)***
Metals sector	.388(0.5)	0.177(0.2)	0.252(0.03)	-
Chemicals sector	.487(1.0)	0.693(1.3)	0.871(1.6)	0.715(1.5)
Textiles sector	1.042(1.6)	0.983(1.3)	0.492(0.7)	0.444(0.8)
Other sectors	-.209(-.4)	0.234(0.5)	0.011(0.01)	0.367(-0.8)
Firm size	.0001(-.2)	-0.0004(-0.5)	0.0001(0.3)	0.0002(.04)
Skill Intensity	-.014(-2.3)**	-0.016(-2.3)**	0.116(1.8)*	0.0004(0.07)
Firm age	-.027(-1.9)*	0.019(-1.2)	0.002(0.15)	-0.010(-0.8)
Total factor productivity	.396(1.7)*	0.866(3.1)***	0.494(2.0)**	0.560(2.5)**
Export experience	-.040(-.6)	-0.055(-0.7)	-0.016(-0.4)	-0.106(-2.4)**

Access to credit	1.138(-2.1)**	-1.185(-2.2)**	-0.973(-2.1)**	0.222(0.58)
Education of the manager	-.018(-.4)	0.0145(0.25)	0.191(2.4)**	-.001(-.02)
R&D	-.098(-0.2)	0.574(0.9)	-0.361(-0.4)	-0.255(0.35)
ICT usage	.162(1.5)	.005(0.4)	-.006(-0.5)	-0.003(-0.2)
log likelihood	-39.2	-37.2	-41.5	-42.0
Pseudo R ²	0.49	0.57	0.43	0.35
No. of observations	178	178	178	178

Note: Reported values are marginal effects and the values in parentheses are the Z-statistics. ***, ** and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

4. CONCLUSION AND POLICY IMPLICATION

The aim of this study was to investigate the determinants of imports of material inputs by Ugandan manufacturing firms. The study was based on descriptive and econometric analysis. It was deemed necessary to identify the determinants of imports of materials, as the world trade in material inputs represents nearly 50% of overall trade flows in goods and their growth has been faster than in final goods. Given the predominant role of materials inputs in international trade and its impact on productivity and competitiveness of firms, the study of the determinants of firms' import decisions is crucial to understand the firm level trade patterns.

The tobit regression results showed that capital labour ratio, foreign ownership, being a chemical firm, being a textile firm, being a plastic firm, being a paper, printing and publishing firm, being a construction firm and import experience were consistently associated with the propensity to import material inputs. The other factor that was found to be associated with propensity to import was firm size although the association was weak. Most of the variables that were analyzed, such as firm age, skill intensity, total factor productivity, ICT usage, and R&D had the expected signs but the coefficients are not significantly different from zero. In general, the results are consistent with comparable studies except the education of the manager and export experience variables. Future studies could investigate the determinants of two-way traders that are known to be more productive than firms which do only export or import.

Several policy implications arise from these findings. First, the government should provide incentives for capital imports such as maintaining the current zero rating of capital imports and loan guarantee schemes to take full advantage of

international trade in imported inputs. Second, strategies aimed at attracting foreign direct investment, should be designed such as improving economic productivity through the provision of infrastructure, and labour force training. Fourth, strategies should be designed to grow small firms into large ones; measures could include loan guarantee schemes for small and medium firms, tax holidays for joint ventures and mergers, etc.

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Technological Content of Merchandise Exports : How are the Developing Countries Catching Up? With focus on India's Merchandise Exports

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Abstract

This study analyses the changing patterns in direction and composition of world merchandise exports in the years around global financial crisis (2005-2010) and the decade after that (2011-2019). The study pays particular attention to emerging patterns amongst developing nations. The study also analyses India's merchandise exports and the developments in this sphere, and place these developments in the context of changing global trade scenario. We find that world trade, and especially exports by developing nations, are moving towards trade in High Tech-High Skill commodities. The study also observes that such a transition has been heavily led by the rise of China as an economic superpower in the recent years. In case of India, the study observes that such a shift towards High Tech-High Skill exports has been led by the pharmaceutical sector, which has historically enjoyed trade and intellectual property rights protection. Based on these results, the study then critically analyses the theories on world trade and comparative advantage. The study attempts to draw attention to the fact that policy suggestions towards leveraging India's factor advantage in labour and relaxation of FDI norms must be approached with care, as the experience of growth in exports in the recent period shows that these policies do not entirely serve the long-term interests of the nation.

Keywords: World Trade, Exports in Merchandise, High-Tech Exports, Global Value Chains, Foreign Direct Investment

1 Introduction

In the years leading up to the global financial crisis, world trade was riding a wave of massive expansion in global economy. After the Asian financial crisis, global economy began to expand drastically from around 2003. This period was also characterized by large flows of financial resources (FDI, FPI, FCCB) into developing nations. Along with this, the easing of outsourcing rules in USA resulted in several services being exported by the developing countries. Combined with this, the increased consumption demand also led to a significant rise in merchandise exports. Together, this period caused the world trade to expand at an unprecedented rate of 16.5% between 2003 and 2008 (Nagaraj (2013)).

But the global financial crisis of 2008 created deep dents in world trade, with global exports plummeting in 2009. Although the growth in world trade was kept afloat in the two years that followed, primarily due to the fiscal and monetary expansions in response to the crisis by the world governments, the period after 2011 is characterized by severe slowdown in global exports. Ratio of global trade to output, after reaching a high of 30% in 2008, gradually declined to settle at 25% in 2020 (UNCTAD (2021)). This decline is not just due to the subdued demand during this period, but also due to sluggish growth in global financial flows, especially towards developing nations.

As a result of such a slowdown, merchandise trade, especially from developing nations, have taken a serious hit. The global merchandise export by ~60 major developing nations (excluding China), which stood at ~\$2.92 trillion in 2005, rapidly rose to ~\$3.71 trillion (rise of ~62%), in the span of just five years, in 2010. But the value of exports increased to just ~\$4.72 trillion (rise of ~27%) in the next nine years till 2019. But, interestingly, in the same period between 2010 and 2019, China's merchandise exports have increased from ~\$1.58 trillion to ~\$2.5 trillion (rise of ~58%). Rise of China into a global economic super-power has played a significant role in the changing patterns of global merchandise exports in the last decade. In case of India, the country's export scenario significantly benefited from the previous period of expanding global trade. India's merchandise export value increased from ~\$100 billion in 2005 to ~\$301 billion in 2011, a massive rise by ~200%. But post this period, merchandise export value reached only ~\$323 billion in 2019 (rise of ~7%)¹.

In this scenario, we try to understand the changing patterns in the world trade in merchandise goods between 2005-2010 period and 2010-2019 period. The study focuses less on the reasons behind the faster or slower pace of growth in global merchandise exports, but more on the changes in direction and composition of

merchandise exports, and the possible factors driving these changes, in the current scenario of slow growth in global merchandise exports. We also place India's exports, and the changes in its composition and direction, in this scenario. Based on the evidences, we try to conclude that the global merchandise trade, and especially exports from developing nations are increasingly moving towards the direction of manufacture of High Tech-High Skill commodities. We also observe that China has been playing a pivotal role in such a shift.

Studies arguing for a greater degree of openness in trade policy for developing countries have been gaining popularity since the onset of the neo-liberal process at the global stage (Krueger (1978)). Such studies, based on a neo-classical framework, often employ the understanding of Heckscher-Ohlin theory at their base. But several studies from developing countries critically view the implications from such a theoretical understanding. These studies point to the fact that Heckscher-Ohlin theory cannot be applied to developing nations due to the prevalence of market imperfections (Marjit & Raychaudhuri (2000), Bhattacharjee *et al.* (2004)). It is also argued that such an approach of export-orientation based pursuing of comparative advantage in developing countries, in the long run, can lower the capacity to export due to worsening terms of trade against the exports of labour intensive goods from these nations (Andreoni & Chang (2019)).

In case of India, the liberalisation policies of the early nineties brought along a series of policies aimed at "export-orientation". A marginally positive shift in the export pattern during the initial years of liberalisation era brought in immense support for such an approach (Virmani (2003)). Traditional theories based on leveraging labour factor advantages, increased integration into global value chains (GVCs) (Veeramani *et al.* (2017)), further relaxations in the flow of foreign investments, etc., were proposed as the way forward in enhancing India's position in the global trade network (Veeramani (2012)), often citing the example of East-Asian economies as the model to be emulated. But such theories often ignore the role of State intervention, and it is now widely recognized that the East Asian experience was a case of strong presence of the State in planning, building infrastructure and capabilities to successfully achieve the goals of industrialisation through export promotion (Amsden (1989)). But the "export-orientation" approach in India comes during the period of liberalisation, where the State is expected to play a minimal role, thereby restricting the transition towards a more desired structure of industries in India (Ghosh (2015)). Evidences of greater advantage to India due to the expanded presence of MNCs and foreign investment, on its export base, have also, at best, shown only a mixed picture (Aggarwal (2002), Joseph & Reddy (2009)). Dastidar (2015) reviews a large set of literature on the "export-orientation"

policy in India, and the myriad of complicated impacts it has created on the Indian economy.

In this background, based on the recent evidences, we critically analyse the policy suggestions based on the traditional theoretical understandings for India, and attempt to see if they fit the current scenario and serve India's strategic long-term interests. Based on the overall trends in growth of exports, and also by specifically analyzing industries which are leading this transition, we try to conclude that a mere "export-oriented" approach will only allow India's merchandise exports sector to become vulnerable to the volatility in global economic and trade situations. Therefore, we argue for an approach where the State continues to retain economic sovereignty through strategic trade restrictions, develop a planned process of industrialisation, develop local capacity and improve technological transfer from foreign investments.

2 Literature Review

Although several studies analyse the global trends on trade and exports, the study by Lall (1998) is considered to be one of the most seminal work. The paper analysed the changing patterns of merchandise trade among various regions of the globe based on the technological content of the exported commodities, and then attempts to provide explanations for such patterns.

Veeramani (2012), analysing the trends in India's exports, identifies that the second decade of liberalisation induced fresh dynamism to India's merchandise exports. The study also shows that India's exports have been becoming more skill-intensive, while the labour-intensive sectors have been less dynamic.

Anand *et al.* (2015) performs a more deeper analysis on the patterns of exports from India by including the analysis on quality and complexity of exports from India. The paper goes on to argue that for India to exploit further opportunities in exports and move up the value chain, she must further embrace greater openness in trade and foreign investment, and focus on infrastructure and skill development.

On the other hand, Chaudhuri (2013) studied the imports and exports of India during the liberalisation era, and concluded that the industries which were developed during the previous strong planning era helped reduce India's merchandise trade deficit, and the expanded presence of services sector in the liberalisation period, which comes along with an increased demand of new technology and equipment, has failed to incorporate dynamism in the manufacturing sector for improved production.

Chakravarty (2015) also performs a deep analysis of patterns of India's foreign trade and concludes that the India has mostly only followed the global patterns of trade, and ascribing the increased exports to the 'success' of liberalisation policies might be too hasty. The study also claims that the expanded exports in certain sectors were built on a fragile base, and is unlikely to be sustained.

The current study contributes to the existing literature by further extending the analysis on patterns of exports to the second decade of the twenty-first century. The study also contributes to the understanding of India's exports by specifically placing the Indian experience, in the larger context of changing patterns in the global merchandise trade.

3 Data and Methodology

The data for this study comes majorly from the UN Comtrade Database, which comprises of reported data on exports and imports in goods and services between all the countries at a very disaggregated level. For this study, we collect data on merchandise trade between world nations during the years 2005, 2010 and 2019 (for analysing India's exports, additionally trade in year 1996 was also taken into account). We collected data for a list of 107 countries (see Appendix Table A.1). These countries were chosen in such a way that these nations' exports constitute at least 98% of world merchandise trade in 2019, while also these countries constituting at least 98% for destinations of India's merchandise exports in 2019. This was done so as to simultaneously perform both the analysis on global and Indian merchandise exports. At a product level, Standard International Trade Classification (SITC) Revision 3 product classification by United Nations Statistical Division was followed². Trade data was collected at a 3-digit product classification level. This provides a total of 261 commodity classifications.

As mentioned earlier, the methodology of this study primarily draws from the work of Lall (1998). In this study we adopt the same classification of commodities based on technological content³. Such a classification and analysis is much more suited to assess the contemporary patterns of exports, as technology is beginning to assume the position of primary determinant in global manufacturing and trade. Along with this, for the case of manufactured goods, UNCTAD Trade Development Report (TDR) 2002 classifies commodities based on the degree and skill of manufacturing⁴. This classification has also been incorporated into the analysis. A new set of classification combining these two classifications has been created (see Appendix Table A.2), and is primarily used in this study to analyse composition of exports.

For the reporting countries, UNCTAD follows the M49 standards to classify nations into various regions and level of development⁵. Based on this, we adopted the classification of countries into various regions (Latin America, South-East Asia, etc.), and classification into Developed and Developing countries⁶. Of the 107 countries, 67 are classified as Developing, and the rest as Developed. Although China is classified under Developing countries, it has emerged as one of the most important center of global trade. Hence, throughout the analysis of this study, we treat China as a separate category, not clubbing it with other developing countries.

After these classifications, we then analyse the patterns in trade of commodities. For the case of both global exports and exports from India, we look at the changes in composition of exported commodities. We also look at the direction of exports for each region and centres of development. Then at a granular level, we also look at the changes in composition of exports from and between various centres of development. This allows us to understand the drivers of these changes. For the case of India's exports, apart from these analyses, we also perform a preliminary analysis of trends in composition and direction at a more granular stage of 3-digit product classification level. This allows us to deeply understand the nature of industries driving the changes in India's exports.

4 Trends in Global Merchandise Trade

In modern history, global merchandise exports has been dominated by a handful of nations. The concentration of trade among top nations is provided in Table 1. After sharp increase in concentration between 2005 and 2010, the situation appears to have eased between 2010 and 2019. But still, only 10% of the nations are responsible for more than 53% of the global merchandise exports.

Table 2 provides the share of global merchandise exports contributed by various regions of the world. During the period of boom in world trade, between 2005 and 2010, the share of exports by several regions comprising of developing nations like Central & South Asia, Latin America, South East Asia, etc., increased tremendously. But after 2010 it declined, settling for a lower share in 2019 (but higher than 2005). The share of Western nations dropped significantly between 2005 and 2010, but remained stable between 2010 and 2019. But the share of East Asia (comprising of China, Hong Kong, Japan, Korea, etc.), though dropping initially, increased to levels higher than in 2005.

This is also corroborated by Table 3, which shows the share of centers of development in exports. Developing countries other than China (hereafter, simply,

"developing countries"), after gaining a significant share of exports between 2005 and 2010, lost a portion of the share between 2010 and 2019. The inverse is true for developed nations. But one significant observation is that, China has consistently increased its share from 7.9% in 2005 to 13.9% in 2010 and 14.6% in 2019.

4.1 Direction of Global Merchandise Trade

Table 4 provides the share of global exports emanating from one center of development to another. Even in 2019, single largest share of world exports emerge and end within developed countries. But the share has considerably declined from 2005, with a marginal gain after 2010. Share of exports from developed to developing countries (excl. China) has marginally increased between 2005 to 2019, and from developed nations to China has been consistently increasing from 3% to 3.7% and 4.9% in 2005, 2010 and 2019 respectively.

The most notable trend is the change in exports from developing countries. During the period of boom in world trade, share of trade within developing countries sharply increased between 2005 and 2019 (7.6% to 13.4%). This was also the period hailed for massive rise in South-South trade. But this share in trade considerably fell to 9.1% in 2019. The trend is also similar for exports from developing countries to developed countries, albeit to a lesser extent.

But, interestingly, share of exports of developing countries to China consistently increased and even gained pace after 2010, rising from 2.6% in 2005 to 4.4% in 2019. The same is the case for exports from China to other developing countries, whose share increased from 3% in 2005 to 7.2% in 2019, while the share of its exports to developed countries has been fluctuating.

Therefore, this data on direction of trade points to the fact of strong gains in South-South trade between 2005 and 2019, and China emerging to play a central role in facilitating the same, especially after 2010.

4.2 Composition of Global Merchandise Trade

The changes in composition of exports presents a slightly more complex picture to analyse. Following earlier discussions, Table 5, and Table 6 presents the composition of exports for the world, as well as each center of development, across various technological content of the exports and degree and skill embodied in manufactured exports.

A primary takeaway from the world average is that between 2005 and 2010, Primary (Fuel) and Resource Based exports gained a significant share of global

merchandise exports at the expense of High and Medium skill exports. But this trend reversed after 2010, with High and Medium Skill gaining significant shares of global exports. In case of manufactured goods, we can clearly see High and Medium skill commodities gaining prominence. As a result, in the combined classification in Table 7, primary and resource based manufacturing commodities, which gained prominence between 2005 and 2010, have lost out to High Tech-High Skill (hereafter, HT-HS) and Low/Medium Tech-Low/Medium/High Skill (hereafter, LMT-LMHS) manufacturing exports after 2010. A part of this transition is led by the drop in international oil prices since 2014. But the fact that it is the HT-HS and LMT-LMHS sectors which have specifically gained in share during this decade points to the growing prominence of these commodities in global merchandise exports.

At a dis-aggregated level, the most important observation from Table 5 is the rapid shift in composition of exports by developing countries towards High Tech manufacturing commodities, and a significant drop in Primary (fuel) exports. International oil prices alone cannot account for such a transition. We explore for further reasons in the upcoming analyses. In terms of skill, too, Table 6 shows that High Skill manufacturing commodities' composition has significantly risen and is now the single major constituent of manufacturing exports from developing countries. Medium skill commodities' share is slow to rise. As a result, in Table 7, we see a significant rise in share of HT-HS manufacturing commodities, and a considerable rise in share of LMT-LMHS manufacturing commodities between 2005 and 2019, while the share of other commodities have fallen, especially after 2010.

China's export composition has remained more or less stable throughout the period of study, with non-resource based manufacturing constituting ~90% of the country's exports. We see a marginal trend of both medium skill and medium tech commodities gaining in share at the cost of labour intensive and low skill commodities. As a result, in Table 7, we see a prominent rise in share of LMT-LMHS manufacturing commodities, while the share of HT-HS manufacturing commodities have remained stable and consistently high.

To further understand these changes, we look at the share of each center of development in the global exports of each commodity category. Table 8 provides this data. This table reminds us that still majority of the manufacturing exports remain with Developed countries, although there is a major drop in share in many categories, compared to 2005.

In case of developing countries, between 2005 and 2010, the share of both resource based manufacturing and HT-HS manufacturing commodities

significantly increased. But post 2010, only HT-HS sector maintained its share, while the share of all other commodity categories declined. This shows that this is the only sector which grew keeping pace with global average after 2010. This is the reason behind significant rise in composition of HT-HS manufacturing commodities in developing countries' exports.

China also wrested a significant share of HT-HS exports away from developed countries between 2005 and 2010, which more or less remains consolidated in the next decade as well. But along with this, China has also been able to gain a significant share in exports of LMT- LMHS manufacturing commodities consistently, which is reflected in its export composition as well.

Overall, we clearly see a trend of shifting of export-based manufacturing of HT-HS manufacturing commodities away from developed countries towards China and other developing countries, while also observing a considerable shift in exports of LMT-LMHS manufacturing as well, especially towards China.

4.3 Commodities, Concentration and Destination of Developing Countries' Exports

After having established this trend of rising prominence of HT-HS & LMT-LMHS sectors in the developing world, we delve deeper to understand the drivers of this shift.

4.3.1 Commodities

Within developing countries' exports of HT-HS commodities, we look at the share of various individual commodities. Table 9 shows that the rise of HT-HS exports from the developing countries is led by the manufacture of Electrical machinery and appliances (e.g: Televisions). While the share of data processing machines (e.g.: Laptops, Computers) declined between 2005 and 2010, it bounced back in the following decade. Despite the boom in global exports of telecommunication equipment (e.g.: Mobile phones), the share of this industry in developing countries' HT-HS exports has only declined since 2005. A part of the rise of HT-HS exports is also contributed by increase in share of pharmaceutical industry, led by India (we shall discuss this in detail in later sections).

Although HT-HS exports have increased from developing countries, given that it is led by industries like electrical appliances and data processing machines, it is often argued that the complex processes in these commodities remains with developed nations and only the labour intensive processes in assembly of advanced components are performed in developing countries. While there are evidences to support this argument, this alone cannot explain such a

massive shift in composition of exports from developing countries. A detailed study of individual country's policies and initiatives for building domestic capacities, upgrading skill-level and technological capabilities needs to be studied in detail. Such an exercise is beyond the scope of this study.

4.3.2 Concentration

Table 10 shows the share of various geographical regions in the exports of HT-HS and LMT-LMHS manufacturing commodities from developing countries.

In case of HT-HS exports, we see a severe concentration of exports in the regions of SouthEast Asia and East Asia (East Asia comprises of only Hong Kong). Several countries in this region have historically held a prominent export-oriented policies towards the manufacture of these commodities, which has allowed them to gain significant leadership in the recent years (Hong Kong's huge share is contributed by its position as being a trading hub). The significant jump in exports from Middle East is due to emergence of UAE as an important trading hub. Exports from Latin America are primarily led by Mexico, whose share has only declined over the years.

In case of LMT-LMHS manufacturing, Latin America still holds a prominent position, led by the strong and diverse industrial bases built in Argentina and Brazil. But here too we see a dominant share lying with South East Asian nations, although there is a steady rise in share of South Asia, led by India's automobile exports (we shall discuss this in detail in later sections).

Table 11 also presents the details of top developing countries responsible for driving the transition of exports towards HT-HS manufacturing commodities. The most striking entrant is Viet Nam, whose share in global exports of HT-HS manufacturing commodities increased from a mere 0.3% in 2010 to 2.7% in 2019.

4.3.3 Destination

To understand the shifts in compositions better, we look at the destinations for these exports for HT-HS and LMT-LMHS manufacturing commodities. Table 12 shows the share of exports from each center of development reaching another destination center of development, for these commodity categories.

In case of HT-HS exports, the most significant takeaway from the table is the direction of exports from developing countries. The value share of exports from these countries reaching developed countries has consistently declined between 2005 and 2019. A part of this share has been gained by trade amongst

developing countries. But the share of exports going towards the single nation of China, has massively jumped by ~7 percentage points, from 22.8% in 2005 to 29.6% in 2019. This is also true for the case of exports from China. China's share of HT-HS exports to other developing countries increased consistently from 41.5% in 2005 to 49.8% in 2019.

In case of LMT-LMHS exports, the most important observation is again China's share of ex- ports to other developing countries increasing consistently, which should also be understood in consonance with a rise in share of Medium Tech-Medium Skill commodities in China's export composition. After a rise in share of developing countries' LMT-LMHS exports going to other developing countries between 2005 and 2010, the reliance on developed nations once again significantly increased in the decade that followed.

To emphasise the role of China in changing composition of developing countries' exports, we present the trade in HT-HS manufacturing commodities between the top developing countries responsible for driving the transition of exports towards HT-HS manufacturing commodities and China. Table 13 shows that both share of HT-HS exports from these countries reaching China, as well as share of China in the imports of these countries has only increased between 2005 and 2019. China features as the very top trading nation (in HT-HS manufacturing commodities) for all these countries.

4.4 Discussion on Trends in Global Merchandise Trade

Based on recent data and trends, we see a pattern of gaining prominence of HT-HS and LMT-LMHS manufacturing commodities in global exports. We also see that, while the share of developed and other developing countries have fluctuated between 2005 and 2019, China's share in global exports has increased consistently.

In terms of direction, we observed that the strong gains in South-South trade has been led by China emerging as a central player. In terms of composition, we clearly see that the exports of developing countries and China strongly shifting towards HT-HS manufacturing commodities, and China strongly gaining in exports of Medium Tech&Skill exports. The shift in export-based manufacturing of HT-HS and LMT-LMHS manufacturing commodities towards developing countries is taking place even as developed countries continue to doming the manufacturing exports scene.

We observed that China has emerged as the most player in facilitating the transition of developing countries' export composition towards HT-HS

commodities. China is playing a vital role by emerging both as a supplier and also a large-scale consumer of HT-HS commodities from developing countries.

Lall (1998), while analysing the trends in shifting composition of global trade, pointed to the "low technology" base of China's export structure in 1996. The study attributed it to the very low levels of industry-financed R&D in China, which is not suitable for "sustained upgrading". But since then, China's technology base and export structure have seen tremendous upgradation. China's R&D intensity has increased from 0.56% of GDP in 1996 to 2.14% of GDP in 2018⁷, and industry dominates R&D investment with more than 70% share. Since the turn of the century, China has been able to build domestic infrastructure and manufacturing capacities, while also gaining strong advantages in technological capabilities. Due to such a large scale and sustained transition, China has emerged to be capable of leading the changes in direction and composition of South-South trade.

5 Trends in India's Merchandise Exports

In this section, we attempt to analyse India's exports and the changes in its composition and direction, in the light of the developments in global merchandise exports.

Figure 1 presents the trend in India's export value over time. The breakpoints were estimated using the Bai-Perron breakpoints analysis method (Bai & Perron (1998)). We see that after a nominal growth between 1996 and 2003, India's merchandise exports started growing at a rapid pace of 18.4%, riding the global boom in trade. But the growth started stagnating after 2010. From 2011 to 2019, there is hardly any growth. The rate of growth of exports has declined to 0.2%. This points to the fact that India's export sector is heavily integrated to and dependent on the global trade scenario. A part of this decline in rate of growth is due to the significant drop in international oil prices (we shall discuss this in detail in the upcoming sections).

5.1 Direction of India's Merchandise Exports

Table 14 presents India's top exporting partners. USA continues to be the most important destination for India's merchandise exports. Although India's export share to China has considerably increased since 1996, comparatively, it has not grown at a faster rate. The most important entrant is UAE, which has emerged as one of the top destination for our exports, even overtaking USA for a brief period in 2010. India's strong links with its diaspora in UAE and the emergence of UAE as the trading hub in the Middle East are the probable

reasons.

Table 15 presents the region-wise share of India's export destinations. Although the Western world remains the top destination for India's merchandise exports, its relative importance has been continuously declining, albeit with a marginal gain in share after 2010. Share of exports to Central & South Asian neighbors, after stagnating for a long time, significantly increased after 2010. Although East and South East Asian partners enjoy a considerable share in exports, the share has only declined after 2010. But the most important observation which can be drawn from the table is the consistent and significant rise in share of exports reaching West Asia, North Africa and Sub-Saharan Africa. Especially the share of exports to Sub-Saharan Africa has more than doubled between 1996 and 2019. Share of exports to Latin America too, although low, has considerably risen over the years.

Hence, it is amply evident that India has been able to diversify its export destinations away from the Western countries, towards other regions of the world, during the era of Globalization.

5.2 Major Exporting Commodities

Table 16 shows the top commodities exported from India, and their share in total export value. The most apparent development is the extremely high gain in share of exports of refined petroleum products. From a mere 1.4% share in 1996, its share increased to 17% in 2010, and ~20% in 2013. But post-2014, due to the fall in prices of oil, its share has come down significantly to 13.2% in 2019. In terms of quantity, India's exports of Petroleum oils or bituminous minerals increased from 12 million tonnes in 2003 to 71 million tonnes in 2013. After the price crash in 2014, although the quantity came down to 64 million tonnes in 2016, it once again increased to 72 million tonnes 2019⁸. Hence, the significant drop in share of this commodity in India's exports is due to the reduction in unit price of exports, which declined from \$914 per ton in 2013 to \$419 in 2016 and \$587 in 2019.

The share of exports of Gems and Jewellery, which used to dominate India's exports, has reduced in the recent years, but still remains high. Other sectors like pharmaceuticals, chemicals and automobiles sectors, where India carefully built its advantage, have also seen a considerable increase in their shares in export value.

But the extreme reliance on a single commodity of refined petroleum exports have had major impact on India's export basket. Hirschman Herfindahl (HH)

Index, which is the sum of squared share of each commodity in the country's exports, measures the diversity in a country's export basket. Figure 2 plots this index for India, for 261 commodity categories (SITC Rev.3 3-digit level). After 2010, we see a sharp rise in the index until 2014, indicating concentration in exports. Only after the drop in oil prices in 2014, does the index come down. The plot also shows the HHI index without considering commodity-code 334, the 3-digit code for this product. We see a more or less steady decline in the index since the beginning of this century, indicating diversification. Hence, this one particular product is heavily responsible for the loss in diversity in India's merchandise exports.

Such a high level of dependence on one commodity, especially a resource based manufacturing commodity such as refined petroleum products, whose value is highly susceptible to the volatility in international prices, has been a prime factor in the stagnation in India's exports.

5.3 Composition of Exports

Table 17 provides the share of India's exports at 2-digit level of commodity classification. As discussed earlier, led by the export of refined petroleum products, share of Mineral fuels category has significantly increased. As a result, the share of Food & live animals and Manufactured goods categories have declined (although share of Food & live animals has marginally increased after 2010). We see a steady decline in share of non-fuel primary commodities. Led by the automobile and pharmaceutical industries, the exports of chemical products and Machinery and transport equipments have steadily gained in share since 1996.

To see the overall nature of these changes, Table 18 provides the share of exports by Skill & Tech categories of the commodities. The table also provides the overall composition of exports of developing countries, for comparison (Hong Kong and UAE, being trading hubs, have been excluded, for better comparison).

India's reliance on exports of primary products significantly declined between 1996 and 2005, but remained stagnant thereafter. But this share is still much less than the average of developing countries. But, India's reliance on exports of resource based manufacturing commodities has increased, and is very high compared to developing countries' average (we've already discussed the pitfalls of this reliance).

Despite the fall in share of labour intensive manufacturing, it is still higher than developing countries' average. The share of LMT-LMHS manufacturing

commodities has been growing, and it is even higher than developing countries' average.

Most importantly, following the trend in other developing countries, India's share of HT-HS manufacturing commodities have consistently risen. But it is rising at a much slower pace. Its share in exports (10.4%) is much lower than the average of developing countries (22.7%) in 2019.

Overall, the share of various types of non-resource based manufactured exports and its growth is comparable to that of the average of developing countries.

To understand these changes, Table 19 shows the rate of growth of exports of each commodity category. We see that, after very high rates of growth prior to 2010, the growth rate of all the categories have come down during 2011-19 period. As discussed earlier, the resource-based manufacturing exports, after a very high growth rate in 2004-10, saw a negative growth rate in 2011-12. Overall, the growth rate of exports of HT-HS and LMT-LMHS manufacturing commodities have been the highest between 2005 and 2019. This is more or less in accordance with the growth pattern of all developing countries (excl. China).

5.4 Type of Destination for India's Exports

Table 20 provides the destination for India's exports based on centers of development. Similar to other developing countries, India's overall reliance on exports to developed countries has significantly reduced in the Globalization period. Although share of India's exports to China has increased since 1996, unlike other East & South East Asian countries, India's exports and export patterns are not too centred around China, and remains diversified with other developing countries. Across most commodity categories, after drop in share of exports to developed countries between 1996 and 2010, the share has marginally increased between 2010 and 2019.

Among the fast growing sectors, in case of LMT-LMHS manufacturing exports, India has been successfully able to substitute a significant share of its exports away from developed countries towards developing countries and China (especially more towards China after 2010). But in case of HT-HS manufacturing exports, India is still majorly reliant on developed countries, and the share has not significantly changed since 2005.

5.5 High Tech-High Skill Exports: Deep Dive

As one of the fastest growing sectors, we look deeper into the high tech-high skill manufacturing exports from India. Figure 3 shows the share of each

industry within the total value of HT-HS exports from India. As it can be clearly seen, the exports are led by the pharmaceutical industry.

During a brief period between 2009 and 2014, the exports of telecommunication equipments gained a high share. But this has reduced once again. A similar trend can be seen with the manufacturing of data processing instruments during the initial years of this century.

Except for these brief interruptions, pharmaceutical industry has clearly played a dominant role in driving India's composition towards HT-HS manufacturing exports, maintaining a share of over 50%. Share of exports of electrical machines have been constantly declining.

5.6 Discussion on Trends in India's Merchandise Exports

The period of 2011-19 saw India's export value stagnating, growing at a mere 0.2%. As we saw, this slow growth rate is primarily led by the fall in unit price of exports of refined petroleum products. This experience pointed to the pitfalls of heavy reliance on resource-based manufacturing exports. Especially in case of petroleum products, India is at a further disadvantage, as almost the entire crude oil input for this industry is imported, which not just raises questions on the value added content of the export, but also leaves the export value of this industry vulnerable to international price shocks.

In terms of direction, India's reliance on developed countries for exports has substantially declined. Moreover, deviating from the trends among other East and South East Asian partners, where the export patterns are gradually becoming centered around China, India's export destinations are becoming much more diversified, with the share of exports to regions like Sub-Saharan Africa, North Africa and West Asia making substantial gains.

In terms of composition, India is rightly reducing its dependence on primary commodities. The period of 1996-2010, saw the share of resource based manufacturing increase sharply. But, in the next decade, following the pattern of China and other developing countries, the share of HT-HS and LMT-LMHS manufacturing exports made considerable gains, although the growth is at a comparatively slower pace.

Here, in this scenario, we are forced to re-investigate the policy suggestions for India to ease its Foreign Direct Investment norms and leverage its factor advantage in labour, so as to advance its export prospects. In case of HT-HS exports, we observed the case of Telecommunication equipment export industry. The share of this industry in HT-HS exports sharply rose during

2009-14, and then dropped abruptly. This industry is characterized by large investments via FDI and strong presence of Global Value Chains (GVCs). Here, the investments primarily arrive in India in search of resources for labour-intensive components of the manufacturing process, and exits the space when the conditions are favourable in other regions. In fact, such experiences contribute to the debates on volatility associated with heavy linkage to GVCs during periods of global economic shocks (Broll & Jauer (2014)). Moreover, despite a long period of experience during the liberalization period, India has not been able to build its own capacities and technological capabilities, and "climb up the value chain" through these investments. The narrative is similar in case of exports of data manufacturing equipment as well, during the initial years of 21st century.

But on the other hand, if we look to the area which has led India's transition towards HT-HS exports, it is the pharmaceutical industry, which has a very long history of growth under a protected environment and favourable intellectual property regime (Patents Act, 1970, which allowed process patenting). This allowed the industry to develop wide-reaching domestic capacities, and strong technological capabilities, with some firms even building world-class R&D facilities.

In case of LMT-LMHS manufacturing too, it is the automobile industry that has led the growth in exports. This is also an industry, despite the large FDI inflows, has enjoyed considerable protection, especially in the 1980s and 1990s. The rules on large percentage of "local content requirement" and tariffs on imports meant that the MNCs were forced to make large capital investments, which built domestic capacities. This also allowed the growth of a strong industry for components manufacture. Moreover, the export obligations on the MNCs provided protection for the domestic firms to build their own capacities. Also, collaboration between foreign firms and domestic suppliers led to spillover benefits and allowed Indian firms to build their own technological capabilities (Miglani (2019)).

These experiences show us that it is those industries where the country's policies and practices allowed for the growth of domestic capacities and technological capabilities, that have led the long-term transition in India's exports. Other industries, where investments arrive with the sole aim of utilising India's factor advantage in labour have only contributed to the volatility in this process of transition.

Hence, policy suggestions which are solely aimed at "export-orientation", leveraging India's factor benefits, and allowing unbridled FDI inflows should

be approached with caution. Even if India wants to leverage its factor advantage in labour to provide more employment, it is not beneficial to allow this through a more relaxed FDI rules. In fact, this very juncture, when we are seeing a transition towards HT-HS manufacturing commodities in global exports and particularly among developing countries, is the ideal time for India to strengthen its investment policies which are aimed at better technology transfers, building capacities and technological capabilities. This alone will serve the long-term strategic interests of the country.

6 Conclusion

This study attempted to understand the changing patterns in exports of merchandise at a global level and in India, by comparing the composition and direction of trade before and after 2010.

The study was able to draw attention to the evidence that the global exports and especially exports by developing countries are shifting towards High Tech-High Skill manufacturing commodities. The study was also able to offer evidence that points to the fact that such a transition is now strongly facilitated by China.

The study was also able to show that India is also following the path of transition of other developing countries, albeit at a slower pace. It was also able to offer evidences suggesting for a careful approach towards policy decisions on leveraging India's comparative advantage in factors and easing FDI rules. The study was able to offer alternative suggestions that would serve India's long-term interests.

In case of global exports, further study on the nature of transition of developing countries towards HT-HS exports, through analysis of the policies of individual countries, might help us better understand the shifting patterns. In case of India, a stronger empirical study on volatility associated with GVCs and "export-oriented" FDI rules might help substantiate the findings of this study.

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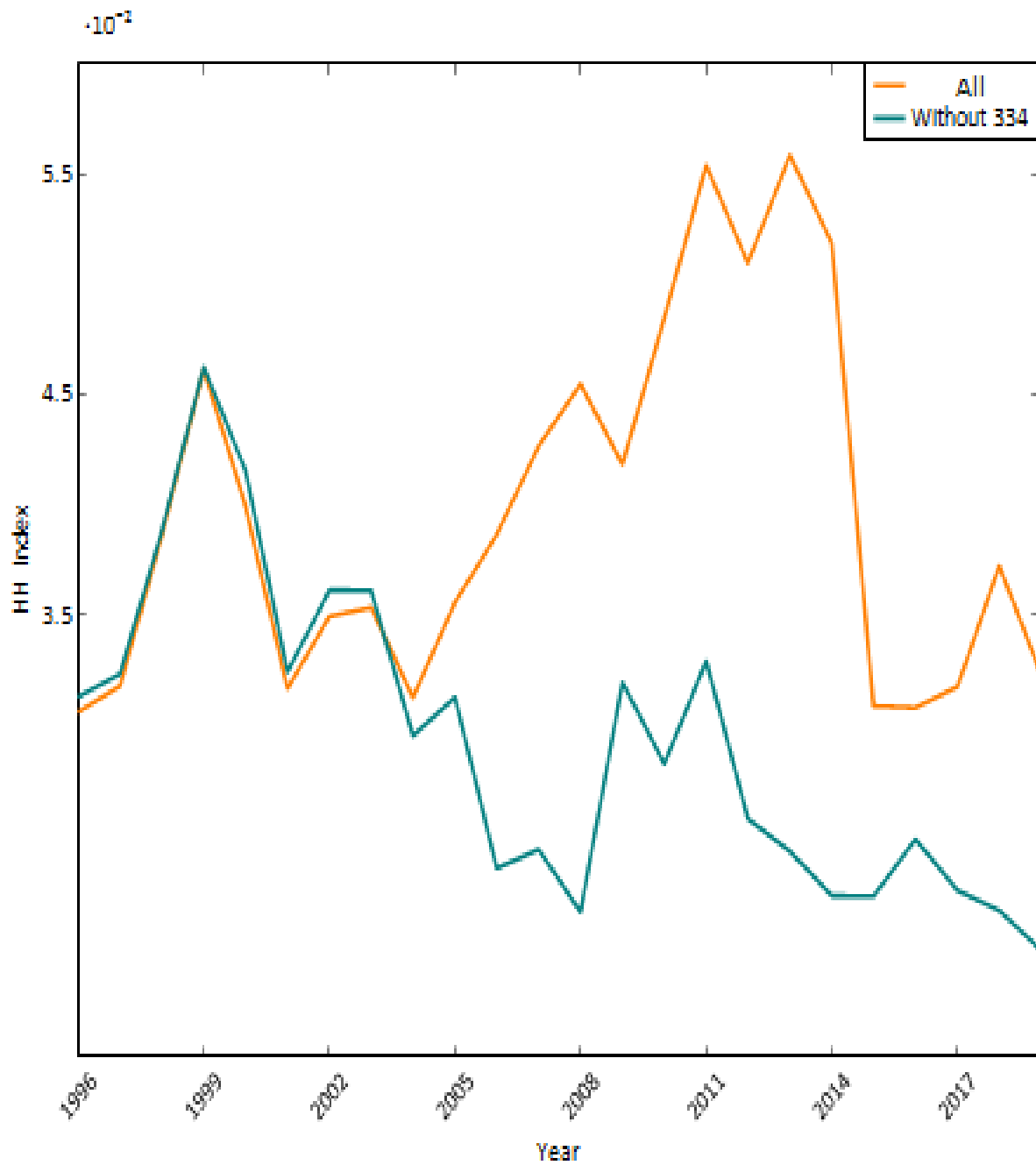
Figure 1: Semi-Log plot of India's Value of Exports (w/ Growth Rate in Each Period)



Note: Growth Rate Calculated by regressing $\log(X_{t+1}) = \alpha + \beta t$, where $\beta = \log(1 + r)$, r being the rate of growth.

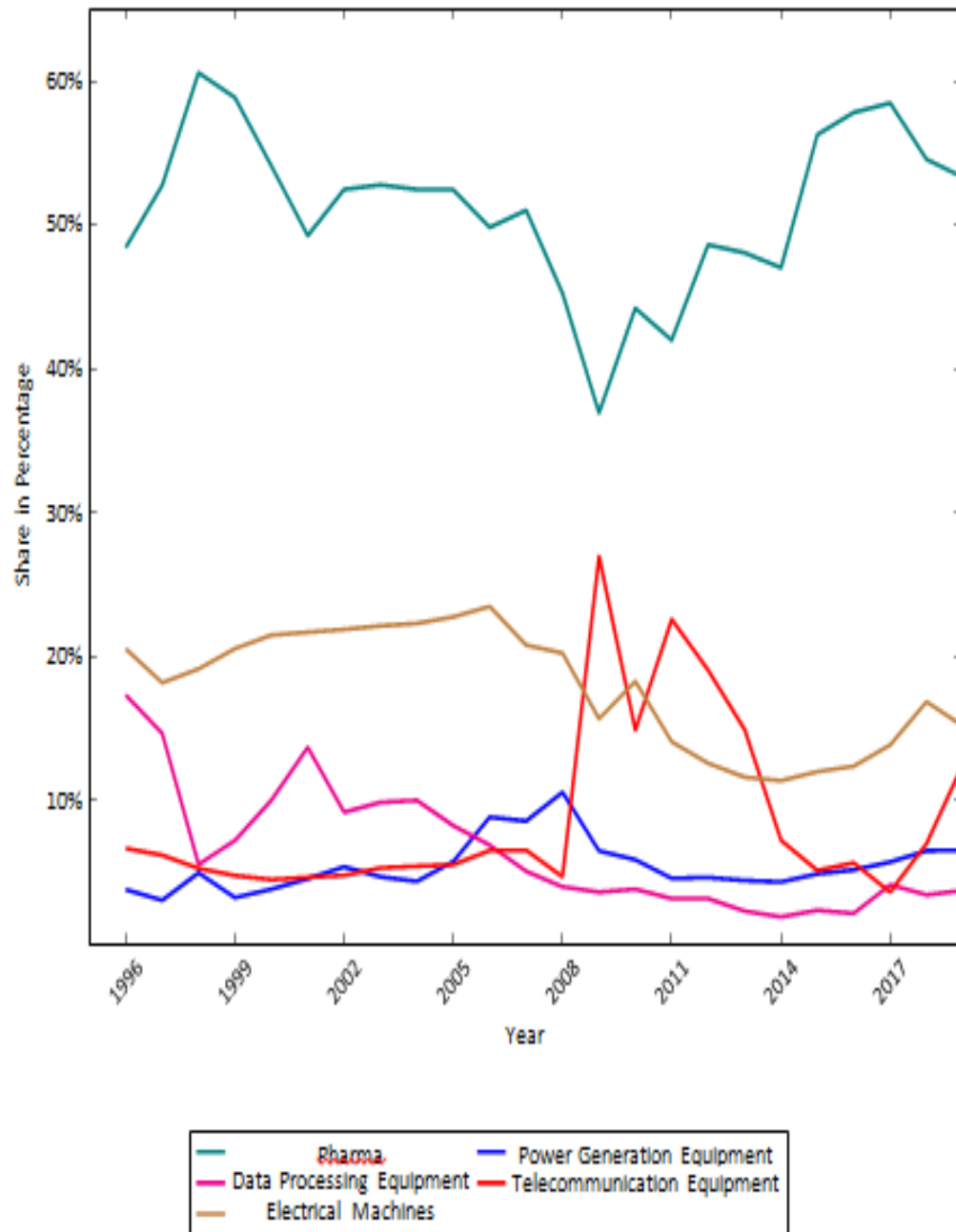
Source: Author's estimation using UN Comtrade Database

Figure 2: Hirschman-Herfindahl Index for India's Exports



Source: Author's estimation using UN Comtrade Database

Figure 3: Within India's HT-HS exports, share of various industries



Source: Author's estimation using UN Comtrade Database

Table 1: Percentage of World Exports Contributed by Top Trading Nations

Percentage of World Exports			
Percentile	2005	2010	2019
1%	17.9%	23.6%	22.4%
5%	38.7%	45.5%	40.5%
10%	54.7%	58.6%	53.7%

Source: Author's estimation using UN Comtrade Database

Table 2: Share of World Exports by Each Region

Region	2005	2010	2019
Central & South Asia	2.2%	3.5%	2.4%
East Asia	19.7%	17.3%	24.1%
Eastern & Southern Europe	12.2%	11.5%	12.8%
Latin America	4.1%	6.8%	4.0%
NA, W&N Europe, Australia & NZ	47.3%	39.3%	39.3%
South East Asia	8.5%	11.2%	9.8%
Sub-Saharan Africa	0.7%	1.9%	1.3%
West Asia and Northern Africa	5.2%	8.4%	6.3%

Note: NA, W&N Europe, Australia & NZ - North America, Western & Northern Europe, Australia & New Zealand

Source: Author's estimation using UN Comtrade Database

Table 3: Share of World Exports by Nations' Developmental Category

Developmental Stage	2005	2010	2019
Developed	70.1%	56.6%	60.9%
Developing (Excl. China)	22.0%	29.5%	24.5%
China (Developing)	7.9%	13.9%	14.6%

Source: Author's estimation using UN Comtrade Database

Table 4: Share of World Exports between Nations' Developmental Category

		Destination Nation Development								
China)		Developing (Excl. China								
		Destination Nation Development								
		Developed			(Developing) (Excl. China)			China Developing		
Exporting Nation Development		2005	2010	2019	2005	2010	2019	2005	2010	2019
Developed		54.2%	40.9%	42.8%	12.9%	12.0%	13.2%	3.0%	3.7%	4.9%
Developing (Excl. China)		11.7%	13.2%	11.0%	7.6%	13.4%	9.1%	2.6%	2.9%	4.4%
China (Developing)		4.9%	7.8%	7.4%	3.0%	6.1%	7.2%			

Note: To read the table: In 2005, 54.2% of total global exports started from developed nations and ended at developed nations

Source: Author's estimation using UN Comtrade Database

Table 5: Composition of World's and Each Region's Exports by Commodities' Technology Categories

Commodity Technological Category	World		
	2005	2010	2019
High Tech Manufacturing	21.2%	20.5%	22.9%
Low Tech Manufacturing	14.3%	13.9%	13.9%
Medium Tech Manufacturing	31.7%	27.4%	30.8%
Primary (Fuel)	7.3%	9.0%	4.6%
Primary (Non-Fuel)	6.0%	6.5%	7.1%
Resource Based Manufacturing	14.7%	17.8%	15.5%
Unclassified	4.7%	4.9%	5.2%
Total	100%	100%	100%

	Exporting Nation's Development								
	Developed			Developing (Excl. China)			China (Developing)		
Commodity Technological Category	2005	2010	2019	2005	2010	2019	2005	2010	2019
High Tech Manufacturing	19.3%	16.7%	17.9%	21.9%	21.0%	28.0%	35.2%	35.0%	34.7%
Low Tech Manufacturing	12.4%	11.4%	11.0%	14.7%	11.6%	12.8%	30.4%	29.6%	27.5%
Medium Tech Manufacturing	37.0%	32.3%	35.4%	18.9%	19.5%	22.4%	22.9%	24.0%	26.1%
Primary (Fuel)	4.6%	6.4%	4.9%	18.0%	18.0%	6.7%	0.4%	0.3%	0.1%
Primary (Non-Fuel)	5.7%	6.8%	6.8%	8.0%	7.7%	10.3%	3.2%	2.7%	2.7%
Resource Based Manufacturing	16.1%	19.9%	17.1%	13.0%	18.4%	15.9%	7.4%	8.0%	8.1%
Unclassified	5.0%	6.6%	6.8%	5.5%	3.9%	3.9%	0.5%	0.4%	0.8%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Author's estimation using UN Comtrade Database

Table 6: Composition of World's and Each Region's Exports by Commodities' Skill Categories

Commodity Skill Category	World		
	2005	2010	2019
High Skill	29.9%	29.8%	31.2%
Labor Intensive	10.0%	9.1%	8.9%
Low Skill	7.3%	7.0%	6.6%
Medium Skill	26.3%	21.9%	26.4%
Others/Unskilled	26.5%	32.3%	26.8%
Total	100%	100%	100%

	Exporting Nation's Development								
	Developed			Developing (Excl. China)			China (Developing)		
Commodity Skill Category	2005	2010	2019	2005	2010	2019	2005	2010	2019
High Skill	29.7%	28.2%	28.1%	27.4%	28.5%	35.7%	39.0%	38.9%	36.9%
Labor Intensive	8.2%	6.6%	6.8%	11.1%	8.0%	8.9%	22.1%	21.9%	17.8%
Low Skill	7.8%	7.3%	6.5%	4.8%	4.7%	4.6%	10.2%	10.9%	10.3%
Medium Skill	30.5%	25.4%	29.5%	15.3%	14.9%	17.8%	20.9%	22.0%	28.1%
Others	23.8%	32.5%	29.1%	41.4%	43.9%	33.0%	7.7%	6.2%	6.9%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Author's estimation using UN Comtrade Database

Table 7: Composition of World's and Each Region's Exports by Commodities' Technology & Skill Categories

Commodity Category	World		
	2005	2010	2019
Unclassified/Non-Manufacturing	4.1%	4.5%	4.7%
Primary	13.4%	15.5%	11.7%
Resource Based Manufacturing	8.9%	12.3%	10.3%
Labor Intensive Manufacturing	10.0%	9.1%	8.9%
HT-HS Manufacturing	21.2%	20.5%	22.9%
LMT-LMHS Manufacturing	42.4%	38.2%	41.5%
Total	100%	100%	100%

Commodity Category	Exporting Nation's Development								
	Developed			Developing (Excl. China)			China (Developing)		
	2005	2010	2019	2005	2010	2019	2005	2010	2019
Unclassified/Non-Manufacturing	4.3%	6.0%	6.2%	5.1%	3.5%	3.6%	0.3%	0.2%	0.6%
Primary	10.3%	13.2%	11.7%	26.0%	25.7%	17.0%	3.6%	3.0%	2.8%
Resource Based Manufacturing	9.1%	13.3%	11.2%	10.1%	14.6%	12.4%	3.8%	3.0%	3.5%
Labor Intensive Manufacturing	8.2%	6.6%	6.8%	11.1%	8.0%	8.9%	22.1%	21.9%	17.8%
HT-HS Manufacturing	19.3%	16.7%	17.9%	21.9%	21.0%	28.0%	35.2%	35.0%	34.7%
LMT-LMHS Manufacturing	48.8%	44.3%	46.3%	25.7%	27.2%	30.2%	34.9%	36.9%	40.6%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Note: HT-HS : High Tech-High Skill ; LMT-LMHS : Low/Medium Tech-Low/Medium/High Skill

Source: Author's estimation using UN Comtrade Database

Table 8: Share of each developmental center in Global Exports by Commodity Categories

Developing (Excl. China)

Commodity Category	2005	2010	2019
Unclassified/Non-Manufacturing	28.3%	23.1%	18.6%
Primary	44.6%	48.8%	35.7%
Resource Based Manufacturing	25.9%	35.0%	29.5%
Labor Intensive Manufacturing	25.4%	25.9%	24.5%
HT-HS Manufacturing	23.8%	30.1%	30.2%
LMT-LMHS Manufacturing	13.9%	20.9%	17.9%

China (Developing)			
Commodity Category	2005	2010	2019
Unclassified/Non-Manufacturing	0.6%	0.5%	1.9%
Primary	2.2%	2.7%	3.5%
Resource Based Manufacturing	3.4%	3.3%	5.1%
Labor Intensive Manufacturing	17.7%	33.1%	29.5%
HT-HS Manufacturing	13.3%	23.4%	22.4%

LMT-LMHS Manufacturing	6.6%	13.2%	14.4%
	Developed		
Commodity Category	2005	2010	2019
Unclassified/Non-Manufacturing	71.0%	76.3%	79.5%
Primary	53.2%	48.5%	60.8%
Resource Based Manufacturing	70.7%	61.6%	65.5%
Labor Intensive Manufacturing	56.9%	41.1%	46.0%
HT-HS Manufacturing	63.0%	46.5%	47.5%
LMT-LMHS Manufacturing	79.6%	65.9%	67.7%

Note: To read the table: Developing Countries' Share in Global Exports of Primary Commodities was 44.6% in 2005

Source: Author's estimation using UN Comtrade Database

Table 9: Within Developing Nations (Excl. China), Within HT-HS category, composition of various industries

Within HT-HS export

Industry	2005	2010	2019
Electrical machinery, apparatus and appliances, n.e.s.	37.8%	47.5%	49.6%
Office machines and automatic data processing machines	27.9%	17.9%	22.7%
Telecommunication and sound recording apparatus	22.8%	21.7%	17.3%
Professional and scientific instruments, n.e.s.	4.9%	5.1%	3.4%
Medicinal and pharmaceutical products	1.9%	3.0%	3.3%
Other transport equipment	1.7%	2.5%	1.7%
Power generating machinery and equipment	2.3%	1.7%	1.6%
Photo apparatus, optical goods, watches and clocks	0.8%	0.3%	0.2%
Inorganic chemicals	0.1%	0.3%	0.2%
Total	100.0%	100.0%	100.0%

Source: Author's Calculation Using Comtrade-WITS database

Table 10: Within Developing Nations (Excl. China), Within HT-HS/LMT-LMHS category, share of various regions

Within HT-HS export

Region	2005	2010	2019
Central & South Asia	1.3%	2.7%	3.3%
East Asia	26.9%	27.0%	30.0%
Latin America	13.7%	12.1%	9.2%
South East Asia	55.0%	55.1%	52.7%
Sub-Saharan Africa	0.5%	0.5%	0.3%
West Asia & Northern Africa	2.6%	2.6%	4.6%
Total	100.0%	100.0%	100.0%

Within LMT-LMHS export

Region	2005	2010	2019
Central & South Asia	7.6%	9.1%	11.3%
East Asia	17.2%	11.0%	9.0%
Latin America	23.4%	19.7%	20.9%
South East Asia	36.0%	40.8%	36.4%
Sub-Saharan Africa	4.1%	4.4%	3.5%
West Asia & Northern Africa	11.7%	14.9%	18.8%
Total	100.0%	100.0%	100.0%

Source: Author's estimation using UN Comtrade Database

Table 11: Top Developing Nations (Excl. China) responsible for increase in HT-HS exports (Within HT-HS export share of each country as a % of Global Exports)

Within HT-HS export

Country	2005	2010	2019
China, Hong Kong SAR	6.4%	8.1%	9.1%
Singapore	2.5%	5.2%	4.0%
Viet Nam	0.1%	0.3%	2.7%
United Arab Emirates	0.3%	0.3%	1.0%
India	0.3%	0.7%	0.9%

Source: Author's estimation using UN Comtrade Database

Table 12: Share of Exports of each export nation category going to each destination nationcategory

Within HT-HS Export Destination Nation Development									
Exporting Nation Development	Developed			Developing (Excl. China)			China (Developing)		
	2005	2010	2019	2005	2010	2019	2005	2010	2019
Developed	71.4%	72.1%	67.0%	22.8%	21.7%	23.0%	5.9%	6.2%	10.0%
Developing (Excl. China)	48.4%	39.6%	36.8%	28.9%	31.7%	33.6%	22.8%	28.7%	29.6%
China (Developing)	58.5%	56.0%	50.2%	41.5%	44.0%	49.8%			

Within LMT-LMHS Export Destination Nation Development									
Exporting Nation Development	Developed			Developing (Excl. China)			China (Developing)		
	2005	2010	2019	2005	2010	2019	2005	2010	2019
Developed	76.3%	71.6%	71.3%	19.5%	22.1%	21.5%	4.2%	6.3%	7.2%
Developing (Excl. China)	51.4%	43.3%	49.7%	36.1%	43.8%	38.4%	12.5%	12.9%	11.9%
China (Developing)	63.5%	53.4%	50.8%	36.5%	46.6%	49.2%			

Note: To read the table: In 2005, of all the HT-HS exports by developed nations, 71.4% were imported by other developed nations

Source: Author's estimation using UN Comtrade Database

Table 13: Share of China in the country's global export/import in HT-HS commodities

Export					Import
Country	2005	2019	2005	2019	Remark on China
China, Hong Kong SAR	58.4%	63.6%	47.4%	53.3%	Top import source and export destination
Singapore	7.9%	12.6%	13.8%	22.1%	Top import source; 2nd export destination
Viet Nam	5.5%	19.7%	13.6%	37.0%	Top import source and export destination
United Arab Emirates	0.1%	8.8%	8.6%	25.5%	Top import source
India	2.4%	3.1%	19.0%	39.2%	Top import source; 4th export destination

Source: Author's estimation using UN Comtrade Database

Table 14: India's Top Export Partners and their share in India's Total Exports

Country	1996	2005	2010	2019
USA	20.7%	16.5%	11.1%	16.9%
United Arab Emirates	4.6%	8.4%	12.6%	9.2%
China	1.7%	7.2%	6.5%	5.4%
China, Hong Kong SAR	6.1%	4.4%	4.5%	3.6%
Singapore	3.2%	5.4%	4.3%	3.3%
Netherlands	2.5%	2.4%	3.1%	2.8%

Source: Author's estimation using UN Comtrade Database

Table 15: Share of each region in India's Total Exports

Region	1996	2005	2010	2019
Central & South Asia	6.3%	6.6%	6.5%	8.4%
East Asia	15.1%	15.6%	15.2%	11.9%
Eastern & Southern Europe	7.2%	6.6%	6.0%	6.1%
Latin America	1.4%	2.8%	4.4%	4.3%
NA, W&N Europe, Australia & NZ	45.6%	36.1%	27.8%	32.2%
Oceania	0.0%	0.1%	0.0%	0.1%
South East Asia	10.8%	10.9%	11.9%	11.2%
Sub-Saharan Africa	3.1%	5.2%	6.6%	7.4%
West Asia & Northern Africa	10.5%	16.1%	21.7%	18.5%
Total	100.0%	100.0%	100.0%	100.0%

Note: NA, W&N Europe, Australia & NZ - North America, Western & Northern Europe, Australia & New

Zealand

Source: Author's estimation using UN Comtrade Database

Table 16: India's Top Export Commodities and their share in India's Total Exports

Commodities	1996	2005	2010	2019
Petroleum oils or bituminous minerals	1.44%	10.17%	17.03%	13.19%
Pearls, precious & semi-precious stones	12.57%	12.40%	10.50%	7.04%
Medicaments	1.91%	2.24%	2.68%	4.70%
Jewellery & articles of precious materials	1.65%	3.80%	4.25%	4.28%
Motor vehicles for the transport of persons	0.72%	0.96%	2.10%	2.17%
Rice	2.67%	1.65%	1.07%	2.11%
Articles of apparel, of textile fabrics	1.58%	1.77%	1.29%	1.85%
Ships, boats & floating structures	0.12%	0.65%	1.96%	1.80%
Parts & accessories of vehicles	0.83%	1.16%	0.97%	1.68%
Crustaceans, mollusks & aquatic invertebrates	2.59%	1.18%	0.66%	1.64%

Source: Author's estimation using UN Comtrade Database

Table 17: Composition of India's Exports : Commodity Type-wise

Commodity Type	1996	2005	2010	2019
Food and live animals	16.5%	8.0%	7.3%	9.3%
Beverages and tobacco	0.8%	0.3%	0.5%	0.4%
Crude materials, inedible, except fuels	5.2%	7.5%	7.3%	3.3%
Mineral fuels, lubricants and related materials	0.1%	10.4%	17.7%	13.2%
Animal and vegetable oils, fats and waxes	0.7%	0.3%	0.4%	0.4%
Chemicals and related products, n.e.s.	9.3%	11.4%	11.1%	16.6%
Manufactured goods	38.8%	33.6%	26.9%	23.8%
Machinery and transport equipment	7.9%	10.5%	15.0%	19.2%
Miscellaneous manufactured articles	18.7%	16.8%	12.8%	13.8%
Commodities and transactions, n.e.s.	2.0%	1.1%	1.1%	0.0%
Total	100.0%	100.0%	100.0%	100.0%

Source: Author's estimation using UN Comtrade Database

Table 18: Composition of India's Exports : Commodity Skill & Tech-wise
(In Comparison to Developing Nations (Excl. China, Hong Kong & UAE))

India				
Commodity Category	1996	2005	2010	2019
Unclassified/Non-Manufacturing	2.0%	1.1%	1.1%	0.2%
Primary	20.2%	11.5%	10.5%	11.5%
Resource Based Manufacturing	18.1%	28.9%	34.0%	23.6%
Labor Intensive Manufacturing	32.1%	21.3%	14.4%	14.9%
HT-HS Skill Manufacturing	4.9%	5.3%	7.6%	10.4%
LMT-LMHS Manufacturing	22.7%	32.0%	32.5%	39.3%
Total	100.0%	100.0%	100.0%	100.0%

Developing (Excl. China,HK,UAE)			
Commodity Category	2005	2010	2019
Unclassified/Non-Manufacturing	5.8%	3.3%	3.0%
Primary	28.8%	27.4%	20.0%
Resource Based Manufacturing	11.5%	15.9%	13.4%
Labor Intensive Manufacturing	9.7%	9.0%	9.6%
HT-HS Skill Manufacturing	19.1%	17.4%	22.7%
LMT-LMHS Manufacturing	25.1%	27.1%	31.4%
Total	100.0%	100.0%	100.0%

Source: Author's estimation using UN Comtrade Database

Table 19: Rate of Growth of Exports from India across Commodity Skill & Technology Categories

Commodity Category	1996-2003	2004-2010	2005-2019	2011-2019
Unclassified-Non Manufacturing	8.8%	41.0%	-1.5%	-25.7%
Primary	1.4%	16.0%	9.5%	-0.1%
Resource Based Manufacturing	13.9%	22.0%	5.5%	-4.2%
Labor Intensive Manufacturing	5.3%	8.2%	6.3%	4.8%
HT-HS Manufacturing	12.8%	16.2%	16.2%	3.3%
LMT-LMHS Manufacturing	12.2%	13.5%	10.9%	3.4%
Overall	8.4%	18.4%	7.8%	0.2%

Note: Growth Rate Calculated by regressing $\log(Y_{export}) \sim a + \beta t$, where $\beta = \log(1 + r)$, r being the rate of growth. *Source:* Author's estimation using UN Comtrade Database

Table 20: Share of each development region as destination for India's exports, for eachCommodity Skill & Technology category

Commodity Category	1996			2005		
	(1)	(2)	(3)	(1)	(2)	(3)
All Commodities	60.7%	37.6%	1.7%	47.8%	45.0%	7.2%
Unclassified/Non-Manufacturing	82.4%	17.6%	0.0%	30.9%	67.4%	1.6%
Primary	47.6%	48.6%	3.8%	36.8%	56.8%	6.4%
Resource Based Manufacturing	63.3%	35.3%	1.5%	36.7%	48.3%	15.0%
Labor Intensive Manufacturing	73.3%	26.1%	0.6%	71.6%	27.6%	0.8%
HT-HS	55.9%	43.2%	1.0%	52.5%	45.2%	2.4%
LMT-LMHS Manufacturing	51.9%	46.4%	1.7%	45.7%	48.6%	5.6%
Commodity Category	2010			2019		
	(1)	(2)	(3)	(1)	(2)	(3)
All Commodities	39.1%	54.4%	6.5%	42.4%	52.2%	5.4%
Unclassified/Non-Manufacturing	25.3%	73.9%	0.8%	10.4%	89.6%	0.1%
Primary	28.1%	58.8%	13.1%	32.4%	58.6%	9.0%
Resource Based Manufacturing	30.8%	59.2%	10.0%	38.0%	55.3%	6.7%
Labor Intensive Manufacturing	60.5%	37.2%	2.3%	58.5%	38.9%	2.6%
HT-HS	53.8%	44.1%	2.1%	52.8%	44.1%	3.1%
LMT-LMHS Manufacturing	38.8%	57.3%	3.8%	39.2%	55.6%	5.2%

Note: (1) - Developed ; (2) - Developing (Excl. China) ; (3) - China (Developing)

Source: Author's estimation using UN Comtrade Database

Appendix

Table A.1: List of Countries considered as "reporting country" while downloading data from UN Comtrade Dataset

List of Countries in the Analysis		
Afghanistan	Ethiopia	Pakistan
Algeria	Finland	Peru
Angola	France	Philippines
Argentina	Germany	Poland
Australia	Ghana	Portugal
Austria	Greece	Qatar
Azerbaijan	Guinea	Rep. of Korea
Bahrain	Hungary	Romania
Bangladesh	India	Russian Federation
Belarus	Indonesia	Saudi Arabia
Belgium	Iran	Senegal
Benin	Iraq	Serbia
Bhutan	Ireland	Singapore
Bolivia (Plurinational State of)	Israel	Slovakia
Botswana	Italy	Slovenia
Brazil	Japan	South Africa
Brunei Darussalam	Jordan	Spain
Bulgaria	Kazakhstan	Sri Lanka
Burkina Faso	Kenya	Sweden
Cote d'Ivoire	Kuwait	Switzerland
Cambodia	Latvia	Thailand
Cameroon	Lithuania	Togo
Canada	Luxembourg	Tunisia
Chile	Malaysia	Turkey
China	Mauritius	Uganda
China, Hong Kong SAR	Mexico	Ukraine
Colombia	Morocco	United Arab Emirates
Congo	Mozambique	United Kingdom
Croatia	Myanmar	United Rep. of Tanzania
Cyprus	Nepal	USA
Czechia	Netherlands	Uzbekistan
Denmark	New Zealand	Venezuela
Dominican Rep.	Nigeria	Viet Nam
Ecuador	Norway	Yemen
Egypt	Oman	Zambia
Estonia	Other Asia, nes	

Table A.2: Commodities Classification

Tech Level	Skill Level	Commodity Category
High	High	HT-HS Manufacturing
Medium	Medium	
Primary (Non-Fuel)	Others	Primary
Primary (Fuel)	Others	
Resource Based	Others	Resource Based Manufacturing
Low	Labor Intensive	Labor Intensive Manufacturing
Medium	Labor Intensive	
Resource Based	Labor Intensive	
Low	High	LMT-LMHS Manufacturing
Medium	High	
Resource Based	High	
Low	Low	
Medium	Low	
Low	Medium	
Medium	Medium	
Resource Based	Medium	
Medium	Others	
Unclassified	High	
Unclassified	Others	Unclassified/Non-Manufacturing

Note: HT-HS : High Tech-High Skill ; LMT-LMHS : Low/Medium Tech-Low/Medium/High Skill

Notes

¹ Estimations on value of global and India's exports by the author using UN Comtrade Database

² Standard International Trade Classification (SITC) Revision 3 (https://unctadstat.unctad.org/en/Classifications/DimSitcRev3Products_Official_Hierarchy.pdf)

³ Product by technological categories

(https://unctadstat.unctad.org/en/Classifications/DimSitcRev3Products_Ldc_Hierarchy.pdf)

⁴ Manufactured goods by degree of manufacturing

(https://unctadstat.unctad.org/en/Classifications/DimSitcRev3Products_Tdr_Hierarchy.pdf)

⁵ Classification of countries (https://unctadstat.unctad.org/en/Classifications/DimCountries_All_Hierarchy.pdf)

⁶ Note: The classification of countries categorizes South Korea as "developed", along with Japan

⁷ Source for data on China's R&D intensity: The World Bank Data (<https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=CN>)

⁸ Estimations on unit price of exports of refined petroleum products by the author using UN Comtrade Database

GVCs and Bilateral Trade Integration: A Sector-level Analysis of India and United Kingdom Trade

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Abstract

India and the UK could in future move to a deeper level of global value chain (GVC) integration by signing a free trade agreement (FTA). The FTA with ease in market access can support the GVC participation of both India and the UK. This paper attempts to present the sectoral-level linkages by analysing the factors that affect India's bilateral export flows to the UK from the lens of GVC participation for nine sectors. The most important question that arises is that besides tariff easing and trade liberalisation between these sectors, how the nature of trade will be developed and will it be strengthened further through strong and supportable value-added linkages between these sectors. The findings, however, reveal that for the low-technology sectors like textile, clothing & leather and base metals, the GVC participation is important for boosting India's exports to the UK and for high-technology sectors like chemical and pharmaceutical products, it is mainly the intensive margin and expenditure on R&D that positively associate with exports.

Keywords: Free Trade Agreements; GVC trade; Foreign Value Added; Deep Integration

JEL Classification: F02; F10; F14; F15; O24

1. Introduction

Strong historical and cultural ties exist between India and the UK. The year 2022 further highlights these ties when India commemorates its 75th anniversary of Independence and both India and the UK celebrate 75 years of bilateral ties. However, it was in 2004 that Strategic Partnership led to India's complex bilateral engagement with the UK getting more intense. The foundation for this was laid through a Joint Declaration titled "India- UK: Towards a New and Dynamic Partnership," which called for annual summits and frequent meetings between foreign ministers. Additionally, it indicated potential opportunities for collaboration in the fields of civil nuclear energy, space exploration, defence, counter-terrorism, economic linkages, science & technology, as well as education and culture. The relationship was upgraded to an "Enhanced Partnership for the Future" following the visit of the Government of UK to India in July 2010. The UK backs India's bid for permanent membership in the UNSC and serves as an essential conduit for India in discussions with the EU, G8, and other international organizations.

However, it was mainly the Brexit that caused a big upheaval for the UK economy as it was a part of EU since 1973. In this context, UK government's "Global Britain" strategy, released in March 2021, laid out a noted shift towards the "Indo-Pacific" area leading to growth in geopolitical and economic significance over the next decade. As a result, even in the midst of the pandemic, the UK has been negotiating trade deals with many sectors as part of its new trade policy. The governments of the India and UK recently announced the "Enhanced Trade Partnership" (ETP) and their intention to negotiate a comprehensive free trade agreement. This has made UK's relations with India paramount during the recent times as further significant steps have been taken for the future of India-UK relations by signing the 2030 Roadmap¹.

This outlines the plans for the relationship over the next ten years which will focus on removing trade barriers and leading to more than doubling of India-UK trade by 2030², while including the consideration of an Interim Trade Agreement to deliver an "early harvest". Therefore, the India-UK relations have been elevated based on a shared commitment towards democracy, fundamental freedom and multilateralism³. However, recently both nations have launched a vision 2047 for shared security and prosperity for their people and the world. This mainly focuses on sustained economic recovery, building resilience and trusted partnerships to assuage any external disruptions⁴.

Even so at this juncture, with the US-China trade war, the COVID-19 epidemic, and the Ukraine conflict exacerbating each other's crises, the potential of supply chain shocks has never been more real. Global Value Chain integration at this point therefore calls for building sustainable and resilient GVCs where the rising delivery times along with shortage of essential commodities have led to

increasing discussions about re-shoring (and friend-shoring) in many countries⁵. The signing of FTAs in this scenario will not only allow countries to build redundancies and diversified sources of inputs but will also ease in the market access. Also, in order to achieve \$2-trillion export target by 2030, India's active participation in GVCs is essential. With 70 per cent of the global goods and services exports coming from GVCs—they require close trade cooperation, lower duties, and efficient customs administration⁶. An FTA ensures increased trade cooperation and lower duties. Additionally, the inclusion of new-age areas like digital trade in FTAs is a welcome step since digital technology continues to disrupt and transform GVCs by lowering entry barriers, increasing transparency, and facilitating collaborative networks.

2. Literature Review

The literature emphasizes that the rise of GVCs may generate greater demand for deep preferential trade agreements with partner sectors in order to facilitate intermediate goods trade across national borders (Lawrence, 1996; Antràs & Staiger, 2012). Furthermore, a different body of literature (e.g., Baier & Bergstrand, 2007; Gonzalez, 2012; Noguera, 2012; Johnson, 2014; Johnson & Noguera, 2017) emphasises the role of trade agreements in promoting trade, including value-added trade, and finds some evidence of a favourable relationship between the two. Studies (e.g., Li & Yu, 2014; Xie & Tan, 2014; Kee & Tang, 2016; Liu, 2016) on the effect of PTAs on GVC integration in the setting of Asia have usually produced evidence that is consistent with the aforementioned conclusions.

It has been suggested informally in key studies by Lawrence (1996), Baldwin (2011) among others, that the rise of deep trade agreements and the rising prominence of GVCs are related. It makes intuitive sense that the unbundling of production phases across borders will result in new types of cross-border policy spillovers and issues with timeliness. Greater levels of integration may help with these issues of commitment and coordination by enforcing the national regulations required for GVCs to function properly. Moreover, prior research on the implications of PTAs for economic welfare (Viner, 1950; Frankel & Wei, 1996; Krueger, 1999; Limo, 2006; Baier & Bergstrand,

2007; Goldstein, Rivers, & Tomz, 2007; Bhagwati, 2008; Magee, 2008; Yarbrough & Yarbrough, 1992) and more recent studies of the impact of PTA design on trade flows.

With the above arguments and trade agreements in place, the purpose of the paper is to understand the bilateral trade relationship between India and the UK from the point of view of value addition. The global integration in the form of participation in larger regional and global markets offers many opportunities to raise the productivity. Simply looking at the evolution of exports may misrepresent the international competitive position of a country. This is

because sectors with more diversified exports at the higher end of the quality spectrum tend to grow faster, by capitalising on their comparative advantages to boost export growth while creating jobs (Amiti & Freud, 2010; Broda & Weinstein, 2006; Funkel & Ruhwedel, 2001; Hausmann et al., 2007; Hummels & Klenow, 2005). Hence, it is crucial to understand the effect of participation in GVC on the value of exported products, especially given the rise in the share of globally traded intermediates. We discuss the export performance of India and the UK along the value chain by distinguishing upstream activities (i.e. the production of intermediate inputs) and more downstream activities (e.g. the final assembly of products) of different sectors.

Several studies state that the trade of intermediate inputs accounts for a considerable portion of international trade (Johnson, 2014; Johnson & Noguera, 2017; Koopman et al., 2014; Los et al., 2016), reflecting the growing fragmentation of production processes across borders and reinforcing the multiregional interdependence of the production and trade structure.

So, this paper extends the existing studies in two important ways. First, to the best of our knowledge this is the first study that analyses the factors that affect India's bilateral exportflows to the UK from the lens of GVC participation for nine sectors, namely; textiles, wearing apparel, leather, coke and refined petroleum products, chemical and chemical products, pharmaceuticals, medicinal chemical and botanical products, rubber and plastics products, basic metals, electrical equipment, machinery and equipment and motor vehicles, trailers and semi-trailers. The paper presents the linkage between GVC participation and trade between the sectors by utilising advanced panel-time series from 1995 to 2018. This sheds light on the diverse sectors, describing their long-term patterns of cointegration among the factors and establishing causation between these pairs of factors. Second, it will aid in understanding the potential of industrial value chain between India and the UK and possible areas of further trade cooperation. The third section of the paper focuses on trends and patterns of the bilateral trade, also including intra-industry trade and GVC participation and position index. Section four and five explain the research methodology and the application of the model. And, finally section six and seven discuss about the results and conclusion.

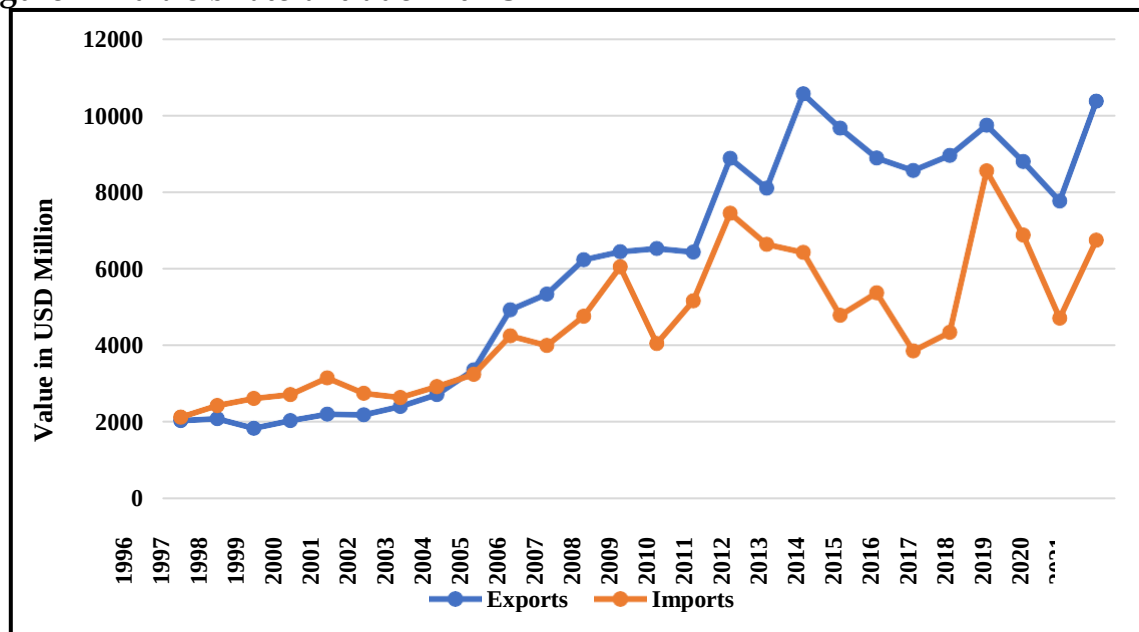
3. Bilateral Trade: Trends and Patterns

In 2021, India was the UK's 12th largest trading partner, 20th largest export destination, and 12th largest import source. This meant that 1.9 per cent of all UK's trade, 1.3 per cent of all UK's exports, and 2.4 per cent of all UK's imports in goods and services came from India. In continuation with strong bilateral trade relations (as can be seen from figure-1), Free Trade Agreement (FTA) negotiations between India and the UK were launched in January 2022 with a target to conclude the majority of talks by the end of October 2022. As far as the

tariff barriers are concerned, exports from the UK to India face average tariffs of 19 per cent, which is much higher than those from the US, which are only 2 per cent. This shows that there is much more room for trade liberalization. FTA with India could also give UK companies a competitive edge over exporting companies in the US and the EU that don't have preferential access to the Indian market.

The UK also wants to lessen its reliance on China (Scott, 2017). This gives India a chance to grow its share of supplies in areas where China is strong, such as fashion and footwear, homeware and furniture, electrical machinery, and general industrial machinery. The UK recently concluded agreements with Singapore and Japan where major sectors like automobiles, textiles, pharmaceuticals, food and beverage, machinery, chemicals, and agriculture were negotiated. In the FTA with India, the UK may request concessions on similar products⁷. In the field of services, the UK may wish to gain market access in areas of their interest, such as communication and technology, which provide considerable prospects for UK exporters to enter the Indian market. The India-UK FTA has the potential to almost double UK exports to India, boost total trade by as much as USD 33 billion a year by 2035, and increase wages across the UK by up to USD 3.62 billion.

Figure-1 India's bilateral trade with UK



Source-WITS

While annual trade between the UK and India is already impressive at £24 billion, a realistic goal of £50 billion over the next ten years is a step towards a better UK-India partnership (DIT, 2021). India's total trade with UK has

although reduced from US\$ 17 BN in 2013 to US\$ 13 BN in 2020. But the trade surplus has been positive (as can be seen from figure-1).

Table-1 India's Exports to UK in USD Million (Top 5 sectors)

HS Code	Product Description	2005	2010	2015	2020	Growth (2005-2020)
84	Machinery, mechanical appliances	288.7 (5.8%)	361.5 (5.6%)	678.6 (7.6%)	653.3 (8.4%)	2.5%
61	Articles of apparel and clothing	351.0 (7.1)	458.4 (7.1)	897.5 (10.1)	588.3 (7.6)	0.5%
30	Pharmaceutical products	125.8 (2.5)	281.5 (4.4)	457.7 (5.1)	563.6 (7.3)	7.3%
62	Articles of apparel and clothing accessories	582.6 (11.7)	742.9 (11.5)	909.1 (10.2)	533.9 (6.9)	-3.5%
71	Gems & Jewellery	246.9 (5.0)	338.9 (5.3)	522.6 (5.9)	526.5 (6.8)	2.1%
India's total Export to UK		4958.9	6436.4	8889.8	7767.6	3.04%

Source: ITC Trade Map [in () is the % share]

Table-2 India's Imports from UK in USD Million (Top 5 sectors)

HS Code	Product Description	2005	2010	2015	2020	Growth (2005-2020)
71	Gems & Jewellery	2107.7 (49.0)	1519.9 (29.4)	1582.3 (29.4)	862.5 (18.3)	-6.4%
84	Mechanical Machinery	477.0 (11.1)	773.5 (15.0)	699.5 (13.0)	809.9 (17.2)	3.0%
85	Electrical machinery	234.5 (5.5)	352.1 (6.8)	348.9 (6.5)	391.2 (8.3)	2.8%
90	Optical, photographic,	138.4 (3.2)	191.0 (3.7)	268.9 (5.0)	277.0 (5.9)	4.1%
72	Iron and steel	351.5 (8.2)	463.2 (9.0)	423.0 (7.9)	226.8 (4.8)	-3.5%
India's total Imports from UK		4300.4	5166.8	5379.0	4710.8	0.61%

Source: ITC Trade Map [in () is the % share]

Considering the top traded products between the India and UK, from Table-1 and 2, it can be seen that India's top five exports to UK account for around 40 per cent of India's total exports to UK and imports account for 55 per cent of India's total imports from UK. This reflects the concentration of the product basket seen from India's point of view. These sectors having both high exports and imports were machinery, electrical machinery and cotton and apparel. The India primarily imported gems and jewellery, mechanical and electrical

machinery and iron steel from UK in 2020. While it exported machinery, pharma products, and clothing and gems to the UK.

3.1 Intra-Industry Trade

Intra-industry trade index between two countries refers to the extent to which they trade in similar products (Krugman, 2000). The idea of global production fragmentation has arisen as a result of the development of more affordable and dependable transportation and communication technology, with regional groups being essential to profitability. And this, Akram, explains the huge increase in commerce within industries (2013). Even in products with comparable factor input requirements, differences in the level of technology and human capital result in intra-industry competition (Grubel and Lloyd, 1975). According to Yeats (1998), intra-industry trade accounts for about 30 per cent of all manufactured commodities traded globally.

Table-3 shows the main tradable sectors between India and UK from 1995 to 2020 and the sector-by-sector level of intra-industry trade between the two countries. The intra-industry trade between the two countries has gradually increased during the past 15 years. Next, we examine each country's position and involvement in GVCs. The gems & jewellery, minerals, machinery, mechanical appliances, nuclear reactors, boilers, as well as articles of clothing and clothing accessories that are not knit or crocheted, plastic, iron and steel and miscellaneous chemicals have consistently and significantly high index values.

Table-3 Sector-wise Degree of Intra-Industry Trade between India and UK

HS Codes	Product Description	1995	2000	2005	2010	2015	2020
71	Gems & Jewellery	0.23	0.12	0.21	0.36	0.50	0.76
30	Pharmaceutical	0.22	0.46	0.26	0.25	0.20	0.22
27	Minerals	0.01	0.06	0.00	0.47	0.61	0.64
84	Mechanical Machinery	0.37	0.64	0.75	0.64	0.99	0.89
87	Automotive	0.86	0.77	0.14	0.47	0.36	0.43
29	Organic chemicals	0.77	0.96	0.79	0.67	0.44	0.49
62	Art of apparel & clothing access, n	0.00	0.00	0.01	0.01	0.02	0.01
61	Art of apparel & clothing access,	0.01	0.00	0.01	0.02	0.01	0.01
63	Other made-up textile articles; set	0.08	0.05	0.03	0.04	0.05	0.03
85	Electrical Machinery	1.00	0.73	0.86	0.90	0.93	0.92
39	Plastics and articles thereof	0.70	0.91	0.87	0.86	0.89	0.67
73	Articles of iron or steel	0.98	0.53	0.43	0.53	0.38	0.48
38	Miscellaneous chemical products	0.38	0.52	1.00	0.97	0.91	0.96
76	Aluminium and articles thereof	0.34	0.75	0.58	0.27	0.31	0.36

Source: Authors' calculations

3.2 GVC Participation and Position

Trade is increasingly flowing through GVCs, where firms in one country produce/import intermediate products (parts and components) to sell to firms in other countries while adding or creating value along the chain. In addition to their traditional specialisation in certain goods and sectors, this worldwide fragmentation enables (or requires) countries to specialise in many tasks related to the production process i.e manufacturing of intermediates, final assembly (OECD, 2012). By expanding on the idea of value addition, involvement in value chains can take place either through backward or forward participation, or even both. Importing raw materials or semi-processed goods, adding value to create a finished or processed good, and exporting it for use in other countries or for final consumption would be considered backward participation. Forward participation would entail exporting raw materials, such as agricultural products or metal ores, for the trading partner to further process and add value to.

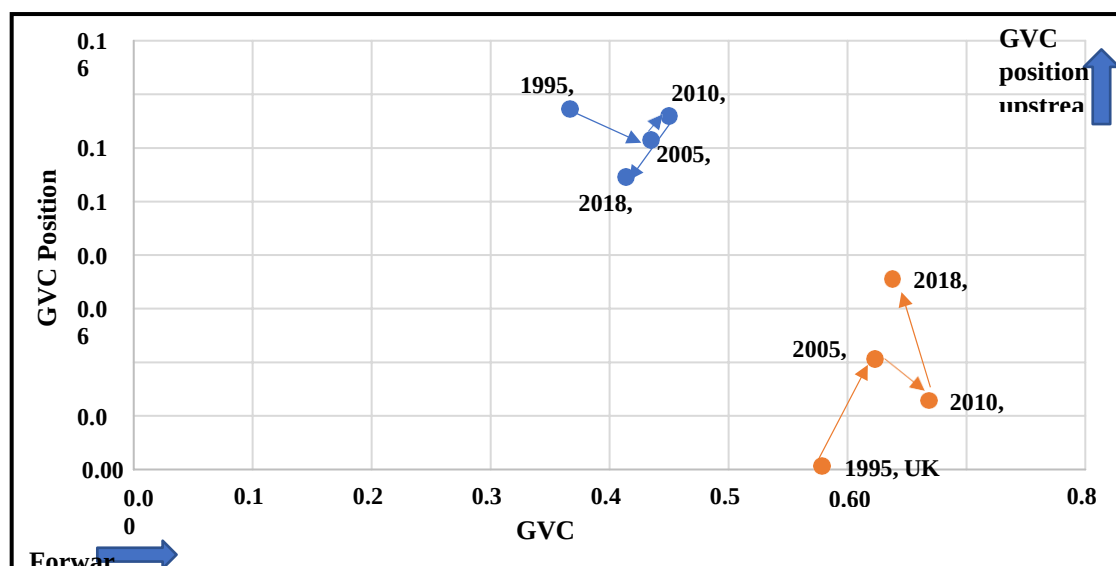
Using the Eora Multi-Region Input-Output (MRIO) database, the interaction between GVC participation and position (Koopman et al. 2014) is shown for India and UK from 1995 to 2018. These two GVC indicators show whether the nations with higher participation indices are comparatively more upstream (defined by position indices), i.e., whether they add more value to the exports of other nations than those of other nations do. Of course, two nations can have the same GVC position index values in one sector while participating in GVCs to quite different extents. The participation index, which summarises the significance of the global supply chain for that country, should therefore be employed in addition to the position index. From 1995 to 2018, Figure-2 shows that India's participation in GVC increased but went downstream implying more import of inputs. For UK, both the GVC participation and position increased from 1995 to 2018. Comparing the two countries in 2018, both of them experienced increase in backward participation. But, India's GVC participation was towards more forward linkage and UK's GVC position was more upstream during the same year.

In GVCs, each member nation's involvement to the creation of a product is minimal and only concerned with value addition. So, in terms of bilateral trade, where each country's value addition to the exports of the other country is calculated, the trends and patterns of this fragmentation of trade are contrasted.

Table-4 shows the amount of India's contribution to UK's exports, which has increased while remaining within the range of 0.8 to 0.27 percent. India's value addition to UK's exports is rising in relation to gross exports. The trend is constant. However, from 1995 to 2018, UK's contribution to Indian exports was comparatively consistent ranging 1.14 to 0.88 per cent. For India and UK's

domestic value addition as a percentage of total exports has been on a similar line, suggesting that India and UK established a production-sharing agreement to change their current trade into one with strong trade complementarities.

Figure-2: Country-Wise Participation in global value chains



Source: Authors' calculation based on EORA Database

Table-4 Share of Value Addition in Exports (%)

GVC Indicators	1995		2005		2010		2018	
	India	UK	India	UK	India	UK	India	UK
Domestic Value Addition	77	71	75	68	74	66	76	67
UK VA in India's Exports	1.14		1.17		1.16		0.88	
India's VA in UK Exports		0.08		0.18		0.23		0.27

Source: EORA database (UK-United Kingdom, VA-Value Addition)

With this background, the most important question that arises is that besides tariff easing and trade liberalisation between these sectors, how the nature of trade has developed and will it be strengthened further through strong and supportable value-added linkages between these sectors. Not much emphasis has been laid on highlighting the bilateral GVC participation between India and the UK. Therefore, this paper focuses on the developmental dimension of the proposed FTA in the context of GVCs. Gaining access to GVCs has allowed sectors to upgrade their technological skills, however the results differ depending on the country or sectors in issue. Many sectors' development paradigms have changed as a result of their integration into GVCs, which has

been made possible by the widespread removal of political obstacles to trade and foreign investment. Falling trade costs through declines in transportation and communication costs have allowed MNCs in pursuit of efficiency to globalise their production. Nowadays, production is sliced into a different sequence of stages of value-creating activities or tasks that are performed in different cost-saving locations across the world (Foster-McGregor et al., 2015; Grossman & Rossi-Hansberg, 2008). In line with the rise of GVC, there is now a large body of literature suggesting that through GVC participation, firms are provided with essential opportunities to access the international markets, specialise in core tasks, access higher quality and sophisticated inputs, and benefits from new ideas, technology transfer, and spill over to stimulate productivity growth and expand the scale of exports (Collier & Venables, 2007; Criscuolo & Timmis, 2017; Pahl & Timmer, 2019).

The proliferation of regional trade agreements (RTAs), preferential trade agreements (PTAs) and FTAs and the growing fragmentation of global production through GVCs have proceeded more or less in tandem in the past decades. FTAs are a class of trade agreements that aim to reduce or eliminate trade barriers, thus promoting international trade⁸. Such agreements usually "center on a chapter providing for preferential tariff treatment", but they also often "include clauses on trade facilitation and rule-making in areas such as investment, intellectual property, government procurement, technical standards and sanitary and phytosanitary issues.

4. Research methodology and variable description

The variables selected for this paper are taken to understand certain aspects of the India-UK trade relations which correspond to the trade complementarity⁹ in the trade pattern of the two countries through which important sectors are identified. Further, the role of intra-industry trade in bilateral trade relation is examined to provide the extent of engagement between the sectors. And, finally the extent of value addition between the countries is witnessed through global value chain participation and position of the sectors concerned.

The panel data is taken for the period 1995–2018 and for nine different sectors namely textiles, wearing apparel, leather, coke and refined petroleum products, chemical and chemical products, pharmaceuticals, medicinal chemical and botanical products, rubber and plastics products, basic metals, electrical equipment, machinery and equipment and motor vehicles, trailers and semi-trailers where the selected time period enables to develop linkages between trade through GVCs, thus predicting the co-integration (long-run relation) among the selected variables. As the data for value-added variable is obtained from UNCTAD-EORA, GVC Database-OECD TiVA (2020), it is seen that the latest available data is till 2018.

The variables are selected for the study based on the existing literature and

theories. The variables have been accessed from various sources for the 1995–2018 period as the value-added data is available until 2018 globally from the database of Trade in Value-added ((TiVA), WTO–OECD (2018)).

The variables considered are as follows–

Gross Exports (GE) – is taken as the dependent variable. Firms perform exports to become more competitive and earn greater revenues. This results in making firm more efficient due to knowledge spill overs (Wagner 2007). The gross exports as a proportion of total exports to world has been taken for both the sectors. Export data is accessed from TiVA database.

GVC participation: Backward and Forward Linkages – to examine the interlinkage between trade, technology, investment and GVC participation, it is important to break down gross trade flows to origins of value-added (Koopman et al., 2014). Participation in value chains could occur through either backward participation or forward participation or through both. Backward participation would imply importing semi- processed or primary products, adding value to produce a consumable or processed product and exporting it for further value addition or final consumption. Forward participation would imply exporting primary products, such as metal ores, agricultural products or textile raw materials, and less processed material for value addition by the trading partner (Hummels et al., 2001; Arora & Siddiqui, 2020, 2022).

Intensive Margins (IM) – The numerous recent studies highlight the important role played by the intensive margin (Bernard et al., 2009; Besedes and Prusa, 2007; Brenton and Newfarmer, 2007; and Helpman et al., 2008). That is, the growth of trade comes primarily from existing trade flows rather than from new trade flows. In this literature, the intensive margin relates to the extent to which the technology is used within countries, industries or firms. These studies (Comin et al., 2008, and Battisti et al., 2009) stress the importance of the intensive margin in explaining the growth of technological usage.

Extensive Margins (EM) – provide an indication of specialisation and diversification of exports. Extensive margin refers in the literature of adoption and diffusion of new technology (Battisti et al., 2009; Comin et al., 2006). Few Studies emphasise the importance of extensive margins in explaining the growth of trade volumes (Hummels & Klenow, 2005; Arora & Siddiqui, 2020).

Bilateral Revealed Comparative Advantage (BRCA) – Balassa (1977) analysed the pattern of comparative advantage for industrial countries. Study found the evidence for existence of an association between the size and diversification of exports and findings suggest that first the export diversification increases with increase in technological development and then decrease with further increase in technological development.

R&D Expenditure (R&D)—the endogenous growth models considered generation of new knowledge through investment in R&D as the major source of technical progress and, hence, growth (Romer, 1990). In India, such a long time have been making efforts to promote technological advancement through indigenous or imports of R&D and technology (Basant, 1997). The impact of technological capability measured in terms of R&D effort on export performance of the firms belonging to India's high-technology sectors has shown significant results. R&D intensity is found to be statistically significant in explaining India's export performance in low-and medium-technology industries (Kumar & Siddharthan, 1994) and even for MSMEs in general in highlighting the relevance of R&D resources involving innovation and technology orientation in achieving superior export performance especially in the form of ICT infrastructure readiness and capabilities (Arora & Siddiqui, 2022).

The data set has both temporal and spatial components, resulting in a panel data structure. The model can be written as follows, based on the foregoing theoretical discussion:

$$GE_{it} = \beta_0 + \beta_1 \text{Backward\_Linkages}_{it} + \beta_2 \text{Forward\_Linkages}_{it} + \beta_3 \text{IM}_{it} + \beta_4 \text{EM}_{it} + \beta_5 \text{BRCA}_{it} + \beta_6 \text{R\&D}_{it} + \varepsilon_{it} \quad (\text{Eq1})$$

GE_{it} represents India's gross exports to the UK in year t . The estimated regression coefficients of export and import variables, as well as learning variables, range from β_0 to β_6 , and it is the error component of the regression equation ε_{it} , which includes sectoral-specific fixed effects and time-specific effects.

5. Data and Methodology Application

The correlation coefficient matrix, shown in Table-5 reveals the direction and intensity of correlations between any two continuous variables. The signs of the Pearson correlation coefficients, r , with respect to dependent variable are mixed. Both forward linkages and bilateral RCA witness positive correlation with gross exports.

Table-5 Correlation Matrix

Variables	GE	Backward Linkages	Forward Linkages	IM	EM	BRCA	R&D
GE	1	-0.3	0.03	-0.09	-0.04	0.28	-0.11
Backward Linkages	-0.3	1	-0.57	0.1	0.27	-0.025	-0.25
Forward Linkages	0.03	-0.57	1	-0.3	-0.34	-0.25	0.3
IM	-0.09	0.1	-0.3	1	0.056	0.65	-0.06
EM	-0.04	0.27	-0.34	0.056	1	-0.098	-0.046

BRCA	0.28	-0.025	-0.25	0.65	-0.098	1	-0.024
R&D	-0.11	-0.25	0.3	-0.06	-0.046	-0.024	1

Table-6 presents the summary statistics focussing on average values for all the sectors and years.

Table-6 Summary Statistics (Mean Values)

Variables	GE	Backward Linkages	Forward Linkages	IM	EM	BRCA	R&D
Mean	0.03	0.24	0.63	0.038	0.041	1.65	0.06
Median	0.02	0.22	0.57	0.03	0.03	1.23	0.05
Maximum	0.15	0.73	1.52	0.14	0.1	11.7	0.15
Minimum	0	0.09	0.1	0	0.01	0.03	0
Std. Dev.	0.02	0.11	0.23	0.029	0.022	1.74	0.03
Observations	216	216	216	216	216	216	216

These variables may not be stationary because the data in the form of 9 sectors and 24 years is longer than the cross-section units, but I(1) and the model is most likely dynamic. In this case, the panel-ARDL (Autoregressive distributed lag) model suggested by Pesaran and Smith (1995) and Pesaran et al. (1999) will be more useful. The panel ARDL model is used instead of other dynamic panel methods like fixed effects, instrumental variables, or GMM estimators proposed by Anderson and Hsiao (1981), Arellano and Bover (1995), which can produce inconsistent estimates of the average value of the parameters unless the coefficients are identical across sectors. The approach for panel data analysis is mostly determined by a preliminary understanding of the qualities of the variables being studied. We begin with a cross-sectional dependence test, followed by a panel unit root test to ensure that the variables are stationary, thereafter, panel cointegration tests, long-run estimation approach, and panel causality test are all performed.

5.1 Cross-Sectional Dependence (CSD) test

There is a possibility of common correlation and shocks between sectors in studies employing panel data analysis across sectors. It occurs primarily when the sectors in question are linked locally or worldwide. The hypothesis of cross-sectional independence is problematic in macroeconomic analysis in this context, as Urbain and Westerlund (2006) explain, because economies are highly interconnected. This is verified by using the Breusch and Pagan (1980) LM test, Pesaran (2004) CD, and Pesaran (2004) scaled LM test in a cross-sectional dependency analysis.

5.2 Panel Unit Root Tests

The panel unit root test of stationary is the second test. As macroeconomic variables are included in our research, non-stationarity of the variables is a possibility. Therefore, examining the order of integration of the variables under investigation is critical for developing a long-term relationship between them. When cross-sectional dependencies are present, the traditional first-generation unit root tests are unreliable and produce biased results. As a result, the presence of unit root is tested using Im et al. (2003) cross-sectionally augmented Im, Pesaran, and Shin unit root test (CIPS) and Pesaran's cross-sectional augmented Dickey Fuller unit root test (CADF), (2007). These tests can reduce the impact of cross-sectional dependencies and provide accurate results estimation. The CIPS and CADF tests are both conducted with the null hypothesis of non-stationarity of the variables versus the alternative hypothesis of otherwise.

The following expression is used to calculate the CADF unit root test statistic.

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + c_i \bar{y}_{t-1} + \sum_{j=0}^S d_{ij} \Delta y_{i,t-j} + \sum_{j=1}^S \delta_{ij} \Delta y_{i,t-j} + \varepsilon_{i,t} \dots \dots \dots (\text{Eq2})$$

Where $\bar{y}$ and $\Delta \bar{y}$ denote the cross-sectional averages of the lagged and first differences respectively. The CIPS unit root test statistic is generated from the CADF regression model through t-statistic, which is as follows:

$$\text{CIPS} = N^{-1} \sum_{i=1}^N \text{CADF}_i$$

After this, panel cointegration analysis is performed.

5.3 Panel cointegration tests

The next phase in the empirical research is to look at long-run relationships between the variables using Westerlund (2005) second generation panel cointegration test, which is based on the Durbin-Hausman principle. The method is valuable because it can handle cross-sectional interdependence and variability in data in a way that first-generation conventional panel cointegration tests can't. The test also doesn't require any adjustments to account for the data's temporal dependencies. It is used for a mix of I(1) and I(0) variables since it does not require prior knowledge of the sequence of integration of variables.

The following autoregressive model based on residuals of initial panel regression (Eq. (1)) is used to test the null hypothesis of no cointegration:

$$\widehat{\vartheta}_{it} = \rho_i \widehat{\vartheta}_{it-1} + u_{it}$$

Where,

$$\hat{Z}_i = \sum_{j=1}^T \hat{\vartheta}_{it} \text{ and } \hat{R}_i = \sum_{j=1}^T \hat{\vartheta}_{it}^2$$

5.4 Panel long-run estimates

After confirming that variables are cointegrated, a group of panel estimators is used to estimate the long-run and short-run relationship. We used three estimators that considered slope heterogeneity and cross-sectional dependence. Mean Group (MG), Pooled Mean Group (PMG), and Dynamic Fixed Effect (DFE) estimators are the three options. The first is the Mean Group (MG) estimator established by Pesaran and Smith (1995), which incorporates a regression model that is applied independently for each panel unit and then the average of the individual coefficients to generate a mean group estimate. Pesaran et al. (1999) used the PMG approach to estimate the short-run and long-run parameters of the Panel Error Correction Model (PECM) using the Autoregressive Distributed Lag (ARDL) approach. Weinhold (1999) proposed the DFE estimator, in which the slopes are fixed but the intercepts are permitted to fluctuate across nations.

The model estimated has the form of an ARDL(p,q,q,...,q) model

$$GE_{it} = \sum_{j=1}^p \alpha_{ij} GE_{i,t-j} + \sum_{j=0}^q \delta_{ij} X_{i,t-j} + \mu_i + \varepsilon_{it} \quad \text{..... (Eq3)}$$

Where X is the vector of explanatory variables. Reparametrizing the model, it turns into:

$$\Delta GE_{it} = \varphi_i (GE_{i,t-1} - \beta_i' X_{it}) + \sum_{j=1}^{p-1} \alpha_{ij}^* \Delta GE_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}^* \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \quad \text{..... (Eq4)}$$

Where the β_i are vector of interest measuring the long-run impact of the explanatory variables on gross exports and φ_i is the error corrector mechanism impact. The short-run coefficients are the last set of parameters. The disturbances are distributed independently across time and units, with a constant mean and variance within each unit.

The Hausman's test is used to evaluate which of the three estimators is the best. The null hypothesis (Ho) of the Hausman Test between MG and PMG is that both are consistent, but MG is inefficient when compared to the alternative hypothesis (H1) that PMG is consistent. When comparing PMG to DFE, the Ho is that DFE is inefficient, whereas PMG's H1 is consistent. Finally, using Hausman selection criteria, the results are analysed to choose the best model.

5.5 Robustness Check

In addition, as part of the robustness analysis, we used Fully Modified Ordinary Least Square (FMOLS) (Pedroni, (2001), in predicting long-run relationships for heterogeneous panels, FMOLS is widely employed to correct biases from the data. A non-parametric technique is used in the FMOLS method. To tackle the problems of serial killers, the Newey West was created.

5.6 Panel Causality Test

Having established the long-run relationship between the variables, the causality test by Dumitrescu-Hurlin (2012) is conducted which is suited for heterogeneous panels, like the one incorporated in our study. This test is used when N is growing and T is constant. Moreover, it can also be used when T>N and when N>T. This test assumes that there is no cross-sectional dependency. Yet, the Monte Carlo simulations show that even under the conditions of cross-sectional dependency, this test can produce strong results. This test is used for balanced and heterogeneous panels.

$$y_{it} = \sum_{k=1}^K \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^K \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \quad \dots\dots\dots (\text{Eq5})$$

Here, K stands for the lag length. Moreover, the panel for the test is a balanced panel. $\gamma_i^{(k)}$ which is an autoregressive parameter, and $\beta_i^{(k)}$, which is the regression coefficient pitch can change among the groups. In addition to these, the tests do not have a random process. This test is a fixed one and has a fixed coefficient model.

6. Empirical Analysis and Results

Table-7 summarises the findings of the cross-dependence investigation. As the sectors under consideration are interconnected internationally and associated culturally, historically, and geographically, there is a significant possibility of cross-sectional dependence among selected variables. For testing cross dependencies, we use the LM test of Breusch and Pagan (1980), the CD test of Pesaran (2004), and the Scaled LM test of Pesaran (2004). At 1% significance level, we reject the null hypothesis of no cross-sectional dependencies in each example. The findings reveal that all of the variables display significant variation across cross-sections. This demonstrates that the variables have cross-sectional dependence.

Table-7 Cross-sectional dependence test result

Variable	Breusch Pagan LM	Pesaran Scaled LM	Pesaran CD
GE	580*	64*	23*
Backward Linkages	448*	48*	19*
Forward Linkages	90*	6.4*	1.19*
IM	216*	21**	10.2*
EM	248*	25*	-2.8*
R&D	324*	33*	3*
BRCA	158*	14*	0.14*

Note: *p ≤ 0.01, **p ≤ 0.05

Second generation panel unit root tests, such as CADF and CIPS, are applicable due to the presence of cross dependence among the variables. Both tests can deal with the problem of cross-section dependence. The CADF and CIPS panel unit root tests are presented in Table-8. Few of the variables are stationary at level and I(1) for both CADF and CIPS. The Westerlund cointegration test requires this criterion.

Table-8 CADF and CIPS panel unit root tests result

Variable	CADF				CIPS			
	Level		First difference		Level		First difference	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend	Intercept	Intercept & Trend	Intercept	Intercept & Trend
GE	-0.276	-14.44			-0.429	-3.39		
Backward Linkages	-0.78	-3.7			-0.69	-0.066		
Forward Linkages	-0.789	-2.49	-3.71	-4.55	-1.43	-2.53	-2.94	-3.06
IM	-1.83	-0.99	-3.89	-3.89	-0.05	-1.39	-2.89	-2.89
EM	-1.17	-2.66	-4.05	-4.03	-1.29	-2.99	-3.89	-3.5
R&D	2.33	-4.17			0.65	-1.92	-4.09	-4.11
BRCA	-3.27	-3.21	-4.24	-4.32	-1.43	-1.41	-3.21	-3.48

Note: In Bold- The test indicates that the variable is stationary at 5%.

Next, the second-generation cointegration test based on the Durbin-Hausman technique is analysed. The test is used to look at the long-term association between the variables.

The variance ratio (VR) test is performed on three different cointegrating equations specifications. For the null hypothesis of no cointegration, Westerlund (2005) developed a pair of VR test statistics. The alternative hypothesis in one variation of the Westerlund test is that the variables are cointegrated in some of the panels. The test results in Table-4 indicates that we reject the null hypothesis of no cointegration at a 10% significance level and accept the alternate hypothesis in both circumstances when the null hypothesis is rejected.

We conclude that the Durbin-Hausman cointegration tests are valid and indicates that at least one cointegrating vector exists in the prototype. We can deduce from these findings that there is a valid equilibrium relationship in the long run.

Table-9 Westerlund test for cointegration

	With Trend		With Demean		With Demean & Trend	
	Variance Ratio	p value	Variance Ratio	p value	Variance Ratio	p value
Ho is No cointegration, and H1 some panels are cointegrated	0.25	0.39	1.33***	0.09	1.04***	0.1

Note: * $p \leq 0.01$, ** $p \leq 0.05$, *** $p \leq 0.1$

Furthermore, we use Pedroni (2004) first generation cointegration test to arrive at a more parsimonious and robust conclusion, despite the fact that this model does not account for cross-sectional dependencies. Table-10 shows the results of the Pedroni cointegration test. The Pedroni tests also include a common null hypothesis of no cointegration, which pits the variables against the alternative hypothesis that they are cointegrated in all panels. We reject the null hypothesis of no cointegration at the 1% significance level for all three possible model parameters and conclude that the variables are cointegrated across all panels. Both the Pedroni and Westerlund cointegration tests indicate that the variables are cointegrated, according to the findings. This implies that there exists a long-run relationship among the variables in our investigation.

Table-10: Pedroni cointegration test

	With Constant		With trend and constant		Without Trend & Constant	
	t statistic	p value	t statistic	p value	t statistic	p value
Modified Phillips-Perron t	-3.23*	0	-3.83*	0	3.04*	0
Phillips-Perron t	-2.77*	0	-3.56*	0	-2.36*	0
Augmented Dickey-Fuller t	-0.66	0.25	-1.1	0.135	-1.8*	0

Note: * $p \leq 0.01$, ** $p \leq 0.05$, *** $p \leq 0.1$

After confirming cointegration, the next step is to estimate the long and short-run relationships between the variables. We chose three types of panel estimators for this: MG, PMG, and DFE. Table-7 shows the results of the Hausman test. This test is used to compare the null hypothesis of MG inefficiency against the alternative hypothesis of PMG consistency.

Table-11: Result of Hausman test

Ho: difference in Coefficients not systematic	MG and PMG	DFE and PMG	MG and DFE
chi²(7)	1.19	0	-2.91
p value	0.99	1	1
Decision	The Ho of homogeneity cannot be rejected	The Ho of homogeneity cannot be rejected	The Ho of homogeneity cannot be rejected
Which model is Good?	PMG	PMG	DFE

The null hypothesis is accepted by the Hausman test, which has a p value of 0.99. Because we cannot reject the null of homogeneity, we can choose a model that allows heterogeneous short-run dynamics in the model with a common long-run influence. As a result, the PMG model is chosen. The result can be seen from Table-12, where we primarily focus on the PMG estimator's results because of the Hausman test results.

Table-12: Panel ARDL Model Result (PMG)

Variable	Long-Run	Short-Run
ECT (-1)		-0.08** (0.02)
Backward Linkages	0.12 (0.14)	-0.11* (0.00)
Forward Linkages	-0.02 (0.63)	-0.07* (0.00)
IM	3.26** (0.01)	-0.55** (0.04)
EM	-4.25** (0.02)	-0.17 (0.13)
BRCA	-0.01 (0.33)	0.01*** (0.05)
R&D	5.52* (0.00)	-0.27 (0.58)
C	0.11 (0.01)	-0.15 (0.019)

Note: * $p \leq 0.01$, ** $p \leq 0.05$, *** $p \leq 0.1$ (p-values are in the parenthesis)

Table-13: Panel ARDL Model Result (Sector-wise)

Variable	Textiles, wearing apparel, leather	Coke and refined petroleum products	Chemical and chemical products	Pharmaceuticals, medicinal chemical and botanical products	Rubber and plastics products	Basic metals	Electrical equipment	Machinery and equipment	Motor vehicles, trailers and semi- trailers
ECT (-1)	-0.003 (0.65)	0.12 (0.16)	0.01 (0.42)	-0.28 (0.00*)	-0.18 (0.05**)	-0.01 (0.54)	-0.02 (0.31)	-0.07 (0.02**)	-0.01 (0.64)
Backward Linkages	0.07 (0.17)	0.05 (0.98)	-0.03 (0.55)	-0.02 (0.91)	-0.26 (0.41)	0.13 (0.03**)	-0.22 (0.12)	0.01 (0.8)	-0.17 (0.28)
Forward Linkages	0.03 (0.11)	-0.02 (0.00*)	-0.02 (0.00*)	-0.05 (0.00*)	-0.18 (0.40)	-0.02 (0.24)	0.02 (0.05***)	0.01 (0.82)	0.13 (0.02**)
IM	0.69 (0.00*)	-0.19 (0.51)	-0.34 (0.01**)	0.05 (0.00*)	-1.65 (0.03**)	-0.58 (0.03**)	-0.99 (0.00*)	-0.09 (0.49)	-1.83 (0.10)
EM	-0.07 (0.84)	0.15 (0.62)	0.05 (0.00*)	-0.69 (0.37)	0.05 (0.00*)	-0.29 (0.40)	0.13 (0.5)	0.05 (0.00*)	-0.74 (0.0**3)
BRCA	-0.01 (0.01**)	0.00 (0.20)	0.05 (0.00*)	0.05 (0.00*)	0.02 (0.00*)	0.02 (0.00*)	0.02 (0.00*)	0.05 (0.67*)	0.02 (0.03*)
R&D	0.07 (0.68)	-2.83 (0.58)	0.94 (0.00*)	-2.36 (0.00*)	1.68 (0.34)	-0.56 (0.04**)	-0.35 (0.70)	0.05 (0.99)	0.94 (0.10)
C	-0.02 (0.00)	-0.01 (0.5)	-0.05 (0.163)	-0.053 (0.163)	-0.34 (0.16)	0.005 (0.56)	-0.003 (0.8)	-0.02 (0.00)	0.015 (0.126)

Note: * $p \leq 0.01$, ** $p \leq 0.05$, *** $p \leq 0.1$ (p-values are in the parenthesis)

PMG-ARDL(1,1,1,1,1,1) model has been calculated. Long-run coefficients are implied in the first portion of the table. As can be seen from Table-13, in the long run, intensive margin and R&D expenditure positively and significantly impact India's gross exports to the UK. GVC participation captured in terms of backward linkages also positively impacts gross exports but it is not significant. However, the impact of forward linkages, BRCA and extensive margin on gross exports has come out negative. By further looking at the sectoral trends, we witness that in the short-run, for textile and clothing and machinery and equipment, the GVC participation positively impacts gross exports of India to the UK. The bilateral export competitiveness (BRCA) of all these products except for textile and clothing, positively and significantly impact gross exports. The support of R&D expenditure performed in these sectors further positively impacts gross exports, particularly for sectors like textile and clothing, chemical and chemical products, rubber and plastic products, machinery equipments and for motor vehicles. Shifts in positioning and diversification into new sectors (IDR, 2016a), knowledge and technology transfer in the form of technology imports from FDI partners, and increased in-house R&D capability are all factors that contribute to successful technological up-gradation in GVCs.

The short-run relationship is seen in the lower half of the tables. The error correction term (ECT) yields the short-run dynamic adjustment results. Because the ECT coefficient is statistically significant, cointegration among the variables in the panel is also statistically significant. We can observe that the error correction coefficient is negative and significant at the 5% level, any deviation from the long-run equilibrium is adjusted in the short run at 8% adjustment speed. The expected sign of the error term is also negative, implying that any departure from the long-run relationship will return to equilibrium in the following period. Similar outcome may be found in all of the MG and DFE variants.

Check for Robustness

Long-run coefficients can be determined using evidence of cointegration. The long-run coefficients can be calculated using a variety of econometric methodologies. We used FMOLS to assess the robustness of the PMG model in this scenario. Table-14 shows the results of the FMOLS test. Because of the high Adjusted R^2 value, the model's explanatory power is quite strong. With this, the sign of the coefficient is also consistent with both the theory and the PMG model results.

Table-14: FMOLS (Dependent Variable-Gross Exports)

Variable	All	Textiles, wearing apparel, leather	Coke and refined petroleum products	Chemical and chemical products	Pharmaceuticals, medicinal chemicaland botanical products	Rubber and plastics products	Basic metals	Electrical equipment	Machinery and equipment	Motor vehicles, trailers and semi- trailers
Backward Linkages	-0.11	0.012	-0.03	-0.05	-0.44	-1.47	-0.102	-0.84	0.29	-0.54
	(0*)	(0.76)	(0*)	0.29	0.035**	(0*)	(0*)	(0*)	(0*)	(0*)
Forward Linkages	-0.058	0.016	-0.005	-0.01	-0.03	-0.7	0.02	-0.62	0.136	-0.15
	(0*)	(0.1)	(0.142)	(0.05**)	(0.45)	(0*)	(0.83)	(0*)	(0.013**)	(0.15)
IM	0.63	0.768	0.188	-0.065	8.69	-2.87	-1.23	0.57	0.06	1.02
	(0.06***)	(0.12)	(0.17)	(0.5)	(0.17)	(0.11)	(0*)	(0.08***)	(0.63)	(0.69)
EM	1.422	0.83	-0.04	1.24	-4.66	-14.56	0.67	0.167	-2.76	-0.309
	(0*)	(0.11)	(0.77)	(0.13)	(0*)	(0.1)	(0.03**)	(0.632)	(0.049**)	(0.67)
BRCA	0.001	-0.05	0.05	0	0.55	-0.012	0.018	-0.012	0.002	0
	(0.58)	(0.198)	(0*)	(0.5)	(0.02**)	(0.036**)	(0*)	(0.28)	(0*)	(0.9)
R&D	0.19	0.307	-3.89	0.6	4.27	2.73	-0.28	1.36	0.06	-0.31
	(0.342)	(0*)	(0*)	(0*)	(0*)	(0.159)	(0*)	(0.078***)	(0.68)	(0.57)
R-Squared	0.55	0.95	0.86	0.93	0.93	0.84	0.97	0.91	0.92	0.80
Adjusted R-Squared	0.53	0.93	0.82	0.91	0.91	0.78	0.95	0.87	0.82	0.72
No. of observations	207	23	23	23	23	23	23	23	23	23

Note: * $p \leq 0.01$, ** $p \leq 0.05$, *** $p \leq 0.1$ (p-values are in the parenthesis)

The results show that GVC participation in the long-run is strengthened with the knowledge created through expenditure on R&D by these sectors. As a result, we can conclude that the PMG is a reliable model for determining the long and short-term relationships between gross exports and GVC participation, trade margins, BRCA and R&D expenditure. FMOLS estimating methodology support similar conclusion.

Finally, we investigate the causal link between the selected explanatory and control variables. The long-run coefficients calculated with PMG and FMOLS, only show the relationship's direction and outcome. They are, however, not suitable for establishing any form of causal relationship. The findings of the heterogeneous pairwise Dumitrescu- Hurlin Panel Causality Tests to assess the causal nexus between the variables under investigation are presented in Table-13.

Table-15 below shows important causality results. It shows that backward linkages unidirectionally causes gross exports. And, gross exports uni-directionally cause both intensive and extensive margins, bilateral RCA and R&D expenditure. Therefore, the strength of GVC participation in impacting the bilateral trade relation between India and the UK gets witnessed.

Table-15: Pairwise Dumitrescu-Hurlin panel causality test (Lags: 2)

Variables	GE	Backward Linkages	Forward Linkages	IM	EM	BRCA	R&D
GE		0.41	0.77	0.03**	0.03**	0.03**	0.6*
Backward Linkages	0.10***		0.89	0.94	0*	0.45	0.26
Forward Linkages	0.43	0.98		0.77	0.65	0.9	0.43
IM	0.32	0.75	0.86		0.6	0.10***	0.46
EM	0.18	0.12	0.44	0.5		0.33	0.51
BRCA	0.85	0.87	0.67	0.79	0.65		0.38
R&D	0.93	0.91	0.5*	0.02**	0.7	0*	

Note: * $p \leq 0.01$, ** $p \leq 0.05$, *** $p \leq 0.1$

When trade and technology variables are incorporated in GVCs, both direct and indirect linkages between them enable functional upgrading. When a firm's technology upgrading trajectory suggests process improvement, it may change from assembly to manufacturing, beginning to incorporate a bigger share of self-produced or locally sourced components with an increase in capabilities (Kaplinsky 2015a). Therefore, for India, all these sectors with different base of technological capabilities and with the help of fragmentation of production processes can further

reap the benefits through trade once India and the UK deepen their trade relations through FTA which focuses on complementing their export competitiveness.

7. Conclusion and Policy Implications

Both of these nations have set an ambitious goal for bilateral trade in products and services to reach \$100 billion by 2030. Even while India only represents for 0.6% of the UK's inward FDI stock and barely 2% of its goods and services imports, the potential for growth on both of these fronts is enormous and far more than with any other country. Additionally, the FTA is believed to immediately provide both sides with major economic benefits. More than 90% of tariff lines may be covered by the agreement, which is likely to be a comprehensive one (an earlier plan called for an interim agreement first). Moreover, it might result in a surge in services trade between the UK and India, which now accounts for 60% of total annual trade between the two nations¹⁰. This FTA being termed as new-age and modern FTA involves broader issues such as labour, climate/environment, digital technology, public procurement, supply chains, e-commerce, gender, health, education and even some evolving sectors, in addition to the traditional pillars¹¹. Albeit, this agreement goes beyond the exchange of trade concessions—they are designed to enable a stronger position for India in the GVCs.

We have included the merchandise side for this paper and the result from the model indicate that for the high-technology sectors (OECD, 2011) such as chemical and chemical products and pharmaceuticals, medicinal chemical and botanical products the GVC participation linkage with gross exports has come out to be negative, however the association is not significant. Further, the competitiveness of the bilateral trade positively boosts India's gross exports to the UK for these sectors. It is for the chemical sector that the expenditure on R&D and extensive margin positively impact gross exports and for the pharmaceutical sector, intensive margin positively impacts the gross exports. Therefore, the support from technology is needed to strengthen the bilateral trade. For the textiles, wearing apparel, leather (low-technology sector), the GVC linkages have a positive relation with gross exports. In fact, the path dependence nature of exports measured in terms of intensive margin also has a positive and significant association with gross exports. The expenditure on R&D also plays a major role in boosting exports in predicting the market trend, quality control and building a brand as well as in managing it, (Arora & Siddiqui, 2020, 2022). The impact of R&D on gross export has come out to be positive in this case. For the base metals and rubber and plastics products (medium low-technology sectors), the role of BRCA in boosting exports significantly has come out positive. For motor vehicles, trailers and semi-trailers sector, the forward linkages have a positive and significant relation with gross exports. And this positive relationship is also witnessed for BRCA and R&D expenditure with gross exports.

The pairwise causality shows a positive relation of all the factors with gross exports, however the backward participation causes gross exports is significant for all the sectors concerned. R&D expenditure significantly causes forward linkages and intensive margin.

Further, intensive margin significantly causes BRCA, thus strong linkage is witnessed between GVC participation, gross exports, BRCA, trade margins and R&D expenditure—underpinning the fact that for both India and the UK, combination of factors are at play in strengthening the trade relationship which is supported by the FTA looking at trade more holistically which reflects the changing paradigm of international economic relations.

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Appendix

1. Trade Complementarity Index

The TC between countries k and j is

defined as: $TC_{ij} = 100(1 - \sum (|m_{ik} - x_{ij}| / 2))$

Where x_{ij} is the share of good i in global exports of country j and m_{ik} is the share of good i in all imports of country k. (We have taken it for different sectors)

2. Sectoral Intra-Industry Index

$$Sectoral\ GII_{sij} = 1 - \frac{\sum s |M_{sij} - X_{sij}|}{\sum s (M_{sij} + X_{sij})}$$

Where, sectoral GII_{sij} represents the sectoral Grubel-Lloyd index of Intra-industry trade between countries i and j.

M_{sij} represents the imports of sectors by country i from j. X_{sij} represents the exports of sectors by country i to j.

The index zero represents pure inter industry trade in the given sector and one indicates pure intra-industry trade in a given sector.

3. Bilateral RCA

A bilateral RCA above one tells that for that particular good that country i have a revealed comparative advantage in country j's market, compared with the rest of the world, which is computed as follows:

$$BRCA_{kij} = X_{kij} / X_{ij} \mid X_{kwj} / X_{wj}$$

Where X_{kij} , X_{ij} are the country i's export of goods k and its total export to country j, respectively. X_{kwj} , X_{wj} are the world's export of goods k and the world's total export to country j. A value of this index smaller than one again reveals a comparative disadvantage but in country j, while index above one represents comparative advantage in country j.

4. Intensive and Extensive Margins

$$IM = \sum X_{ij} / \sum X_{wj}$$

$$EM = \sum X_{ij} / \sum X_w$$

where, x=exports,
i= exporting
country, j= sector
of interest, w=the
world,

4. GVC Participation

$$GVC_{Participation} = \frac{FVA + DVX}{Gross\ Exports}$$

5. GVC Position

$$GVC_{Position} = \ln\left(1 + \frac{DVX}{Gross\ Exports}\right) - \ln\left(1 + \frac{FVA}{Gross\ Exports}\right)$$

Notes

¹ <https://www.gov.uk/government/publications/india-uk-virtual-summit-may-2021-ro> There are no sources in the current document. admap-2030-for-a-comprehensive-strategic-partnership/2030-roadmap-for-india-uk-future-relations

² <https://www.mea.gov.in/bilateral-documents.htm?dtl/33838/Roadmap+2030+for+IndiaUK+future+relations+launched+during+IndiaUK+Virtual+Summit+4+May+2021>

³ <https://www.ciiblog.in/india-and-the-uk-working-towards-a-sustainable-global-future/>

⁴ <https://www.newindianexpress.com/opinions/2022/may/09/india-uk-ties-and-a-sustainable-global-future-2451321.html>

⁵ <https://www.mckinsey.com/~media/McKinsey/Business%20Functions/Operations/Our%20Insights/Ris%20resilience%20and%20rebalancing%20in%20global%20value%20chains/Risk-resilience-and-rebalancing-in-global-value-chains-full-report-vH.pdf>

⁶ <https://www.thehindubusinessline.com/opinion/changing-contours-of-indias-ftas/article65915078.ece>

⁷ <https://timesofindia.indiatimes.com/business/india-business/explained-what-is-the-uk-india-free-trade-agreement-all-about/articleshow/90930976.cms>

⁸ "3 Types of Free Trade Agreements and How They Work". The Balance. Retrieved 2019-03-24.

⁹ Trade complementarity index shows how the exports of a country match the import of the partner country. In other words, it provides a sense of how well two countries are natural trading partners. A value of 100 depicts a perfect overlap of what a country exports, India in this case and what the other country imports, UK in this case. A value of 0 depicts no trade possibility as exports of the country don't match the imports of the other country. The calculation of the index for the product categories shows that the trade basket of India and UK are highly complementary. To identify the products in which India has a comparative advantage, this study calculated the Revealed Comparative Advantage index. An RCA index value greater than 1 show that India has a comparative advantage in that product. A value less than 1 shows that India has a comparative disadvantage in that product. This analysis reveals a list of top products in each category, in which India has a comparative advantage

¹⁰ <https://www.financialexpress.com/economy/free-trade-pact-to-bring-quick-economic-gains-to-india-uk/2656478/>

¹¹ <https://www.financialexpress.com/economy/india-inc-ready-to-embrace-broader-new-age-ftas/2620884/>