The Impact of Digital Technology adoption in Indian Companies on Value Capture in Global Value Chains.

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Abstract:

This study aims to examine the impact of digital technology adoption on value capture within global value chains. It explores the use of a digital capability index within Indian companies to upgrade their products throughout the value chain. To analyze this relationship, an econometric model was constructed and estimated for a group of Indian manufacturing companies participating in global value chains from 2001 to 2022. The study found that an increase in a company's digital capability has a significant positive impact on product development, holding other factors constant. The literature further supports that digital technology adoption helps developing countries transition toward higher value-added activities.

1- Introduction:

Indeed the global trade pattern has experienced noteworthy changes recently years, propelled by globalization and information, and communication technology that today's manufacturing of goods and provisioning of services is done with a mix of products, services, and intermediate inputs sources from around the globe. This production process producing goods and services- is now fragmented in the way that the value chains are formed in both goods and service-providing firms. These value chains play a central role in the process of growth in many developing countries; they take the form of manufactured parts in various components produced in developing countries spread all around the other developing countries.

Such changes have compelled India to reframe its developmental policy since 1991, with a departure towards economic liberalization. It enacted a wide-ranging economic reform program and opened up to the global capitalist economy. India is thus one of the rapidly growing economies, with growth of almost 7.3% since 2018 escalating to 7.7% in 2021. Developing a strong human, scientific, and technological base, India has used allocation to national research centers, institutes, and specific labs as a means of keeping abreast of global developments and occupying strong presences in economic indices, international trade, and global value chains.

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To keep pace with the modern dimensions of manufacturing, India has adopted digital technologies from the Fourth Industrial Revolution, such as 3D printing, the Internet of Things, blockchain, and other smart technologies. These advancements have significant implications for global value chains and value capture, as they enhance manufacturing processes in several ways. For instance, **mass customization** enables products to be tailored to individual needs and demands, allowing for the simultaneous production of various products without additional costs. **Complexity** is another advantage, as these technologies produce items with high levels of intricacy unachievable through traditional methods, leading to more precise product manufacturing. Additionally, **tool reduction** is notable, as these technologies eliminate the need for tool production in low- to medium-volume manufacturing, reducing both costs and lead time. Finally, they enhance **sustainability**, with energy savings of up to 90%, thus reducing energy consumption and extending the operational lifespan of products, resulting in a lower carbon footprint compared to conventionally manufactured items.

Moreover, digital technology significantly lowers production costs. Companies utilizing big data, for instance, can reduce average costs by approximately 8%. This reduction is achieved through the enhanced data management capabilities of technological tools, which allow for precise handling of global and local market data, contributing to cost minimization across value chains. Big data management and analysis further support cost and risk reduction strategies by assessing different suppliers and markets. Robust simulation software offers users a selection of optimal strategies, refining the supply chain based on demand, factory capacity, shipping costs, and other fixed and expected costs. Digital technology also reduces transportation expenses by providing comprehensive information on transportation routes, enabling optimal, cost-effective selections. Additionally, the Internet of Things and autonomous robots streamline energy use and task distribution by minimizing time, materials, and human resources, thereby enabling efficient and profitable low-volume, diverse product manufacturing due to their flexibility, speed, ease of programming, and reconfigurability.

The adoption of digital technology also reshapes the "smile curve" of global value chains, which illustrates the value added across various stages of a product's production, from design to marketing. As digital technology transforms both manufacturing and service sectors, it reduces production costs and reshapes manufacturing processes, often substituting traditional resources like capital and labor. These cost and performance improvements, stemming from digital systems integrated throughout global value chains, lead to a restructuring of production steps. As a result, the smile curve has become flatter and shorter, altering global production geographies and necessitating the relocation of production zones. The entire curve shifts upwards due to overall productivity gains from adopting Fourth Industrial Revolution technologies.

2- Features of the Indian Economic Rise:

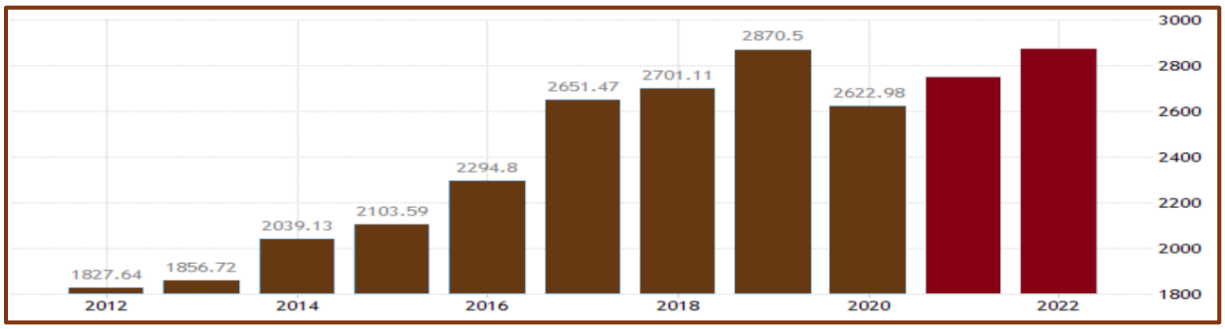
2-1- Evolution of India's Gross Domestic Product (GDP):

India began to adopt free market principles more broadly following the financial crisis of 1991, which enhanced its engagement in international trade. Starting in 1999, the country undertook a series of economic reforms, most notably the development of infrastructure and the establishment of a highway network that facilitated connectivity among industrial,

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agricultural, cultural, and other key regions. This initiative came to be known as the " Golden Quadrilateral' project".

Figure (01): India's GDP (2012-2022)



Source: Tradingeconomics.com, Word Bank

As a result, economic growth rates rose significantly, with World Bank statistics indicating a growth rate of approximately 8.8% in 1999, up from about 1.05% in 1990. With a remarkable capacity for recovery from the impacts of economic crises, India emerged as one of the largest economies in the world, with a gross domestic product exceeding one trillion dollars annually. By 2018, India had become the sixth-largest economy globally and held the fifth position as the world's strongest economy, with a GDP growth rate of 6.8%. This growth can be attributed to the diversity and rapid expansion of its economy, which supports key sectors such as information technology, services, agriculture, and manufacturing, as well as benefiting from its extensive domestic market and skilled labor force.

Over the past 7 years, India has placed a series of initiatives designed to shore up its manufacturing sector, only for the COVID-19 pandemic to hit a devastating blow to the economy. This actually is what happened when a prolonged lockdown with factories closed in masse during the initial months of the pandemic helped in building the capacity and infrastructure for disease containment, which in turn stifled the economy. For the record, India's real GDP had fallen by 23.9 percent during April to June 2020. On a cautious note, there was growth in GDP in the next quarter by 0.4 percent. Though complete rehabilitation may take some more months, fingers are being crossed that India will surge ahead with a very steep growth in its GDP in 2021 and 2022.

Unlike most countries worldwide that relied on the industrial revolution to generate wealth, India followed a different path in its economic transformation, characterized by a shift from an agrarian economy to a service-based economy.

This is evident in Indian GDP data. While agriculture has sharply fallen (from 26% in 1990 to 16% in 2019), services in the same period rose from 37% to 49%, and manufacturing fell marginally from about 16.5% to 13.6% and is far off the pace of rising in a number of other emerging Asian markets.

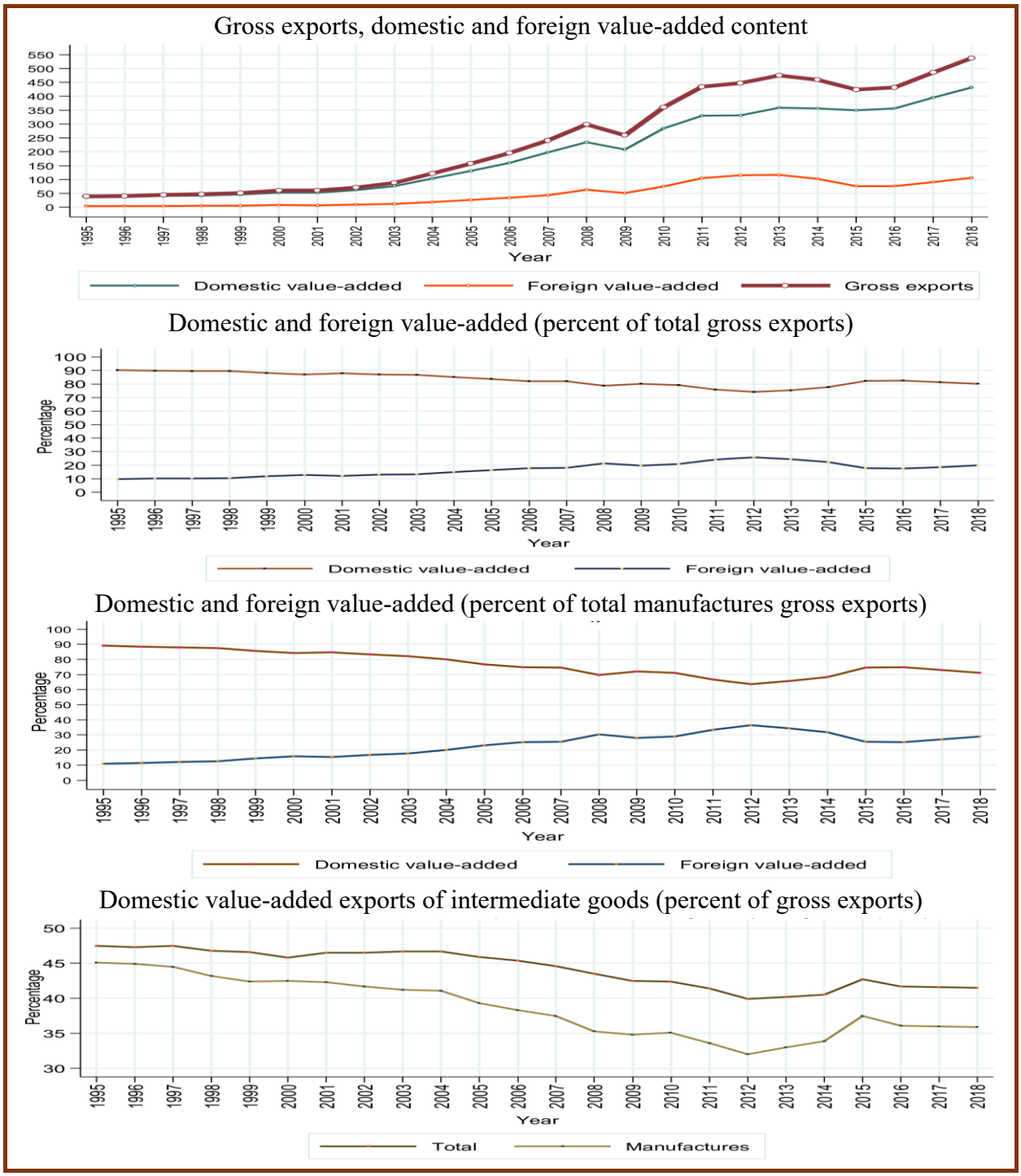
2-2- Evolution of India's Participation in Global Value Chains:

These changes in global value chains have given fresh impetus to the long-standing competition among nations to secure a larger slice of global manufacturing. Every country,

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therefore, will have to come up with a strategy that suits its capabilities and resource endowments.

Figure (02): Trends in India's domestic and foreign value-added 1995 – 2018



Source: Based on OECD TiVA Database 2021

The preceding data indicate that India possesses a comparative advantage in participating in the upstream stages of value-added production within global value chains (GVCs), rather than in downstream segments that rely more heavily on foreign value added. This pattern is largely attributed to India's greater reliance on **domestic value added (DVA)**, which represents

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the share of domestically generated value embodied in intermediate goods exports as a proportion of gross exports, thereby highlighting the contribution of domestic production capabilities to the country's integration into global production networks.

By contrast, India's participation in GVCs through network products remains relatively limited, accounting for less than 10% of its overall involvement in these chains. These products mainly include electronics, computers, and telecommunications equipment. This limited engagement suggests that India's integration into technology-intensive manufacturing sectors remains below the levels achieved by leading Asian economies, where participation in these industries has become a major driver of export competitiveness and higher-value-added production. The same data further reveal that:

- since 2012, India's forward participation in global value chains (GVCs) has exhibited a sustained and progressive upward trend. This expansion has been driven primarily by the machinery and equipment sector, followed by the chemical industry, petroleum and coal products, basic and fabricated metal products, textiles, and agricultural products, respectively. The growing contribution of these sectors highlights India's increasing integration into the upstream segments of global production networks through the domestic supply of intermediate goods and value-added activities.
- n contrast, India's backward participation in global value chains (GVCs) declined significantly from 35% in 2012 to 23% in 2016, indicating a reduced reliance on imported intermediate inputs in domestic production processes. This trend reflects a gradual strengthening of domestic production capabilities and an increasing contribution of locally generated value added within India's manufacturing sector.
- Furthermore, the six aforementioned sectors collectively account for approximately 60% of India's total manufacturing exports within GVCs. Coal and petroleum products constitute the largest share (18.3%), followed by machinery and equipment (14.9%), chemical products (11.2%), basic and fabricated metal products (8.6%), and transport equipment (6.3%), respectively. The concentration of exports in these sectors underscores their strategic importance in enhancing India's integration into global production networks and reinforcing its export competitiveness.

Overall, India has yet to achieve its stated goals of strengthening an export-oriented manufacturing sector, especially when compared to similar economies. In 2019, manufacturing exports accounted for 71% of India's total exports, in contrast to 93% in China and more than 86% in Japan.) (Banga, 2022).

2-3- The features that have enabled India to develop:

It is to deliver in its manufacturing potential that India can hope for sustainable long-term growth, Generally represented by:

2-3-1- Drive:

Despite the Indian government's substantial efforts to promote the manufacturing sector, it has, for the most part, succeeded only in attracting investment flows that have been largely directed toward the services sector and modern technology platforms—particularly through the "Make in India" and "Atmanirbhar Bharat, Self-Reliant India" initiatives" which aims to:

- Labor reforms: The Indian government has enacted new legislation and regulations aimed at regulating wages, ensuring occupational safety, improving working conditions, and

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enhancing social security (Press Information Bureau, 2019). These reforms are expected to enhance the industrial sector by reducing administrative procedures and improving conditions for approximately 400 million workers through the expansion of minimum wage guarantees, access to healthcare, and social security coverage.

- Production Linked Incentives (PLI): India aims to reduce imports and promote exports. To this end, it launched the Production Linked Incentive (PLI) scheme in 2020 to support key sectors through the provision of financial incentives and tax exemptions. Sectors that have benefited from this support include electronics, pharmaceuticals, automobiles and auto components, food processing, renewable energy, battery manufacturing, telecommunications, among others l (Press Information Bureau, 2020).million unorganized, gig and platform workers) (Press Information Bureau, 2020).) (Press Information Bureau, 2020).
- **Transformation of India's Infrastructure Landscape:** India's recent infrastructure reforms have constituted a fundamental pillar in strengthening the country's industrial and manufacturing capacity. A notable example is the **Bharatmala** highway development programme, which significantly accelerated the pace of road construction, increasing average daily completion rates from approximately **12 km in 2014** to nearly **30 km in 2019**. Building on this momentum, the Government of India introduced the **National Infrastructure Pipeline (NIP)** in 2019, a large-scale investment framework that allocated approximately **US$1.8 trillion** in capital expenditure to more than **7,500 infrastructure projects** scheduled for implementation between **2020 and 2025**. The planned investments span a broad range of strategic sectors, including transport, energy, and water infrastructure, with the primary objective of improving the quality and availability of infrastructure services required to enhance manufacturing productivity and industrial competitiveness (Ministry of Commerce and Industry, 2020).
- **Improving the Business Environment.** India has recorded substantial progress in enhancing its business and regulatory environment over recent years. According to the **World Bank's Ease of Doing Business Index**, the country's overall ranking improved markedly from **130th in 2016** to **63rd in 2020**, placing India among the **top ten global reformers** during this period. This improvement was driven by significant advances across several key regulatory dimensions, most notably in **dealing with construction permits**, where India's ranking rose from **183rd to 27th**, **trading across borders** (**133rd to 68th**), **resolving insolvency** (**136th to 52nd**), and **getting electricity** (**70th to 22nd**). These reforms reflect sustained efforts to streamline administrative procedures, improve the regulatory framework, and create a more conducive environment for investment and industrial development.) (World Bank, 2019).

Assessing the Overall Impact of the "Make in India" Initiative. Despite the encouraging performance indicators observed in several strategic sectors, which suggest that the "Make in India" initiative has contributed positively to industrial development and investment promotion, it remains premature to draw definitive conclusions regarding its overall effectiveness. The achievements recorded thus far represent important steps toward structural transformation; however, they still fall short of the ambitious objectives initially

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established by the initiative, particularly those related to transforming India into a globally competitive manufacturing hub and a major destination for foreign direct investment (FDI).

The limited pace of progress can be attributed to a combination of persistent structural constraints, including historical industrial weaknesses, social disparities, demographic pressures, and economic challenges that continue to influence India's development trajectory. While policy reforms, infrastructure investments, and improvements in the business environment have enhanced India's attractiveness for investors, significant challenges remain in terms of strengthening manufacturing capabilities, improving productivity, upgrading technological capacity, and integrating more deeply into global value chains.

Therefore, the success of "Make in India" should be assessed not only through short-term improvements in selected sectors but also through its ability to generate sustained industrial transformation, create high-quality employment opportunities, and enhance India's long-term competitiveness within the global economy.

2-3-2- Demand: Enormous Domestic Market Potential

India's consumer market is projected to grow by 300% by 2030, increasing from USD 1.5 trillion to USD 6 trillion, as the country is expected to become the most populous nation in the world and the third-largest global economy. This growth is anticipated to drive a significant rise in the proportion of middle-income households, reaching around 80%, compared to 50% in 2019 (World Economic Forum, 2020).

With GDP per capita exceeding **US$2,100 in 2019** and continuing to increase despite the economic impact of the COVID-19 pandemic, India appears to be approaching a potential transition toward a faster-growing consumption trajectory. This shift is expected to bring about significant changes in the country's overall consumer expenditure structure, as an increasing number of middle-income households begin to demand higher-value discretionary goods, including automobiles, personal computers, smartphones, and beauty products, in addition to essential consumption items such as food and apparel (World Bank, 2024).

For multinational corporations, India represents a substantial market with significant potential to become the next major source of growth. Moreover, the country can serve as a strategic manufacturing base, enabling companies to expand production within India not only to meet domestic demand but also to supply international markets.

2-3-3- Demographics:

By 2030, India is anticipated to hold the largest workforce globally, with the working-age population estimated to reach around one billion individuals, a figure that would exceed the corresponding labor force levels of both China and the United States. Despite this demographic advantage, India's labor cost structure remains highly competitive, as average and minimum wages continue to be substantially below those prevailing in a number of rival manufacturing destinations, particularly Malaysia and Chinan (World Economic Forum, 2021)

Recognizing the economic potential of its demographic scale, the Indian government has undertaken measures to enhance human capital development and improve workforce capabilities. These efforts include the introduction of vocational education and skill-oriented training within schools as part of the National Education Policy. Through these initiatives, India seeks to transform its population size into a productive advantage that supports its integration

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into global value chains (GVCs) and facilitates greater participation in advanced manufacturing sectors AMSg (World Economic Forum, 2021).

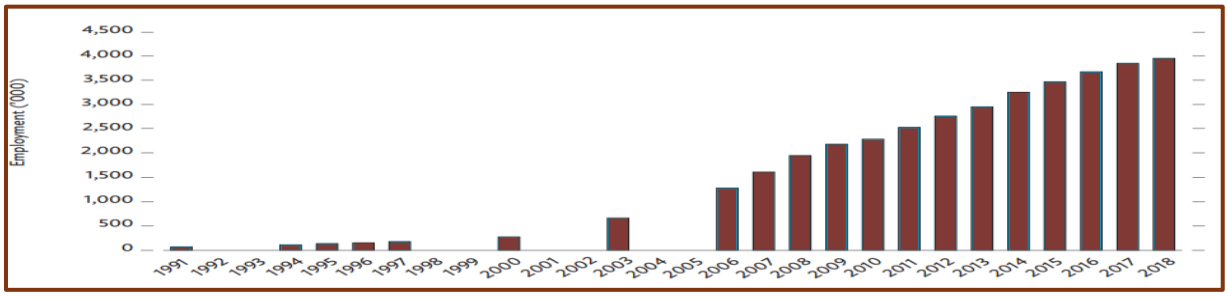
3- India's position in global value chains through the utilization of digital technology

3-1- The development of information technology services employment

India's information technology (IT) sector has experienced remarkable growth, strengthening the country's role within global value chains through digital capabilities. The contribution of IT exports to India's total exports increased substantially from 20% in 2002 to 40% in 2018, with export revenues reaching US$125 billion out of the sector's total revenue of US$167 billion. Consequently, the sector's contribution to national output expanded to 6.1% of GDP in 2018, compared with 3.2% in 2002. This rapid expansion enabled the creation of approximately four million direct employment opportunities in 2018, representing a level of job creation unmatched by any other sector in the Indian economy.

Over the past three decades, employment in the information technology (IT) industry has grown at an average annual rate of approximately 16%, reflecting the sustained expansion and increasing global competitiveness of India's IT sector. In addition, wage levels within the industry increased by 8% to 12% over the previous decade, highlighting the sector's growing economic significance. Furthermore, existing research estimates that IT activities generate substantial indirect employment effects, supporting approximately 12 million additional jobso (Jalote & Natarajan, 2019).

Figure (03): Information Technology Services Employment in India, 1991–2018



Sources: global value chain, development report 2021, beyond production

major obstacle confronting India, as well as many developing economies, in their efforts to integrate into **global value chains (GVCs)** is their substantial dependence on lead firms to overcome both technological limitations and restricted access to international markets. Such dependence can constrain their ability to achieve deeper and more effective participation in GVCs. On the one hand, these economies often lack the capabilities required to perform sophisticated and high-value manufacturing activities; on the other hand, they face difficulties in establishing direct connections with final consumers.

Furthermore, the limited scope of employment opportunities, particularly in routine and repetitive tasks, combined with expectations of long and flexible working hours, has contributed to relatively high employee turnover rates in India. This situation is partly explained by the migration of highly skilled workers toward final-demand markets, where greater opportunities are available. As a result, annual labor turnover in Indian call centers can reach approximately **44%**s (Nano & Victor, 2021). The combination of intense customer-related pressures and the repetitive nature of these occupations creates additional challenges for maintaining high levels of worker productivity.

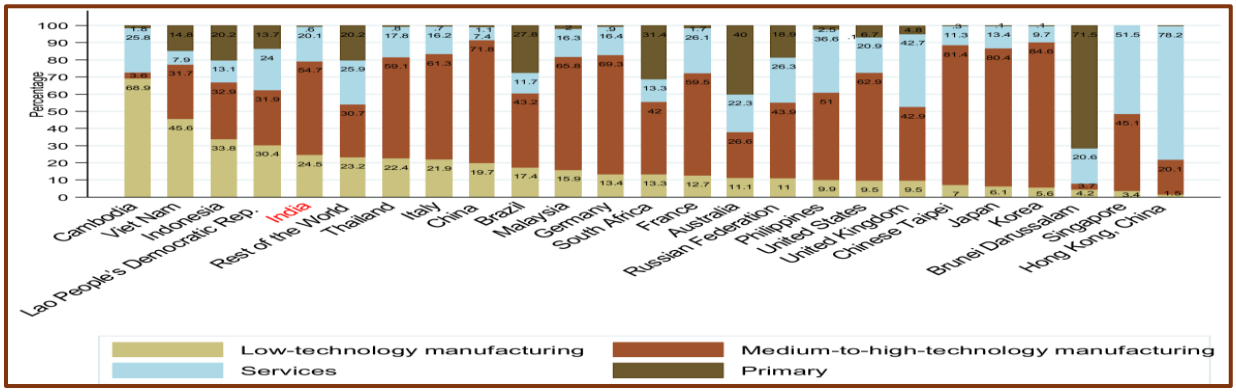
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3-2- India's comparative advantage in medium to high-tech manufacturing:

Companies are increasingly responding to these challenges by accelerating their investments in **artificial intelligence (AI)** technologies, which are now capable of performing routine and low-skilled tasks traditionally associated with information technology (IT) and business process outsourcing (BPO) activities. Evidence from the **People's Republic of China (PRC)** indicates that, despite the growth in call center revenues in **2018**, the number of call center employees declined by **161,000 workers**, representing a reduction of more than **30%**.

The adoption of AI enhances productivity by automating simple, repetitive, and labor-intensive tasks, allowing firms to achieve greater operational scale without a corresponding increase in employment or wages, particularly at the lower levels of the employment structure in these industries. Similar to the impact of automation on low-skilled manufacturing jobs, the expansion of AI-based technologies is expected to intensify competitive pressures on routine occupations. As AI systems continue to develop more advanced capabilities, these pressures are likely to extend progressively toward higher levels of the skills hierarchys (World Trade Organisation, 2019).

Figure (04): Industry foreign value-added contribution to gross exports (percent), 2018.

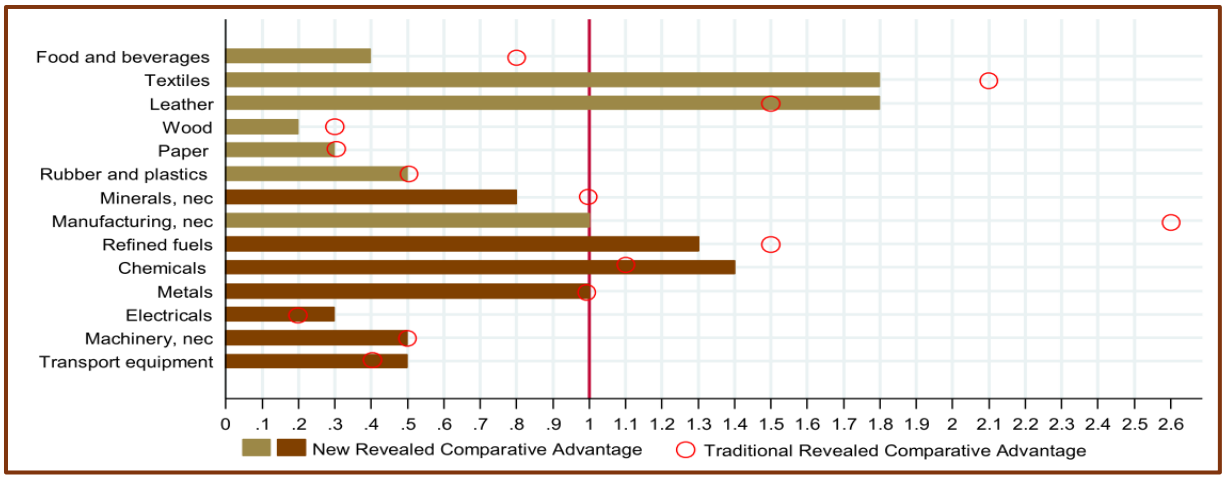


Source: Based on OECD TIVA Database 2021

The **Traditional Revealed Comparative Advantage (TRCA) index** is a widely used measure for evaluating a country's export specialization by comparing the proportion of a particular sector within the country's total exports with the corresponding sector's share in global exports. A value of the index exceeding **1** indicates that the country demonstrates a revealed comparative advantage in that sector, implying that its export performance is stronger than the international average. In contrast, a value below **1** suggests the absence of a comparative advantage, as the country's export specialization in that sector remains lower than the global benchmark. The **Revealed Comparative Advantage (RCA)** indicator is commonly applied to analyze the degree of trade specialization of an economy and to determine its relative position in international markets regarding competitiveness in the export of specific goods and services (Asian Development Bank, 2022).

Figure (05): India's . India's revealed comparative advantage traditional and new (Low and Medium to High Technology manufacturing)

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Source: Based on ADB 2022

The **GVC activity-adjusted Normalized Revealed Comparative Advantage (NRA)** index, which is derived from **value-added exports**, provides a more comprehensive assessment of international competitiveness than the conventional **Revealed Comparative Advantage (RCA)** measure based on gross exports. By incorporating domestic value added embodied in exports, the indicator offers a more accurate representation of sectoral specialization. An **NRA value exceeding one** indicates that the domestic value generated by a particular sector is embodied in the economy's exported products, thereby revealing a comparative advantage in that sector.

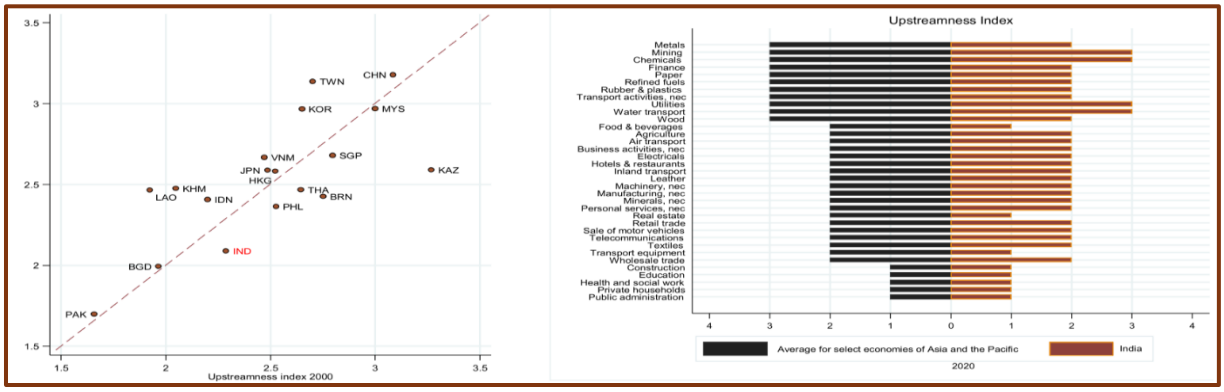
For **2020**, the comparison between the two indicators reveals several differences in sectoral specialization. In **agriculture** and **utilities**, sectors that exhibited a revealed comparative disadvantage under the traditional RCA measure recorded a comparative advantage when evaluated using the NRA index. Within **low-technology manufacturing**, both indicators produced broadly consistent results, confirming a comparative advantage in the **textiles** and **leather** industries. However, the comparative advantage previously identified in **minerals, n.e.c.** and **manufacturing, n.e.c.** under the conventional measure disappeared once exports were assessed on a value-added basis. Likewise, in **medium- and high-technology manufacturing**, both indicators consistently identified comparative advantages in **refined petroleum products**, **chemicals**, and **metals** (Fig. 16b).

A similar pattern is observed in the **services sector**. Both gross-export and value-added measures identify revealed comparative advantages in **telecommunications**, **air transport**, **business activities, n.e.c.**, **inland transport**, **personal services, n.e.c.**, and **private households**. By contrast, sectors such as **education**, **financial services**, and **retail trade**, which appear to have a revealed comparative disadvantage under conventional trade statistics, display a revealed comparative advantage when exports are measured in value-added terms. As emphasized by the **Asian Development Bank (2022)**, identifying these "hidden" sources of specialization contributes to a more comprehensive understanding of the positioning of firms, industries, and national economies within **global value chains (GVCs)**. Conversely, **construction**, **hotels and restaurants**, **real estate**, **transport activities, n.e.c.**, and **water transport** continue to exhibit a revealed comparative disadvantage under the value-added approacht (Asian Developmant Bank, 2022)

3-3- The direction India is taking in global value chains :

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Figure (06): Upstreamness index, Asia-Pacific, 2000-2020 Medium-to-high-technology manufacturing (The indices are rounded to integers to highlight the index as a measure of the average number of discrete stages it takes for an output of sectors in rows to reach its final consumers)



Source: Based on ADB 2022

The figure illustrates significant changes in the positioning of economies within global value chains (GVCs) between 2000 and 2019. During this period, several emerging and advanced economies in the Asia-Pacific region, including China, Chinese Taipei, Viet Nam, Lao PDR, Cambodia, Korea, and Japan, moved toward more upstream positions in GVCs. This indicates a greater role in supplying intermediate inputs to other economies, with their production activities becoming relatively more distant from final consumer demand.

In contrast, India shifted toward a more downstream position in medium- and high-technology manufacturing, reflecting a greater proximity of its output to final demand compared with upstream activities. Similarly, Kazakhstan and Brunei Darussalam experienced the largest declines in the number of production stages separating their sectoral outputs from their productive utilization.

Within the manufacturing sector, the positioning of industries varies considerably. Activities such as metals and chemicals are generally located closer to the upstream segments of GVCs, while sectors including textiles and electrical products tend to occupy relatively downstream positions. Compared with the average position of Asia-Pacific economies, India is more downstream in sectors such as paper, refined fuels, rubber and plastics, wood products, food and beverages, and transport equipment.

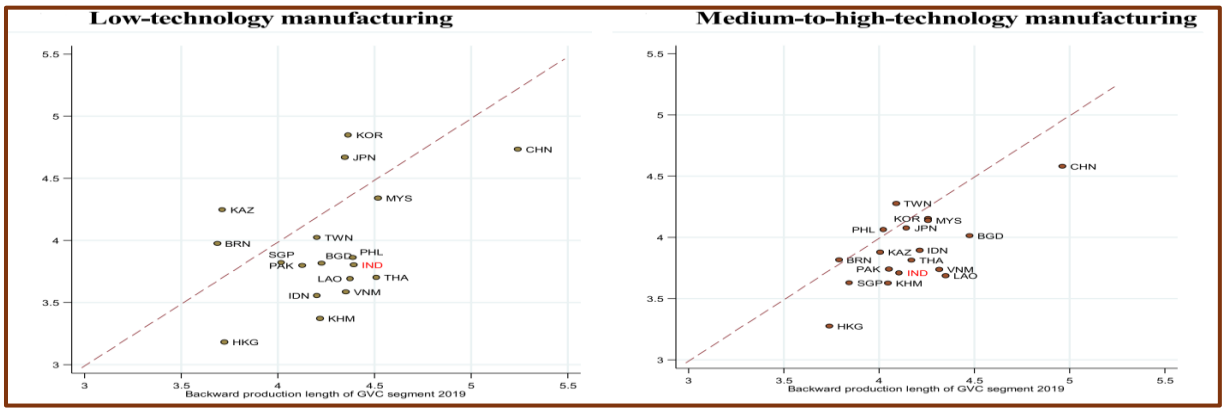
The assessment of GVC positioning is based on indicators that measure both the length and location of production stages within global value chains. These indicators isolate the GVC-related segment of production chains by excluding activities associated with purely domestic production processes and traditional trade networks. The backward GVC length indicator measures the average number of production stages between the final consumption of products generated by economy *s* and sector *i* within GVCs and the sources of their value added. A higher value indicates that production activities are located further from final demand, implying a more downstream position within the chain.

Conversely, the forward GVC length indicator captures the average number of stages separating the creation of value added by economy *s* and sector *i* from the final consumption of products involved in GVCs. A larger value reflects a longer forward production chain and therefore indicates a more upstream position. Accordingly, when the forward GVC length

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exceeds the backward GVC length, an economy is considered to occupy a relatively upstream position within global value chains (Antras & Chor, 2013).

Figure (07): Positioning of Asia-Pacific economies in the GVC, backward (forward) length of the GVC segment, 2019



Source: Based on ADB 2022

The figure illustrates the **average production length of the GVC segment (forward and backward linkages) in low-technology manufacturing** across Asia-Pacific economies in **2019**. The relatively high values recorded for **China** indicate its participation in extended value chains involving a large number of production stages, both upstream and downstream, compared with economies such as **Hong Kong**, where production chains are considerably shorter. Furthermore, while **Japan, Korea, Kazakhstan, and Brunei Darussalam** occupy relatively upstream positions within these value chains, economies including **Viet Nam, Thailand, and India** are positioned closer to downstream activities.

The same pattern is observed in **medium- and high-technology manufacturing** in **2019**. Similar to the case of low-technology industries, the results show that **China** is integrated into relatively long production networks, unlike **Hong Kong**, where value chains are shorter. In this category, **Chinese Taipei** occupies a more upstream position, whereas countries such as **Cambodia, Viet Nam, and India** are located further downstream within the production process.

The **GVC Position Index** focuses exclusively on cross-border production-sharing activities occurring within global production networks. It is defined as the ratio between the **forward and backward production lengths** of the GVC segment. A value of the index greater than **1** indicates that economy *s* and sector *i* are relatively positioned upstream within global value chains.

By excluding purely domestic production and consumption activities, the GVC Position Index provides a different perspective from traditional trade measures. Under this approach, traditionally non-tradable sectors, such as **utilities and services**, may appear as upstream activities within value chains, whereas many manufacturing industries, including **textiles, leather and apparel, electronics, and machinery**, tend to be positioned downstream.

In the **Computer, Electronic and Optical Products** sector, economies specialized in assembly and processing activities, such as **China, Indonesia, and Mexico**, together with advanced economies including **Germany, France, and the United States**, are located at the

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downstream end of the value chain due to their involvement in the final stages of production. Conversely, resource-rich economies such as **Australia and Russia** occupy more upstream positions by supplying essential energy and mineral inputs required throughout the value chain.

In the **Textiles and Leather** sector, **India ranks third from the bottom**, alongside **Indonesia and Chinese Taipei**, reflecting their position closer to the final stages of production. In contrast, **Russia** occupies the highest upstream position due to its role in providing natural resource-based intermediate inputs. **Japan** also maintains a relatively upstream position by supplying more technologically advanced manufactured intermediate goods to the production process (Wang & Wei, 2017).

4- The impact of digital technology utilization on product upgrading in companies participating in Indian GVC :

4-1- Econometric model :

At the country level, digital transformation is commonly evaluated using a range of indicators, including robot density, the expansion of e-commerce, the digital integration of manufacturing activities, and internet penetration rates. However, at the firm level, particularly among Indian manufacturing enterprises, comprehensive data regarding the adoption of digital technologies, robotics, and e-commerce applications remain limited. Therefore, assessing firms' digital capabilities provides a more relevant approach, as it captures their underlying capacity to adopt and utilize advanced technologies, such as cloud computing and robotics.

Accordingly, this study does not focus on a specific technological innovation or individual digital achievement. Instead, it develops a firm-level digital capability index designed to measure the extent to which firms possess the necessary technological resources. The index is constructed using three main categories of information:

(1) communication and transport infrastructure;

(2) technological assets, including gross plant, machinery, computers, and electrical installations; and

(3) software-related assets of the firm.

The index is estimated through Principal Component Analysis (PCA), based on the proportion of software, technology, and communication assets relative to total firm sales. To verify the statistical reliability and suitability of the PCA methodology, the study applies the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity. The results, represented by a KMO statistic of 0.67 and a Bartlett test p-value of 0.000, confirm the validity and robustness of the digital capability index (Banga, 2019).

An increase in the PSI_{it} index reflects improvements in product upgrading at the firm level. Such upgrading may occur through the introduction of new and increasingly sophisticated products, for example, a transition from bicycle manufacturing to automobile production, or through a shift in sales toward higher-complexity goods. Firm-level product sophistication is expected to demonstrate considerable persistence over time due to production path dependencies, as firms often face substantial costs related to market exploration and adjustments in their production structures.

For this reason, the study incorporates lagged values of firm-level product sophistication into the empirical models to control for its historical effects. Specifically, the analysis includes $PSI_{it\ t-1}$ and $PSI_{it\ t-2}$ as explanatory variables.

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Based on the existing literature, the baseline empirical specification adopted in the study examines the relationship between digital capability and the average product sophistication of GVC firms (i) at time (t), as presented in the following models (Karishma, 2017):

$$\text{Log}(PSI_{it}) = \alpha_0 + \alpha_1 \log(PSI_{it})_{t-1} + \alpha_2 \log(PSI_{it})_{t-2} + \beta_1 \log(\text{digital capability})_{it} + \beta_2 \log(\text{skilled babour share})_{it} + \beta_3 \log(\text{R \& Dintensity})_{it} + \beta_4 \text{HHI}_{jt} + \beta_5 X_{it} + \alpha_i + \alpha_t + \alpha_j + e_{ijt} \ldots$$

We expect the coefficients on the lagged sophistication variables, digital capacity, share of skilled labor, and R&D intensity to be positive and significant. HHI is the proxy for the effect of industry concentration, but it is unclear. If it is positive, then firms in higher HHI sectors are making more profits. These profits are then plowed back into purchasing more sophisticated lines. A negative HHI would indicate that firms in highly concentrated industries enjoy a reduction in competitive pressure and, therefore, lower incentives for innovation.

The variable $\mathbf{X_{ijt}}$ represents a group of firm-specific characteristics, including **firm age, size, foreign ownership share, labor productivity, and product scope** (i.e., whether firms specialize in a single product or operate across multiple product lines). These variables are incorporated into the model to control for their potential influence on product sophistication.

The expected impact of **firm age** remains theoretically ambiguous. On the one hand, a positive relationship may indicate that older firms benefit from accumulated experience through **learning-by-doing**, have developed stronger market positions, and are therefore capable of producing more sophisticated products. On the other hand, younger firms, as new market entrants, may possess stronger incentives to innovate and introduce higher-quality products due to their need to establish competitiveness, which could result in a negative relationship between age and product sophistication.

Firm size is expected to have a positive effect, as the development of innovative and technologically advanced products generally requires substantial financial and organizational resources. Larger firms are better positioned to undertake innovation activities because they can absorb the significant costs associated with research, development, and the commercialization process before new products successfully reach the market.

The coefficient associated with **foreign ownership share** is also expected to be positive, given that foreign participation can generate knowledge spillovers and facilitate the transfer of advanced technologies, managerial practices, and skills to domestic firms.

However, the expected relationship between **product scope** and product sophistication is less clear. While expanding product lines may enhance sophistication by encouraging firms to explore new technologies and develop more advanced products, some firms may instead broaden their product range primarily to exploit economies of scale and increase market returns, resulting in the production of additional but relatively less sophisticated goods.

Finally, the model controls for unobserved heterogeneity through fixed effects at different levels: **firm-specific effects, industry effects, and time effects**, represented respectively by **a(i), a(j), and a(t)**. (Karishma, 2017).

4-2- Empirical results: impact of digital capability on product sophistication

The empirical analysis is based on a panel dataset of **Indian GVC manufacturing firms** covering the period **2001–2022**, with the objective of examining the determinants of increasing product sophistication. The data are obtained from the firm-level database **Prowess**. To ensure

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data quality and consistency, observations with missing or negative **NSS values** for sales were excluded, as well as firm-year observations characterized by **intensity values exceeding 100**.

Given the emphasis in the existing literature on the role of both **digital capabilities and technological competencies** in enhancing product sophistication, this study investigates differences in firms' product sophistication according to their level of digital capability. The dataset allows for the identification of whether economically capable firms exhibit persistently higher levels of product sophistication compared with digitally less advanced GVC firms, defined as those whose digital capability and skill levels fall below the median threshold. The measures of product sophistication and the digital capability index are derived from the **GVC panel of Indian manufacturing firms** and represent average values over the period **2001–2022**. For presentation purposes, the values of the digital capability index are multiplied by **100**.

In the empirical model, **product sophistication** is specified as the dependent variable, while **digital capability** represents the main explanatory variable. The relationship between these variables is estimated using **system GMM methodology**, with the results presented in the subsequent table.

The first specification (**Model 1**) examines the relationship between current product sophistication and its previous values in order to account for the persistence of firm-level sophistication over time. It also incorporates controls for **foreign ownership share** and the proportion of **skilled labor**.

The second specification (**Model 2**) extends the analysis by introducing the **Herfindahl–Hirschman Index (HHI)** to capture the influence of industrial concentration. The third specification (**Model 3**) adds **R&D intensity** to control for firms' internal innovation efforts and their contribution to product upgrading.

Finally, **Models 4 and 5** include additional controls related to **firm size and firm age**. All model specifications incorporate **time fixed effects** to account for economy-wide shocks and temporal variations, including events such as India's economic expansion during **2003–2004** and the global financial crisis of **2008–2009**.

Table(01) : Dependent variable: firm-level product sophistication (PSit) Standard errors in parentheses *** p < 0.01, ** p < 0.05, * p < 0.1.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
L. (PS_{it})	0.842***	0.841***	0.846***	0.793***	0.796***
	(0.0419)	(0.0419)	(0.0419)	(0.0462)	(0.0451)
L2. (PS_{it})	0.0886	0.0872	0.0852	0.0961	0.103*
	(0.0570)	(0.0571)	(0.0583)	(0.0580)	(0.0571)
Digital capability	0.0103*	0.00989*	0.0104*	0.0109*	0.0117**
	(0.00589)	(0.00586)	(0.00579)	(0.00572)	(0.00569)
Skilled labour share	0.00709***	0.00718***	0.00776***	0.0205***	0.0184***
	(0.00182)	(0.00183)	(0.00184)	(0.00482)	(0.00364)
Foreign shares	2.96e-05	2.86e-05	4.08e-06	-0.000232	-0.000191
	(0.00208)	(0.000208)	(0.00202)	(0.000207)	(0.0041)
HHI		0.0199**	0.0189**	0.0217**	0.0209**
		(0.00829)	(0.00841)	(0.00956)	(0.00973)
R&D intensity			0.000711	0.000242	0.000344
			(0.000759)	(0.000819)	(0.00084)
Firm size				0.0219***	0.0191***
				(0.00731)	(0.00609)
Firm age					-0.014***
					(0.00461)
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
Hansen *p*-value	0.13	0.15	0.19	0.41	0.48
AR(2)	0.11	0.10	0.11	0.18	0.18
Observations	2128	2128	2128	2128	2128
Number of firms	532	532	532	532	532

Source: Prepared by the Researchers Based on the EVIews outputs

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The diagnostic tests confirm the robustness and reliability of the estimated specifications. The **p-values of the AR(2) test statistic** remain above the **5% threshold** in all models, indicating the absence of second-order serial correlation in the residuals. Likewise, the **Hansen test statistics** consistently report p-values higher than **0.05**, suggesting that the instruments employed in the estimations are valid and exogenous. These results confirm the appropriateness of the **system GMM estimator** and support the validity of the empirical framework adopted in this study.

Across all model specifications, the coefficient associated with lagged product sophistication remains **positive and statistically significant**, indicating a strong persistence effect in firms' upgrading trajectories. This finding suggests that product sophistication is not achieved instantaneously but rather results from cumulative processes involving knowledge accumulation, technological learning, organizational capabilities, and previous innovation experience. Such dynamic characteristics are consistent with the modern view of competitiveness, which emphasizes the importance of building long-term capabilities rather than relying solely on static cost advantages.

The positive and significant coefficient of the **Herfindahl–Hirschman Index (HHI)** indicates that firms operating in more concentrated industries tend to achieve higher levels of **product sophistication (PS)**. Specifically, a one-unit increase in industrial concentration is associated with an approximate **2% increase in firm-level product sophistication**, ceteris paribus. This relationship can be explained by the greater financial capacity and market power of firms operating in concentrated industries, which may enable them to allocate more resources toward technological upgrading, product differentiation, and innovation activities. In the context of global value chains (GVCs), firms with stronger market positions are often better equipped to move toward higher-value-added segments rather than remaining limited to standardized production activities.

Although **R&D intensity** does not appear to have a statistically significant impact on product sophistication, this result does not necessarily imply that research activities are irrelevant. Rather, it may reflect the fact that innovation outcomes depend not only on formal R&D expenditure but also on complementary capabilities, including digital infrastructure, managerial efficiency, access to global knowledge networks, and the ability to absorb external technologies. In emerging economies, product upgrading is increasingly influenced by a combination of internal innovation efforts and external knowledge transfer mechanisms.

The results also show that **larger firms produce more sophisticated products**, confirming the importance of scale economies in supporting innovation and technological advancement. Large enterprises generally benefit from greater financial resources, stronger organizational structures, broader market access, and higher capacity to adopt advanced technologies. These advantages allow them to undertake costly product development processes and integrate more effectively into higher segments of global production networks.

Regarding firm age, the findings indicate that **younger firms tend to exhibit higher levels of product sophistication**. While older firms may possess accumulated experience, established market power, and stronger production capabilities, younger enterprises often face greater competitive pressure, encouraging them to innovate, differentiate their products, and rapidly adopt new technologies. This pattern reflects the growing importance of agile firms in modern

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economies, where adaptability, digital capabilities, and continuous upgrading have become essential sources of competitiveness.

Overall, the empirical results highlight that product sophistication among Indian GVC manufacturing firms is shaped by a combination of firm-specific characteristics, industry structure, and dynamic capabilities. The findings suggest that improving participation in higher-value segments of global value chains requires not only increasing production capacity but also strengthening technological capabilities, digital transformation, and innovation-oriented strategies.

No noted significant foreign influence or acquisition with respect to the sophistication at the product level. The justification behind this is that foreign firms may be pursuing cost reducing strategies in India, value of sophistication may not be due to foreign-owned plants in developing countries. Foreign firms in India may, after all, develop incomplete low-technology products at a cheap price and then export them back to their home country. Stressing on the effects of FDI, although foreign direct investment does not have a direct effect on the level of product sophistication in firms based in India, there exist meaningful and positive effects on vertical backward FDI spillovers. These vertical backward linkages measure how much contact there is between Indian suppliers and their downstream industry customers and, further, how high the incentives are for foreign buyers to transfer their knowledge and technology to these suppliers.

Regarding the main firm-level variables of interest, namely **digital capability** and the **share of skilled labor**, the results show a positive and statistically significant relationship with product sophistication. The coefficient of digital capability remains positive and significant at the **10% level** across all model specifications, indicating that firms allocating a larger share of their sales to **software, technology, and communication assets** tend to produce more sophisticated products.

This result suggests that investment in digital capabilities enables firms to upgrade their product lines and participate in higher value-added activities within **global value chains (GVCs)**. Similarly, the share of skilled labor has a positive and significant effect on firm sophistication, confirming the important role of qualified workers in supporting the production of more complex and technologically advanced goods.

4-3- Confirm the results economically :

The empirical findings of this study regarding the positive impact of digital capability on firms' upgrading and participation in global value chains (GVCs) are consistent with previous research examining the relationship between digital transformation and international production integration. A growing body of literature confirms that the adoption of digital technologies enables firms to overcome traditional barriers associated with distance, information asymmetries, and coordination costs, thereby facilitating access to foreign markets and strengthening connections with international suppliers, distributors, and customers.

According tot (Fedyunina, Gorodnyi, & Simachev, 2023). digital infrastructure and information and communication technologies (ICTs) contribute significantly to firms' competitiveness, export performance, and their ability to participate in GVCs. Their analysis highlights that digitalization facilitates more efficient coordination among globally dispersed actors, allowing firms to exchange knowledge, manage international production relationships,

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and integrate progressively into global production networks. Using firm-level evidence, their results show that enterprises adopting digital solutions, particularly **high-speed internet and website technologies**, are **6–10% more likely to participate in GVCs**. These findings are particularly relevant for **small and medium-sized enterprises (SMEs)**, as digital tools reduce entry barriers, improve market visibility, and allow smaller firms to access international production opportunities that were previously dominated by larger corporations. The study also demonstrates that digital adoption remains important for financially constrained firms and firms located in smaller economic agglomerations, confirming the inclusive potential of digital transformation (Fedyunina, Gorodnyi, & Simachev, 2023) .

The results obtained by (Banga, Digital technologies and "value" capture in global value chains: Empirical evidence from Indian manufacturing firms, 2019) provide further confirmation of the role of digital capabilities in promoting product upgrading and higher value capture within GVCs, particularly in the context of Indian manufacturing firms. The study demonstrates that digital competence, measured through firms' ownership of **software, technological assets, communication infrastructure, and the availability of skilled labor**, represents a significant determinant of product sophistication. Firms characterized by stronger digital capabilities achieve an average level of product sophistication that is **4.5–5.5% higher** than firms with lower digital capabilities. These findings support the argument that digitalization is not merely a mechanism for improving operational efficiency but also an important capability that enables firms to move toward more complex products and higher-value-added activities within international production networks.

Furthermore, Banga's (2019) results indicate that other firm-level characteristics, including lagged product sophistication, firm size, industrial concentration measured by the **HHI index**, and, to some extent, R&D intensity, positively influence product upgrading among Indian GVC firms, while firm age has a negative effect. These conclusions are consistent with the results obtained in the present study, particularly regarding the importance of accumulated capabilities, scale advantages, and digital resources in enhancing firms' ability to produce more sophisticated goods.

Similarly, the study conducted by (Gopalan, Ketan , & Subash, 2022) provides additional empirical evidence on the relationship between firm digitalization and GVC participation. Using a dataset covering **24,839 firms across 52 emerging and developing economies over the period 2006–2018**, the authors examine whether digital adoption increases firms' likelihood of joining global production networks while controlling for potential self-selection and reverse causality issues. Their findings confirm that digitalization efforts are significant drivers of GVC participation, with firms adopting **high-speed internet and website-based technologies** exhibiting a **6–10% higher probability of participating in GVCs**.

Moreover, Gopalan, Ketan, and Subash (2022) emphasize that the benefits of digital transformation extend beyond large corporations, as SMEs appear to gain substantially from improved digital capabilities. This result has important policy implications, particularly for developing economies where smaller firms often face financial, informational, and technological constraints when attempting to access international markets. Their findings also show that internet adoption enhances GVC participation among firms located in smaller

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agglomerations, suggesting that digital connectivity can reduce geographical disadvantages and promote broader integration into global production networks.

Overall, the existing empirical literature strongly supports the results of this research by confirming that digital capability constitutes a fundamental driver of firms' upgrading strategies and their ability to capture greater value within GVCs. The evidence suggests that digital transformation, when combined with skilled labor and complementary firm capabilities, enhances not only export participation but also the movement toward more sophisticated and higher value-added production activities.

5- Conclusion:

The emergence of global value chains has provided a new path for industrial formation worldwide. Internationally segmented production has allowed India to join existing production chains rather than build them from scratch or manufacture entire products—an undertaking that requires substantial resources and capabilities. This opportunity has provided India with numerous advantages; however, it has also necessitated that India keep pace with evolving production dynamics in global value chains. Consequently, India has adopted technological and knowledge-based advancements, enabling it to diversify its product offerings and advance toward higher-value segments within the chain.

The technologies from the Fourth Industrial Revolution have significantly reshaped global value chains in terms of both chain length and the number of production stages, from design to marketing. These changes stem from the substantial role of Fourth Industrial Revolution tools in reducing costs and fundamentally altering manufacturing by embedding digital technology across all value chain segments. Technologies like the Internet of Things, autonomous robots, 3D printing, and big data management have reduced low-value-added tasks, thus transforming the manufacturing paradigm and adjusting the length and upward slope of the global value chain curve.

Our study confirmed these findings, showing that digital capability enhances product upgrading in Indian companies within global value chains, thereby enabling them to capture higher value added. Digital capability was measured by the company's level of software, technology, and communications assets utilization.

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