

FDI functional specialization and upgrading via global value chains: an empirical assessment based on automotive industry

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June 12, 2025

Abstract

This study explores a relatively underexamined aspect of Global Value Chains (GVCs)—the transition from backward participation to forward participation, and the role of functional specialization and technology upgrading in facilitating this shift. Focusing on the automotive industries of China, Central and Eastern Europe (CEE), and Western Europe (WE), the analysis provides new insights into how economies at different development stages navigate GVCs to capture greater value. The results demonstrate that deepening backward participation can have opposing effects depending on a country's level of industrial advancement. While WE's well-developed automotive sector shows a negative relationship between backward and forward participation—suggesting resource diversion from existing high value-added activities—CEE benefit from increasing backward participation with a critical threshold effect in CEE indicates that overreliance on foreign inputs (exceeding approximately 53.25%) undermines the long-term goal of transitioning to higher-value segments. Moreover, the study highlights that different types of functional specialization moderate the pace and nature of GVC upgrading. Technology upgrading also emerge as pivotal factors in sustaining forward participation, underscoring the importance of domestic capabilities accumulation and structural change of the industry. Taken together, these findings advance our understanding of GVC dynamics and offer actionable insights for policymakers seeking to foster sustainable economic growth.

Keywords: Global Value Chain (GVC), Technology Upgrading, Foreign Direct Investment, Functional Specialization, Automotive Industry

JEL Classifications: F14, O14, O33, L62, O25

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1 Introduction

The pursuit of long-term, sustainable development goals continually faces emerging challenges. Nowadays, emerging economies and developing countries need to improve their standards of living significantly. To achieve this, it is essential for these countries to pursue sustainable growth strategies over the long term. However, many of these countries are entering in a “middle-income trap,” characterized by high wage level and low productivity growth (Lee et al., 2018). This scenario unfolds amid stagnant global demand (Summers, 2015) and the widespread dispersion of economic activities (Gereffi, 1999). These challenges are closely examined within the literature on Global Value Chains (GVCs), which has traditionally explored avenues for accelerated development, particularly for emerging economies, within a continuously globalized and market-driven economy (Gereffi, 1999; Gereffi et al., 2005; Humphrey & Schmitz, 2002). Renowned for its extensive and detailed case studies for different industries across agriculture, manufacturing, and services sectors, GVC literature assesses the potential opportunities for development of various industries throughout emerging economies, focusing on local firms integrated into GVC networks. In addition to their trade-enhancing benefits, participation in GVC offers significant opportunities for the transfer of knowledge and technology. This makes GVCs regarded as a potential driver for productivity and economic growth in both developing and developed nations (Stöllinger, 2016). A pivotal aspect of this discussion is the notion of upgrading, which includes a range of strategies that firms can employ to boost their competitiveness. These strategies involve investments in productivity, increased specialization, and greater knowledge intensity (Gereffi, 1999; Humphrey & Schmitz, 2002; Pietrobelli et al., 2006). Through upgrading, firms can enhance their positions within GVCs and simultaneously improve the international competitiveness of their respective industries.

As will be discussed in greater detail, upgrading within GVCs is a non-linear process that requires a transition from backward participation to forward participation after surpassing a certain threshold. This is because higher value-added activities are typically associated with forward participation in GVCs (Stojčić & Matić, 2024). Failure to achieve this transition through GVC upgrading may result in countries becoming locked at their current positions within GVCs, thereby limiting opportunities for further advancement (Lee et al., 2018). To better conceptualize the upgrading process within GVCs, the “smile curve” hypothesis has emerged as a widely accepted framework

for understanding value capture capabilities. The smile curve hypothesis, introduced by Stan Shih, the founder of Acer, explains the distribution of value-added across different stages of a value chain (Shin et al., 2012). According to this framework, activities at both ends of the value chain—such as research and development (R&D), design, innovation, branding, and marketing—generate higher value compared to intermediate stages like manufacturing and assembly. When visualized, the value-added distribution forms a “smile” shape, with the highest value-added activities at the two ends and the lowest at the middle. Low-value-added activities, such as manufacturing and assembly, are typically associated with backward participation in GVCs, whereas high-value-added activities are predominantly linked to forward participation. Consequently, the essence of GVC upgrading lies in transitioning from backward to forward participation by capturing a greater share of high-value-added activities.

The purpose of this study is twofold. First, to examine whether deepening backward participation in GVCs positively influences the transition toward forward participation. Second, to explore the moderating role of functional specialization in facilitating this transition. Unlike many previous studies that use GVC position indices to indicate the relative “upwardness” of GVC participation, this research explicitly measures country’s capability to capture different types of value-added activities through a functional specialization index derived from project-level Foreign Direct Investment (FDI) data. This FDI dataset provides information about the specific business activities served by each project, which can be classified into value chain functions such as pre-manufacturing, manufacturing, and post-manufacturing activities. In doing so, this research contributes to the existing literature by explicitly integrating functional specialization into the analysis of GVC-driven upgrading. It also sheds light on the threshold effects associated with backward participation during the transition from backward to forward participation in CEE’s automotive industry, which suggests that overreliance on foreign inputs (exceeding approximately 53.25%) undermines the long-term goal of transitioning to higher-value segments of GVC. Moreover, this paper also highlights the critical importance of domestic capability accumulation and technological upgrading in achieving sustainable economic development. By addressing these gaps, the study provides valuable insights into the complex dynamics of GVC participation and upgrading, with significant implications for both theory and policy formulation.

This study will examine the above-mentioned purposes based on the automotive industry in

China, Central and Eastern Europe (CEE) from a comparative perspective. Western Europe (WE) automotive industry will also be included as a benchmark for comparison as WE has a relatively well-developed automotive industry compared with the counterparts in China and CEE. Following the implementation of the "reform and opening up" policy in 1978, China adopted a strategy of attracting foreign investment to address insufficient domestic capital and outdated management practices. The influx of foreign capital significantly stimulated China's economic growth, particularly within the automotive industry. This foreign investment not only provided much-needed funds but also facilitated technology upgrading through joint ventures and collaborations with domestic enterprises. These efforts laid a robust foundation for enhancing the indigenous capabilities of China's automotive industry. The inflow of foreign capital into this industry saw a marked increase after China joined the World Trade Organization (WTO) in 2001. Generally, the upgrading pattern of China's automotive industry is characterized by leveraging the potential market in collaboration with foreign automotive firms, thereby promoting domestic technology upgrading through foreign capital. This approach is commonly referred to by Chinese scholars as the "trading market for technology" model ([Bai et al., 2020](#)).

Automotive industry is also a pillar industry in European Union, as it provides direct and indirect employment to approximately 13.8 million individuals, accounting for roughly 6.1% of total employment within the EU. It also contributes about 8% to Europe's total manufacturing value-added output ([Ragonnaud, 2024](#)). Similar to China, countries in CEE are also considered as emerging economies. There has been a lot of FDI inflow to CEE's automotive industry in the past 20 years. Some automotive firms in CEE have built upon production capabilities originally established during the Soviet era, whereas many others operate as subsidiaries of major Western European automotive manufacturers, benefiting from foreign direct investment. Auto firms in CEE countries usually have lower production costs compared with WE countries with relatively advanced automotive industries. As a result, WE's auto firms have incentives to relocate some of the production tasks to CEE in order to enjoy the benefit of economies of scale and relatively lower cost of production. Moreover, the geographic advantage of CEE, with its proximity to WE with well-established automotive supply chain and a generally mature demand for automobiles, which gives them easier access to higher-quality intermediate products for final goods manufacturing and it is beneficial to enhance the production capabilities of CEE's automotive industry.

Both China and countries in CEE are considered as emerging market economies. However, due to the distinctive features of FDI and models of development, as well as the GVC participation pattern, this study will adopt a comparative perspective for China and CEE. China and CEE show different GVC participation patterns. China exhibits a preference towards “domestic-led” modernization as its GVC participation shows a “in-out-in” pattern proposed by [Lee et al. \(2018\)](#). On the other hand, CEE’s automotive industry shows a “foreign-led modernization” as it has been deepening backward participation and no sign of concurrent increase in forward participation. Based on the finding of the first chapter, China’s automotive industry enjoy a positive and significant technology upgrading by further expanding forward participation and CEE’s automotive industry shows a positive and significant upgrading by expanding backward participation. However, the magnitude of upgrading achieved by CEE’s automotive industry via backward participation is much smaller than China’s automotive industry technology upgrading via forward participation. It would be interesting to compare China’s and CEE’s automotive industry since they adopted different models of development (Joint Ventures VS Foreign Acquisition of domestic firms) and the types of FDI are also distinctive (Market-seeking FDI VS Efficiency-seeking FDI), and upgrading pattern via GVC is also different (forward participation VS backward participation). We can have a better understanding on which type of development have a better potential on GVC driven upgrading.

The reminder of this paper is structured as follows: Section 2 presents a literature review discussing the upgrading perspectives via GVC and the hypothesis development. Section 3 outlines the data and methodology. Section 4 delves into the construction of functional specialization index and show the functional specialization heterogeneity across three country groups. Section 5 presents the econometric model specification and discusses the empirical results as well as the robustness test. Finally, section 6 concludes this study.

2 Literature review and hypotheses development

The upgrading perspective within GVCs posits that enhancing the complexity and quality of export activities leads to further industrial upgrading and economic growth. This process unfolds through learning accumulation by supporting the development of endogenous technology upgrading, and

involving interactions among various actors within innovation systems. The literature typically contends that GVCs facilitate upgrading in two primary ways. First, for developed countries, GVCs can create opportunities to utilize domestic resources in exploring technological frontiers by reallocating manufacturing activities to developing nations, thereby leveraging the lower labor and intermediate product costs. Second, GVCs offer developing countries an avenue to build domestic capabilities by incorporating external technologies and knowledge that are often lacking domestically. This integration supports knowledge diffusion and technological learning, laying the groundwork for skill advancement and further capability development. These skills are crucial for engaging in higher value-added activities within GVCs. In general, upgrading in GVCs can be categorized into three perspectives: structural upgrading, functional upgrading, and technology upgrading.

2.1 Structural upgrading

Structural upgrading refers to a qualitative shift in a country’s or firm’s position within GVCs, involving changes in the overall configuration of production, enabling higher value capture and more sophisticated participation (Rohit, 2023). Structural upgrading entails reconfiguring the entire governance and organization of cross-border linkages, often transitioning from heavy reliance on backward participation (importing inputs for domestic production) toward forward participation (exporting domestically produced intermediate goods or services to other countries). Central to understanding this process is the “in-out-in” hypothesis articulated by Lee et al. (2018). According to this framework, latecomer economies initially engage global markets by integrating into existing foreign-led production networks through increased backward participation (“in”). Subsequently, they reduce reliance on imported intermediates to strengthen indigenous capabilities and technological competencies (“out”). Eventually, leveraging these capabilities, they re-engage global markets through enhanced forward participation (“in” again). By undergoing this transition from backward to forward participation, countries and firms can reduce dependency on imported inputs, develop indigenous competencies, and ultimately secure greater control over critical segments of the GVC, thus achieving more balanced and resilient global economic integration.

Why is transitioning from GVC backward to forward participation necessary according to the “in-out-in” hypothesis? The upgrading process within GVCs is neither automatic nor linear. Sev-

eral factors, such as power asymmetries between buyers and sellers, absorptive capacities, durability of business relationships, and home-market institutional conditions and policies, can significantly influence successful upgrading outcomes (Stojčić & Matić, 2024). Without favorable alignment of these factors facilitating knowledge and technology flows, countries risk stagnation at their current levels within the GVCs, limiting further upgrading opportunities (Lee et al., 2018). Furthermore, different functional specializations require distinct types of knowledge, which are not always accessible within existing GVC participation patterns. Typically, knowledge transfers are confined primarily to manufacturing activities, consistent with learning-by-doing approaches. The decision to transfer knowledge explicitly or implicitly along the value chain depends on the lead firms. Lead firms, usually from developed economies, rarely share core competencies in pre-production or post-production activities (e.g., R&D, headquarters functions, business services, sales, and marketing) with developing country suppliers (Palpacuer, 2000). As suppliers in developing countries upgrade, they often become more costly, especially in contexts where competitive advantages are based on low labor costs. As a result, it is not preferable for lead firms to transfer knowledge to their suppliers beyond what is necessary to ensure an efficient and high-quality production that meet their standards (Schmitz, 2006). Indeed, suppliers in developing countries are often discouraged from advancing their capabilities in these higher-value segments to maintain cost advantages; otherwise, lead firms may relocate production to lower-cost countries (Baldwin, 2011). This situation contributes to the middle-income trap, where limited capability-building confines domestic firms to low-cost manufacturing, preventing the acquisition of strategic competencies required for innovation and diversification within GVCs. As wages rise and the traditional cost advantage diminishes, firms in developing countries struggle to compete in more advanced value-chain segments, stalling further economic upgrading. This stagnation is a classic feature of the middle income trap, where economies can no longer rely on cheap labor but also lack the technological and organizational capabilities to compete at a high-income level.

Given these theoretical considerations, the “in-out-in” hypothesis underscores the strategic necessity for economies to shift from backward to forward GVC participation after reaching a specific threshold. Extending backward participation offers diminishing returns on learning and upgrading, as high-value-added functions—such as R&D, design, marketing, and sales—are predominantly associated with forward participation (Antràs, 2020; Bontadini et al., 2021; Lee et al., 2018). Pre-

vious studies highlight the upper limit of learning and upgrading potential through GVC backward participation and emphasize the need to reduce dependence on foreign-dominated value chains and imported value-added for domestic production (Lee et al., 2018). However, there is limited evidence on the transition from backward to forward participation (Stojčić & Matić, 2024). Current understanding of GVCs is at a stage where these issues are discussed based on the “in-out-in” hypothesis but lack empirical support. Some researchers suggest that GVC backward participation offers diminishing returns to learning, eventually requiring countries to reduce their reliance on imported intermediate goods and leverage their own strengths. Lee et al. (2018) and Lee et al. (2021) argue that reaching and pushing forward the technological frontier necessitates temporarily separating from the foreign-dominated value chain to build indigenous capabilities, allowing for reintegration into the GVC through expanded forward participation. Another study provides a preliminary descriptive analysis of upgrading from backward to forward participation but lacks rigorous quantitative analysis (Mehta, 2022). A more recent study by Stojčić and Matić (2024) provides the first quantitative analysis of the relationship between backward and forward participation patterns in GVC-driven upgrading. They find that GVC backward participation offers the greatest potential for upgrading to forward participation at lower levels, but this effect diminishes and becomes negative once the share of foreign value-added in domestic exports exceeds 60%. Building explicitly from the “in-out-in” framework and empirical insights, the first hypothesis of this study argues that a shift from GVC backward participation to forward participation is essential, given the limited scope for additional learning under continued backward participation, which may ultimately undermine the long-term sustainable development of emerging economies.

H1: The extent of GVC backward participation positively influences the degree of GVC forward participation, subject to threshold effects.

2.2 Functional upgrading

According to Humphrey and Schmitz (2002), upgrading involves elevating the skill intensity of certain tasks and/or branching into market segments with comparatively higher barriers to entry. They distinguish four types of upgrading to capture its multidimensionality: process upgrading, product upgrading, functional upgrading, and intersectoral upgrading. Process upgrading involves making production processes more efficient, such as substituting labor with capital equipment,

leading to higher productivity. Indicators for process upgrading in previous studies include the growth of capital compensation in terms of profitability (Milberg & Winkler, 2011), capital intensity (Barrientos et al., 2011), and labor productivity (Taglioni & Winkler, 2016). Product upgrading involves introducing new products or improving existing ones compared to competing products, transitioning toward more advanced products within an established value chain. Studies quantify product upgrading using the growth of export share or export unit value (i.e., the average price of exported products). Functional upgrading refers to adopting more complex business functions or engaging in activities requiring higher skill levels, represented by the shifts from low value-added functions to high value-added functions. The transition from Original Equipment Manufacturer (OEM) to Original Brand Manufacturer (OBM) to Original Design Manufacturer (ODM) is a good example of functional upgrading (Hobday, 2003). Intersectoral upgrading requires a shift to a more advanced production chain associated with higher technological capabilities. It involves reconfiguring the production mix to produce goods and services with greater value added, shifting production, employment, and exports across various sectors of the economy, for instance, from agriculture and natural resource extraction to light industries such as textiles, and eventually to more advanced manufacturing and service sectors. Intersectoral upgrading requires applying competence and ability acquired in a specific function to move to a new sector.

Although upgrading is understood in various ways, functional upgrading is often regarded as a cornerstone in this literature. It embodies the “servicification” of manufacturing, marked by a shift toward service-oriented processes and away from the manufacturing or other labor-intensive activities (Kuroiwa & Umezaki, 2024). This tendency becomes especially apparent as pre- and post-manufacturing activities—such as research and development, design, marketing, and sales—gain increasing prominence alongside advancements in functional upgrading. The dynamics of value distribution along GVCs are often associated with the “smile curve” (Mudambi, 2008; Shin et al., 2012), and functional upgrading is closely related to this concept. The smile curve hypothesis highlights the varying degrees of value creation associated with different stages of a product’s value chain and the corresponding potential for value capture among GVC participants. It suggests that firms in emerging and developing economies are often concentrated in segments characterized by low value addition, such as manufacturing and assembly. In contrast, firms in high-income countries or developed countries focus on pre-production functions, such as headquarters, research, design,

and development activities, as well as post-production functions like branding, marketing, sales, and after-sales services, which offer a higher potential for occupying high value-added activities in GVCs. As GVCs become more important in terms of production, the differences in how value is created across various functions are becoming increasingly relevant. Before the time of GVC and global production network, when all value chain functions were concentrated within a single firm at one location, the distribution of value added was more evenly spread across countries with similar functional specialization. However, the development of global production networks and the relocating of specific value chain functions have transformed this dynamic and enabled firms to develop functional specialization. When driven by comparative advantages, this firm-level specialization extends to countries, shaping distinct patterns of functional specialization (Stöllinger, 2021).

Durand and Milberg (2020) extend the smile curve hypothesis by integrating the notion of ‘intellectual monopoly capitalism’ proposed by Pagano (2014) into the study of global value chains. Their framework contends that firms with control over key intangible assets involved in high-value-added segments are able to appropriate monopoly rents, frequently disadvantaging firms from low- and middle-income countries engaged in more tangible, lower-value activities. Since these intangible assets are predominantly controlled by multinational enterprises (MNEs) based in core capitalist countries, high-income economies tend to focus on functions that make extensive use of these assets, thereby capturing the majority of the value generated within GVCs. These intangible assets typically demand specialized management and organizational capabilities and are difficult for firms in low- and middle-income countries to replicate or imitate. Firms in developed countries tend to dominate a significant portion of intangible assets, often protected through legally enforceable rents such as patents, copyrights, and trademarks, or through unique and inimitable organizational structures (Stöllinger, 2021). These firms typically specialize in high-value-added activities in the pre-production and post-production stages of the value chain (Mudambi, 2008). Consequently, low- and middle-income economies are likely to remain confined to low value-added activities unless they actively transit from backward participation in GVCs to forward participation and climb up the value-added ladder to capture more high value-added activities within the GVC. While Stojčić and Matić (2024) examines the transition from backward to forward participation, it does not explicitly investigate the impact of functional specialization on GVC-driven upgrading. The core

of upgrading via GVCs is to capture a larger share of high-value-added activities, particularly for low- and middle-income countries. Including functional specialization in the analysis of the GVC-driven upgrading process will enhance our understanding of the upgrading mechanism and address whether different functional specializations can facilitate the ultimate upgrading via GVC by transiting from backward to forward participation.

2.2.1 An explicit measurement of functional upgrading: FDI functional specialization and its role in GVC upgrading

Since this study will focus on the GVC-driven upgrading patterns for emerging economies or developing countries, we cannot ignore the role of FDI in facilitating the integration into the GVC for these economies because FDI serves as a vital conduit for technological transfer, skill development, and infrastructure enhancement, and ultimately enabling them to access and contribute to global production networks.

FDI contributes to the integration of emerging economies into GVCs primarily by facilitating technology and knowledge transfer in both direct and indirect ways, or also known as the spillover effects. MNEs investing in these countries bring advanced technologies and production processes that local firms might not possess. This transfer of technology and knowledge occurs through various mechanisms such as joint ventures, the establishment of wholly-owned subsidiaries, and partnerships with local firms. For instance, in the automotive industry, global car manufacturers like Toyota and Volkswagen often set up production plants in emerging markets, bringing along sophisticated technology and management practices. These investments not only elevate the indigenous capabilities of local firms but also help in standardizing production processes to meet global standards, thereby enabling and facilitating local firms to become integral parts of GVCs (Keller, 2010).

Moreover, FDI enhances the skill sets of the local workforce, which is essential for effective participation in GVCs. MNEs typically invest in training and development programs for their employees to ensure they can operate new technologies and adhere to international production standards. This investment in human capital development has a spillover effect, also known as the labor mobility effect, as the skills and knowledge acquired by workers can disseminate throughout the local economy, fostering a more skilled and adaptable workforce. One notable example is the

China's automotive industry, which has substantially benefited from FDI . Employees who initially worked for joint ventures between domestic automotive firms and foreign multinational enterprises later moved to domestic firms, thereby generating positive knowledge spillovers through this labor mobility effect, which can improve productivity and quality standards within the industry ([Bai et al., 2020](#)).

FDI also plays a crucial role in improving the infrastructure necessary for GVC participation. The establishment of production facilities by MNEs often necessitates the development of supporting infrastructure such as roads, ports, and communication networks. These infrastructural improvements benefit the broader economy by reducing transaction costs, improving logistics, and facilitating smoother integration into global markets. In Vietnam, for example, substantial FDI inflows have led to significant improvements in the country's infrastructure, which has, in turn, attracted more FDI and strengthened Vietnam's position in GVCs, particularly in electronics and textiles industries ([Athukorala, 2009](#)).

The interconnected relationship between FDI and GVCs is also evident in the way FDI stimulates local entrepreneurship and innovation. By exposing local firms to international competition and collaboration, FDI encourages them to innovate and enhance their productivity. This dynamic is crucial for developing countries, as it helps local firms to climb up the value chain, moving from low-value-added activities to more complex and high-value-added production stages. In the case of India, the information technology sector has seen rapid growth and integration into GVCs, partly due to FDI from major technology firms such as IBM and Intel, which have set up research and development centers in the country, fostering a culture of innovation and entrepreneurship ([Desai et al., 2009](#)). More recent studies also found that GVC activities and FDI are closely connected with each other with greenfield FDI projects play a more important role. [Bénétrix et al. \(2023\)](#) introduces GVC into the analysis of the relationship between FDI and economic growth since 1990s. They did not find statistically significant correlation between FDI and growth for emerging economies or low- and middle-income countries with average levels of education or financial depth. However, they found out stronger positive relationship between FDI and economic growth when there is a GVC activities in manufacturing and service sectors combined with relatively weak absorptive capacity. Their findings further emphasis the interconnected relationship between GVC and FDI and the condition under which FDI can stimulate economic growth for emerging economies

and middle-income countries.

In addition to the interconnected relationship between GVC and FDI, another important reason to bring FDI into the study of upgrading via GVC is to explicitly measure the functional specialization of different activities. A key limitation of prior research is the frequent reliance on ‘upstreamness’ indicators, which failed to provide insights into the specific functions undertaken by the firms within the value chains (Antràs & Chor, 2013; Antràs et al., 2012; Fally, 2011; Hagemeyer & Ghodsi, 2017; Meng et al., 2020; Rungi & Del Prete, 2018). Recent studies have highlighted that input-output measures of upstreamness do not inherently reveal the specific activities countries and industries engage in, which are crucial for defining their functional specialization within GVCs. In other words, these “upstreamness” indicators only reflect the positioning of countries in GVCs at the product level, identifying where a country’s or industry’s products are located relative to final demand or primary production inputs. However, they do not provide insight into the value-adding activities undertaken by the country to bring those products to market. (Coveri & Zanfei, 2023; Coveri et al., 2024; De Vries et al., 2021; Stöllinger, 2021). Therefore, drawing conclusions about the value-adding activities performed or offshored by countries, industries, or firms based solely on input-output statistics may result in misinterpretations. It is essential to distinguish between the GVC position of countries in terms of the number of intermediate products produced and supplied along the production network from the value chain functions they perform (Coveri et al., 2024). By using functional specialization based on FDI data can explicitly capture what value-added activities are undertaken by the countries of interest to bring the products to market.

In general, FDI is a crucial channel through which emerging economies and developing countries can integrate into GVCs by facilitating knowledge and technological transfer, human resources development, infrastructure improvement, and so on. These factors collectively enhance the competitiveness of these economies, enabling them to participate more effectively in the GVCs. A recent study by Coveri and Zanfei (2023) explored the functional division of labor and value capture in GVCs based on FDI data. Their findings offer new empirical evidence in support of the smile curve hypothesis, demonstrating that high-income countries predominantly engage in intangible-intensive functions, whereas low- and middle-income economies are primarily involved in production-related tasks located at the lower segments of the value chain. Other studies also adopt the same FDI functional specialization measurement when examining the relationship between GVC and within-

country inequality (Coveri et al., 2024), testing the smile curve hypothesis regarding the functional specialization and value creation in GVCs (Stöllinger, 2019). However, no study has explicitly measured functional specialization to incorporate the dynamics of value creation through GVCs into analyses of GVC-driven upgrading characterized by the transition from backward to forward participation. This study will fill in this gap by investigating the role of FDI functional specialization in upgrading via global value chains. The detailed classification of the value chain functions can be found in Table 1.

While the smile curve emphasizes the importance of pre- and post-manufacturing functions, the role of manufacturing specialization in GVC upgrading deserves careful consideration. During initial stages of GVC participation, manufacturing activities are critical for emerging economies as these functions provide foundational technological capabilities, facilitating entry and initial upgrading within global production networks. This rationale aligns with the “in-out-in” hypothesis proposed by Lee et al. (2018), where economies initially deepen their participation in manufacturing to acquire skills and technologies necessary for later stages of upgrading. However, sustained long-term growth ultimately requires transitioning from manufacturing specialization towards pre- and post-manufacturing activities, thereby securing greater value capture and higher-level innovation capabilities. Thus, manufacturing functional specialization is initially beneficial but eventually necessitates a strategic shift towards higher-value functions. Building from the theoretical framing of the smile curve and addressing functional specialization explicitly, this study formulates the following hypotheses:

H2a: Functional specialization in pre-manufacturing activities positively facilitate the transition from GVC backward to forward participation.

H2b: Functional specialization in manufacturing activities positively facilitate the transition from GVC backward to forward participation.

H2c: Functional specialization in post-manufacturing activities positively facilitate the transition from GVC backward to forward participation.

2.3 Technology upgrading

Technology upgrading represents a critical driver of both economic growth and structural transformation, enabling firms and industries to enhance their production processes, product quality,

and overall competitiveness. Although initial participation in GVCs may involve assembling imported inputs for labor-intensive products (backward participation), acquiring and assimilating more advanced technologies positions firms to move up the ladder, supplying increasingly specialized, higher-value components to global markets (forward participation). By building stronger technological capabilities—whether through learning-by-doing, licensing arrangements, or collaborative innovation—firms can transition from reliance on external inputs to developing indigenous expertise and design capacities. In developed countries, technology upgrading is typically spurred by extensive R&D investments, robust innovation ecosystems, and sophisticated market demands, which collectively foster a steady progression toward occupying high value-added activities. In developing countries, however, technology upgrading often arises through integration with foreign multinationals, technology transfer, and knowledge spillovers embedded in GVC participation. [Stojčić and Matić \(2024\)](#) also highlight the importance of technology upgrading by showing that domestic capability accumulation has a stronger impact on a country’s ability to build its own forward-integrated value chain than the intensity of backward participation. The core of GVC upgrading is the ability to capture larger share of high value-added activities by transiting from GVC backward to forward participation, and a higher level of technology upgrading not only enhances production efficiency but also raises the knowledge content of exports, thereby facilitating the crucial shift from backward to forward participation that underpins sustainable industrial growth and value capture in both developed and developing economies.

Technology upgrading needs to be understood under the context of a system, it refers to the comprehensive improvement and enhancement of various components, processes, and functionalities to achieve better performance, efficiency, and outcomes. Upgrading should not be regarded as a unidimensional process; a holistic approach ensures that all parts of the system work synergistically to meet higher standards and adapt to evolving demands. However, traditional methodologies often simplify technology upgrading to a single indicator, such as Total Factor Productivity (TFP), labor productivity, R&D expenditures, or patent data. While these indicators can capture aspects of capabilities accumulation, they frequently fail to reflect the multidimensional nature of upgrading ([Bruno et al., 2021](#)). This research introduces a novel conceptual framework for understanding technology upgrading ([Radosevic & Yoruk, 2016, 2018](#)), delving into the multidimensional aspects of technology upgrading: intensity, breadth, and interaction with the global economy. In their

theoretical construct, specifically formulated for middle-income or emerging economies, delineates three distinct dimensions of technological upgrading. The first dimension pertains to the intensity of technology upgrading, encompassing the acquisition of various capabilities, including production, technology, and R&D capabilities. The second dimension is the breadth of technology upgrading, which includes a range of structural factors influencing the intensity of technology upgrading, such as industry structure changes, infrastructure enhancements, and transformations in both firm and broader industrial structures. The third dimension is characterized by interaction with the global economy, emphasizing that successful technological upgrading is not an entirely insular process but is intrinsically linked to the assimilation of foreign knowledge and skills, in conjunction with rigorous domestic efforts. This interaction is pivotal as it facilitates the inflow of external knowledge and augments indigenous technological development. In this study, technology upgrading is measured using the Index of Technology Upgrading (ITU), which integrates both the intensity and breadth of technology upgrading, assigning equal weight to these two dimensions. A detailed discussion of the ITU's constituent indicators and their respective weights is provided in the appendix. In summary, this study argues that a higher level of technology upgrading positively facilitate the transition from GVC backward to forward participation.

H3: A higher level of technology upgrading positively facilitate the transition from GVC backward to forward participation.

3 Data and methodology

This study requires three types of databases. First, FDI related data was downloaded from fDi Market database. This database on cross-border foreign investments includes all countries and sectors. It provides granular information on both the destination region of each investment project and the origin of the investing firm. Through the geo-referencing of these investments, it becomes feasible to generate detailed regional-level statistics on both inward FDI (foreign investments entering the domestic economy) and outward FDI (investments made by domestic firms abroad). More importantly, this database divided FDI projects into different functions such as business services, education and training, logistics and distribution, maintenance and servicing, manufacturing, research and development, and sales and marketing. Therefore, this study will be able to examine

which type of FDI functional specialization is more effective in terms of the upgrading via GVC of the automotive industries. These functions can also be allocated to the three broader groups of pre-manufacturing activities, manufacturing activities, and post-manufacturing activities shown in Table 1. Two sectors related to automotive industries in fDi makret database are selected, which are automotive components and automotive OEM. The details of the sub-sectors under automotive components and automotive OEM, and their corresponding NACE Rev.2 industry is shown in Table 2.

Business functions based on the fDi market	Value Chain activities	Value Chain functions
Research & Development Design & Testing Education & Training	R&D and related services	Pre-manufacturing
Headquarters ICT & Internet infrastructure	Headquarter services	
Manufacturing Recycling	Production	Manufacturing
Business Services Logistic, Distribution & Transportation	Logistics and retail services	Post-manufacturing
Sales, Marketing & Support Maintenance & Servicing Customer Contact Center Shared Service Center Technical Support Center	After-Sales support services	

Table 1: Value chain functions classification

As for GVC participation, data from Trade in Value Added (TiVD) is adopted to examine the participation of global value chain for automotive industries in China, CEE, and WE. This database construct numerous indicators address the flows of goods and services within these global production chains by considering the value added by each country in the production of goods and services that are consumed worldwide. The latest indicators were generated using the 2023 release of the OECD Inter-Country Input-Output (ICIO) tables which cover the period 1995 to 2020. The indicators are provided for 66 economies and the rest of the world based on the ISIC

Sector	Sub-sector	NACE Rev.2 Code
Automotive components	Automobiles Motor vehicle body & trailers Motor vehicle brake systems Motor vehicle electrical & electronic equipment Motor vehicle gasoline engines & engines parts Motor vehicle seating & interior trim Motor vehicle stamping Motor vehicle steering & suspension components Motor vehicle transmission & power train parts Other motor vehicle parts	29
Automotive OEM	All other transportation Automobiles Heavy duty trucks Light trucks & utility vehicles Motor vehicle gasoline engines & engines parts Motor vehicle seating & interior trim Other motor vehicle parts	29

Table 2: fDi market sectors and sub-sectors for automotive industry

Rev. 4 classification. One sector (D29) related to the manufacturing of automotive and automotive component industry will be in this study. In particular, backward participation is measured by foreign value added share of gross exports, which is defined as foreign value added embodied in gross exports as a percentage of total gross exports. Forward participation is measured by domestic value added embodied in foreign exports as share of gross exports. These are the most commonly adopted indicators in terms of GVC participation.

The last dataset is related to technology upgrading. In this study, technology upgrading is measured using the Index of Technology Upgrading (ITU), which integrates both the intensity and breadth of technology upgrading, assigning equal weight to these two dimensions. A detailed discussion of the ITU's constituent indicators and their respective weights is provided in the appendix.

In order to examine the role of FDI functional specialization on the GVC-driven upgrading for automotive industry, this study will adopt the indicator “functional specialization in FDI” (FS) developed by [Coveri and Zanfei \(2023\)](#), which is based on [Balassa \(1965\)](#) index of revealed

comparative advantage. This indicator is an inward FDI-based specialization index which captures for the i -th country in a given year the relative attractiveness of investments in the a -th value chain function. It is calculated as follows:

$$FS_i^a = \frac{\frac{FDI_i^a}{\sum_a FDI_i^a}}{\frac{\sum_i FDI_i^a}{\sum_i \sum_a FDI_i^a}}$$

This indicator is constructed by normalizing the share of inward FDI associated with a specific function in a given country (numerator) against the average share of inward FDI in that same function across all countries in the dataset (denominator). A value above one indicates that the country exhibits a relative specialization in attracting FDI for that particular function. This indicator serves as a useful proxy to identify the position of a country within the automotive value chain, which occurs largely at the functional level.

FDI projects have played a critical role in driving the expansion of global value chains and have significantly contributed to the economic advancement of low- and middle-income countries (Gereffi & Korzeniewicz, 1994). It will be helpful to include this FDI functional specialization in the analysis of GVC-driven upgrading for automotive industry as we can directly proxy whether the relative position of a country (i.e., whether this country focuses more on low value-added activities such as manufacturing or high value-added activities such as R&D) can facilitate the GVC-driven upgrading process. It is important to highlight that FDI-based indicators rely on the number of FDI projects rather than the capital expenditures or jobs created by each project. This is due to the fact that the capital expenditure and job creation figures reported by the fDi Markets database are often based on estimates, with the criteria for these estimates not clearly outlined. As a result, the data on capital expenditure or job creation is considered less reliable than the number of FDI projects. Many previous studies utilizing the fDi Markets database have similarly adhered to this standard by using the number of FDI projects as their primary measurements (Aiyar et al., 2024; Ascani et al., 2016a, 2016b; Castellani et al., 2016; Coveri & Zanfei, 2023; Coveri et al., 2024; Crescenzi et al., 2014, 2016; Stöllinger, 2016, 2019). However, a limitation of this FDI-based approach is that it captures only equity-based GVC participation, overlooking non-equity modes where lead firms coordinate without ownership control (Gereffi, 2005). Nonetheless, a large part of the GVC participation in China’s and CEE’s automotive industry is driven by MNEs and foreign affiliates

of MNEs rather than domestic firms, this limitation will not be a big issue for this study. Another limitation of this database lies in its inclusion of announced or planned investment projects, which may not ultimately be executed or may unfold in ways that differ from their initial specifications and objectives. Although the dataset is updated on a regular basis, this issue is particularly pronounced with more recent data. By restricting the empirical analysis to the period from 2003 to 2020, this study significantly enhances the reliability of the data used. Additionally, the database only includes FDI that are invested on greenfield investment projects and does not provide data on brownfield investment projects such as mergers and acquisitions (M&A). As noted by other scholars who have utilized this database, the lack of data on brownfield investments limits the coverage of international modes of operation but also minimizes the noise associated with M&A strategies, which are often driven by financial motives. In general, the regression model can be expressed as follows:

$$forward_{it} = \alpha + \beta_1 backward_{it} + \sum_{k=1}^n \eta_k FS_{it} + \beta_2 itu_{it} + \alpha_i + \alpha_t + \epsilon_{it}$$

where forward is GVC forward participation, backward is GVC backward participation, FS measures different types of FDI functional specialization, itu is the Index of Technology Upgrading incorporating both the intensity of technology upgrading to reflect the acquisition of different domestic capabilities, and the breadth of technology upgrading to show the general structural change of automotive industry. Both country fixed effect (α_i) and year fixed effect (α_t) are also included in the regression model.

4 Functional specialization discriptive analysis

Figure 1 compares the Functional Specialization Index across pre-manufacturing, manufacturing, and post-manufacturing activities for automotive industries in WE, CEE, and China. An index value above one indicates specialization in attracting FDI to a specific activity, meaning that the share of FDI targeted at this function surpasses the average share across the full sample. The analysis reveals distinct patterns among these regions. WE's automotive industry demonstrates strong specialization in pre- and post-manufacturing activities, including research and development, headquarters operations, education, business services, logistics, retail, and maintenance ser-

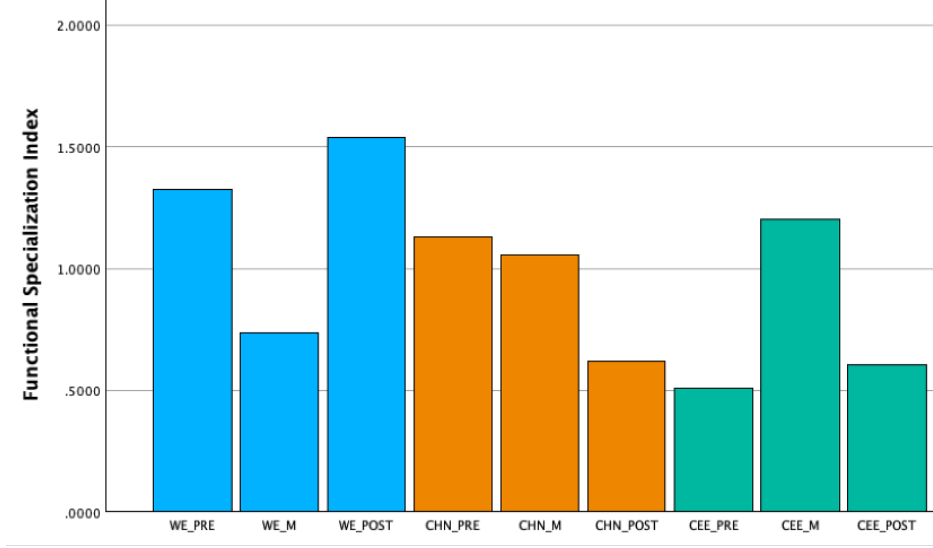


Figure 1: Functional specializaition index for automotive industry

vices. This aligns with the “smile curve hypothesis”, emphasizing higher value-added in these segments captured by WE countries. Conversely, CEE exhibits a clear specialization in manufacturing, a relatively lower value-added activity, reflecting the region’s competitive advantage in production-intensive tasks. This finding also aligns with [Durand and Milberg \(2020\)](#) that companies in developed countries controlling the intangible assets required for activities at the higher ends of the value chain are positioned to extract monopoly rents, often at the expense of low- and middle-income countries engaged in tangible-intensive functions, namely manufacturing activities. In comparison, China’s automotive industry occupies an intermediate position between CEE and WE, exhibiting a relatively higher level of specialization in pre- and post-manufacturing activities than CEE, while its level of specialization in manufacturing activities is somewhat lower but still comparable to CEE. This indicates that China’s automotive industry is not limited to being a “factory economy” concentrated solely on manufacturing but is also expanding its role in capturing higher value-added functions in both pre- and post-manufacturing activities, relative to CEE’s automotive industry.

Figure 2 summarizes the evolution of FDI functional specialization in manufacturing activities within the automotive industry in China, CEE, and WE from 2003 to 2020. Overall, CEE exhibits the highest level of functional specialization in manufacturing activities, followed by China. In contrast, the automotive industry in WE consistently has index values below one, indicating that

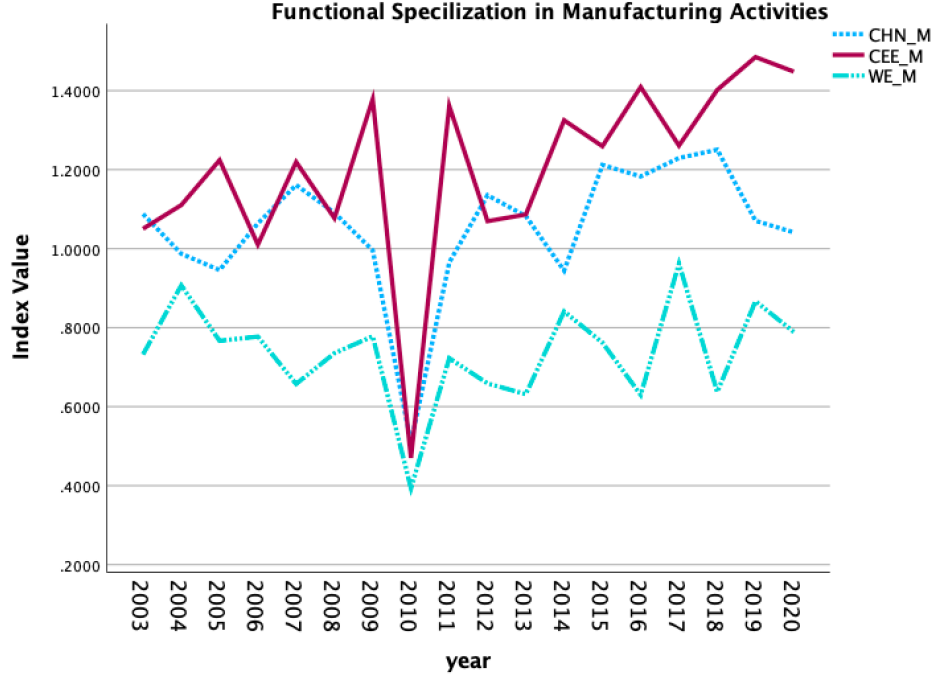


Figure 2: Evolution of functional specialization in manufacturing activities

its inward FDI in manufacturing activities is below average. The 2008 financial crisis significantly impacted FDI in the automotive industries of all three regions, leading to a decline in the index values after 2008, with the lowest point occurring in 2010. However, there was a rapid recovery post-2010. After 2010, CEE’s automotive industry showed a slight upward trend in FDI functional specialization, suggesting an increase in inward FDI targeting manufacturing activities. In contrast, China’s automotive industry remained relatively stable with no clear trend in FDI functional specialization during this period.

In summary, CEE’s automotive industry shows the highest level of FDI functional specialization in manufacturing activities, with a slightly upward trend after 2010. This indicates that inward FDI in CEE primarily capitalizes on the lower production costs in the region, often targeting lower value-added activities such as manufacturing. Although China’s functional specialization in manufacturing is lower than CEE’s, it still attracts substantial manufacturing-focused FDI, maintaining stable, above-average index values. In contrast, WE’s automotive industry prioritizes high-value-added pre- and post-manufacturing functions, reflecting its advanced position in the global automotive industry.

5 Empirical analysis

5.1 Baseline model regression results

The data analysis begins with a baseline specification and progresses to more advanced models to examine the impact of time effects and heterogeneity across country groups. Various regression methodologies were employed to ensure the robustness and validity of the results, including fixed effects, random effects, least squares regression with dummy variables (LSDV), and linear regression with double selection (LASSO). The LSDV approach was used to estimate fixed effects in panel data by explicitly including dummy variables for each country, effectively accounting for unobserved heterogeneity through country-specific indicator variables. LASSO, on the other hand, is a machine learning-based econometric technique designed for high-dimensional data settings. It systematically selects relevant covariates from a large pool of potential predictors, combining the Least Absolute Shrinkage and Selection Operator with econometric methods to estimate causal effects and coefficients of interest robustly.

Table 3 summarizes the results and provides initial insights into the dynamics of transitioning from Global Value Chain (GVC) backward participation to forward participation. A positive relationship is observed between GVC backward and forward participation. Notably, only the LSDV and LASSO models yield positive and statistically significant coefficients for GVC backward participation. Moreover, functional specializations and technological upgrading demonstrate a positive and significant impact on the transition from backward to forward participation, underscoring the role of technological and structural advancements in facilitating this shift.

Further analysis examines the role of functional specialization in the transition from GVC backward participation to GVC forward participation. Table 5 presents the regression results that incorporate both country fixed effects and year fixed effects to better control for potential unobserved heterogeneity across countries and time. Specifically, during the 2008 financial crisis, GVC forward participation of all countries was affected to varying extents, with a generally similar direction of impact. Including time fixed effects helps account for such global shocks. However, incorporating both country and year fixed effects in the regression model may consume substantial degrees of freedom, thereby reducing the statistical power of the analysis. A trend term offers a more efficient way to model time effects without consuming a large number of degrees of freedom,

Table 3: Baseline Regression Results

	(1) FE	(2) RE	(3) LSDV	(4) LASSO
gvcfp				
gvcbp	0.032 (0.025)	0.030 (0.021)	0.031*** (0.010)	0.015*** (0.003)
fs_m	0.397*** (0.091)	0.401*** (0.090)	0.397*** (0.095)	-
fs_pre	0.111** (0.040)	0.110*** (0.040)	0.110*** (0.032)	-
fs_post	0.069** (0.025)	0.066*** (0.023)	0.070** (0.029)	-
itu	4.706*** (1.364)	4.619*** (1.357)	4.705*** (0.740)	-
_cons	-0.470 (1.467)	-0.353 (1.178)	-0.261 (0.260)	-
Group	3	3	3	3
Observations	234	234	234	234

Note: Standard errors are in parentheses.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

particularly given the relatively small number of observations in the subsample regressions. First, Regression (5) reports findings based on the full sample of all countries. The estimated coefficient for GVC backwrdr participation is positive but not significant, indicating that increased backward GVC participation in the automotive industry does not facilitate forward participation within GVCs, thus providing no support for Hypothesis 1. This outcome can be explained by several factors. For developing countries, higher backward GVC participation often correlates with greater reliance on foreign value-added inputs, which may trap them in low value-added segments of GVCs (Gereffi et al., 2005). For developed countries, increased backward participation could lead to resource allocation away from their traditional strengths in high value-added activities. It is important to note that these regression results capture contemporaneous relationships between backward and forward GVC participation, suggesting that in the short term, increased backward participation does not have a positive impact on GVC forward participation. Stojčić and Matic (2024) find that backward participation even negatively impacts forward participation in the short term, with the relationship becoming insignificant within 3-8 years and only turning positive after eight years.

Table 4 illustrates the evolving relationship between GVC backward and forward participation over time, examining whether this linkage becomes positively significant after a certain duration.

Between years 1 and 8, the results indicate no statistically significant relationship between GVC backward and forward participation. This finding suggests a transitional phase characterized by the gradual accumulation of technological and productive capabilities. As [Lee et al. \(2018\)](#) suggested in the “in-out-in” hypothesis, during the “out” period, countries may progressively reduce their reliance on imported intermediate goods, although the necessary conditions for shifting to forward GVC participation have not yet fully materialized. Unfortunately, due to limitations in data availability, this study is unable to determine whether deepening GVC backward participation eventually facilitates a successful transition to forward participation beyond the 8-year threshold in the automotive industry. Nevertheless, the influence of other variables on upgrading remains consistent across the studied timeframe.

Table 4: Effects of GVC backward participation over time

Variables / lag of backward	t-1	t-3	t-5	t-7	t-8
gvcbp	0.016 (0.03)	0.018 (0.024)	0.00003 (0.01)	-0.013 (0.018)	-0.026 (0.022)
fs_m	0.296* (0.139)	0.332*** (0.089)	0.34*** (0.087)	0.354*** (0.087)	0.348*** (0.086)
fs_pre	0.097** (0.039)	0.115** (0.039)	0.114** (0.042)	0.118** (0.047)	0.117** (0.044)
fs_post	0.046 (0.038)	0.059* (0.027)	0.06** (0.027)	0.067** (0.028)	0.069** (0.025)
itu	3.856** (1.701)	3.812** (1.626)	3.736** (1.627)	3.703** (1.549)	3.579** (1.464)
t	0.012 (0.01)	0.01 (0.011)	0.02* (0.011)	0.028 (0.02)	0.038 (0.024)
_cons	0.534 (1.518)	0.417 (1.318)	1.148 (0.755)	1.597** (0.611)	2.068** (0.721)
Observations	234	234	234	234	234
R-squared	0.854	0.854	0.852	0.853	0.858

Note: Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Hypothesis 2 examines the impact of different types of functional specialization on GVC forward participation. The regression results indicate that all forms of functional specialization, including pre-manufacturing, manufacturing, and post-manufacturing activities, positively contribute to GVC forward participation, with manufacturing activities showing the most significant effect. Thus, Hypothesis 2 is supported. Automotive manufacturing is typically characterized by large-

scale operations that demand significant technological capabilities, skilled labor, and sophisticated infrastructure. Investing in manufacturing activities allows domestic firms to build foundational competencies, absorb advanced technologies, and enhance productivity, thereby creating conditions favorable for subsequent upgrading. This phenomenon is evident in the case of China’s automotive industry, where significant investments and accumulated experience in manufacturing activities have facilitated the industry’s evolution into areas of higher value-added activities, such as electric vehicle technologies and the development of autonomous driving software. Thus, despite the expectation that pre- and post-manufacturing activities would drive upgrading due to their inherently higher value-added nature, manufacturing itself serves as an indispensable gateway that ultimately supports and accelerates progression into these advanced functional domains.

Additionally, the estimated coefficient for the Index of Technology Upgrading (ITU) is also positive and significant, a higher level of technology upgrading has a positive impact on GVC forward participation, which suggests that a strong background of domestic capabilities and a more comprehensive structural upgrading of the automotive industry is conducive to higher level of GVC forward participation. Therefore, Hypothesis 3 can be supported. In this part, the result complements the study of [Lee et al. \(2018\)](#) that domestic accumulation of capabilities has a stronger impact on the ability of countries to build their own forward-integrated value chain than the intensity of backward participation.

In order to investigate how distinct levels of economic development shape the transition from GVC backward to forward participation, the dataset was divided into three country groups and separate regression analyses were conducted for China, CEE, and WE. When examining the regressions for each country group, the estimated coefficients for ITU are no longer significant, as the effect of technological upgrading is absorbed by the trend term. The results indicate that for China’s automotive industry, increasing functional specialization in manufacturing activities is the primary driver behind advancing toward forward participation. CEE’s automotive industry, on the other hand, is the only group showing a positive effect of deeper GVC backward participation on forward participation, reflecting its heavy reliance on foreign inputs for domestic production. Moreover, there is a threshold effect for the transition of CEE’s automotive industry to GVC forward participation by increasing GVC backward participation. Specifically, Regression (3) includes the quadratic term for GVC backward participation in CEE’s automotive industry, and this

quadratic term is negative and significant, indicating a threshold value of 53.25%. This threshold represents the point at which the marginal effect of GVC backward participation on GVC forward participation shifts from positive to negative. When GVC backward participation is below 53.25%, increasing backward participation has a positive effect on forward participation, but beyond this value, the marginal impact becomes less positive and eventually negative, suggesting diminishing returns or negative effects of higher GVC backward participation. This threshold effect implies that CEE’s automotive industry cannot continue increasing reliance on foreign value-added for domestic production beyond 53.25% if it aims to maintain a sustainable transition toward GVC forward participation. No similar threshold effects are observed for China and WE. By contrast, WE’s well-developed automotive sector exhibits positive and significant effects of all types of functional specialization (pre-manufacturing, manufacturing, and post-manufacturing) on forward participation. This finding offers empirical support to the “smile curve” hypothesis, underscoring that high-income economies gain a higher share of value through intangible-intensive functions such as R&D, design, branding, and after-sales services. However, the estimated coefficient for GVC backward participation is negative and significant, indicating that further expansion of backward participation may erode the comparative advantage of high-income, well-developed countries in capturing higher value-added activities associated with forward GVC participation. This finding underscores the risks of over-reliance on foreign value-added inputs for developed economies.

The cross-country group differences points out that the upgrading pathways within GVCs are far from uniform, as distinct patterns emerge based on countries’ functional specialization strategies. For example, China’s automotive industry initially embraced a “trading market for technology” strategy, establishing joint ventures with foreign automotive firms and primarily focusing on manufacturing activities domestically. This began with Complete Knock Down (CKD) production methods, wherein components were imported and assembled locally. Over time, China consistently prioritized localizing its automotive supply chains rather than remaining dependent on imported inputs. This strategic shift enabled China’s automotive sector to leverage manufacturing specialization as a key driver of upgrading, facilitating the critical transition from backward to forward GVC participation. In contrast, CEE’s automotive industry demonstrates a distinct upgrading trajectory, driven primarily by deeper integration into GVC through increased backward participation. Here, upgrading has significantly benefited from sustained reliance on imported inputs

and foreign investments, yielding measurable short-term gains. Nevertheless, due to the non-linear nature of GVC upgrading, a threshold effect becomes evident; CEE countries may risk becoming locked into lower value-added manufacturing activities if they continue deepening backward participation without actively securing higher share of high value-added activities. Finally, WE's automotive industry illustrates another unique pattern. High-income countries in WE enjoy the distinct advantage of experiencing upgrading benefits across all types of functional specialization, including manufacturing as well as pre- and post-manufacturing activities, reaping particular benefits from intangible-intensive activities. However, it's crucial to recognize that increased backward participation negatively impacts WE's position within the GVC, potentially eroding its established comparative advantages in higher value-added segments. Thus, developed countries must exercise caution when deepening backward participation, carefully balancing their integration within GVC to protect and strengthen their competitive position in innovation-driven, high-value segments.

Table 5: Regression results with both country- and year-fixed effects

	(1) CHN	(2) CEE	(3) CEE	(4) WE	(5) ALL
gvcfp					
gvcbp	0.052 (0.043)	0.045*** (0.014)	0.213*** (0.029)	-0.021** (0.006)	0.027 (0.026)
gvcbp_square			-0.002*** (0.000)		
fs_m	0.384*** (0.097)	0.180 (0.202)	0.125 (0.171)	0.288** (0.084)	0.378*** (0.092)
fs_pre	0.010 (0.072)	0.060 (0.089)	0.028 (0.076)	0.075** (0.023)	0.112** (0.039)
fs_post	-0.118 (0.134)	0.026 (0.081)	0.010 (0.069)	0.049** (0.017)	0.070** (0.024)
itu	-0.406 (2.422)	1.784 (1.794)	0.269 (1.537)	2.351 (1.177)	3.958** (1.748)
t	0.059** (0.022)	0.034** (0.016)	0.051*** (0.014)	0.005 (0.009)	0.010 (0.010)
_cons	0.093 (0.972)	0.150 (0.946)	-2.801*** (0.929)	2.151*** (0.458)	-0.070 (1.585)
Observations	18	108	108	108	234
R-squared	0.885	0.793	0.707	0.862	0.859
Country fixed-effect	N.A.	YES	YES	YES	YES
Year fixed-effect	YES	YES	YES	YES	YES

Note: Standard errors are in parentheses.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

In conclusion, the econometric analysis highlights the nuanced relationship between functional specialization, GVC backward participation, and GVC forward participation across different country groups. The inclusion of both country and year fixed effects controls for unobserved heterogeneity, such as the 2008 financial crisis, though it reduces statistical power by consuming degrees of freedom. A trend term was utilized to address time effects more efficiently. Overall, while functional specialization generally supports GVC forward participation, the impact of GVC backward participation differs by region. In CEE, increased backward participation has a positive effect only up to a threshold of 53.25%, beyond which the marginal impact turns negative. In China, transition towards GVC forward participation are primarily driven by manufacturing specialization, whereas in WE, all forms of functional specialization are beneficial, but excessive GVC backward participation can undermine competitiveness and ultimately leads to negative impact on GVC forward participation. These findings emphasize that different GVC strategies and participation patterns will lead to divergent upgrading pathway and outcome. It shows the importance of targeted policy interventions to manage GVC integration, considering each country’s development stage and specific industrial dynamics.

5.2 Robustness test

The results in Table 1 suggest that GVC backward participation has a positive impact on forward participation; however, this relationship is only statistically significant when using the LSDV and LASSO regression models. The analyses in Table 5, which examine country group heterogeneity, provide valuable insights into how distinct patterns of GVC backward participation can facilitate the transition to forward participation, and how various forms of functional specialization can foster this transition across different country groups. Nonetheless, the separate regressions for each country group suffer from a low number of observations. To address these limitations, a mixed-effects random slope model is adopted in this section to test the robustness of the previous results.

A mixed-effects random slope model is a multilevel framework that simultaneously accounts for both within-country variation and between-country variation by allowing each unit to have its own intercept and slope on one or more predictors. In contrast to a purely fixed-effects model where the slope is held constant across all country or estimated separately for each country, the mixed-effects

approach introduces a hierarchical structure in which the slopes are assumed to be drawn from a common distribution. This partial pooling of information helps “shrink” extreme estimates toward an overall mean unless a country’s data strongly indicate otherwise, thereby mitigating problems caused by small subgroup samples. Furthermore, it addresses the drawback of running separate regressions for each country group: instead of discarding cross-group information and yielding imprecise results for smaller groups, the random slope model retains all data in a single estimation and captures heterogeneity across countries more robustly (Rabe-Hesketh & Skrondal, 2008).

Table 6 presents the regression results from the mixed-effects random slope model, in which GVC backward participation (gvcbp) is allowed to vary by country. Consistent with earlier findings, the estimated coefficient for gvcbp remains positive but is not statistically significant, likely reflecting diverse upgrading patterns across different country groups. The random-effects parameters indicate that the variance of gvcbp slopes across countries is approximately 0.00178, with a standard deviation of 0.0422. In practical terms, this implies that 95% of countries have slopes ranging from about -0.077 to 0.091 , suggesting that some countries exhibit moderately negative effects while others show more strongly positive ones. This variation explains why the overall coefficient for gvcbp is not significant. Examining the random slopes for individual countries in Figure 4 highlights the heterogeneity of upgrading patterns across the three country groups. All WE countries display a negative relationship between GVC backward participation and forward participation, indicating that increased backward participation could lead to resource allocation away from their traditional strengths in high value-added activities. By contrast, CEE countries generally exhibit a stronger positive impact of GVC backward participation on forward participation, owing to their heavy reliance on imported intermediate goods. Although China’s automotive industry also shows a positive slope for gvcbp, its effect is smaller relative to that observed in CEE average. Overall, these results from the mixed-effects random slope model are consistent with previous findings, suggesting that while separate regressions for each country group may suffer from a low number of observations, the main conclusions remain robust.

Table 6: Mixed-effects REML regression result
Group variable: `country`

Number of obs = 234
Number of groups = 13
Obs per group: min = 18, avg = 18.0, max = 18
Wald $\chi^2(6) = 70.14$
Prob > $\chi^2 = 0.0000$
Log restricted-likelihood = -102.24454

	Coefficient	Std. err.	z	P> z	[95% conf. interval]
gvcbp	0.0070283	0.0135134	0.52	0.603	[-0.0194576, 0.0335141]
fs_m	0.3024357	0.0915404	3.30	0.001	[0.1230198, 0.4818516]
fs_pre	0.0810357	0.0317477	2.55	0.011	[0.0188113, 0.1432601]
fs_post	0.0518595	0.0318954	1.63	0.104	[-0.0106544, 0.1143733]
itu	2.643046	0.7357405	3.59	0.000	[1.201021, 4.08507]
t	0.0163455	0.0054486	3.00	0.003	[0.0056664, 0.0270245]
_cons	1.377198	0.5271125	2.61	0.009	[0.3440763, 2.410319]

Random-effects parameters	Estimate	Std. err.	[95% conf. interval]
var(gvcbp)	0.0017818	0.0008507	[0.0006989, 0.0045423]
var(_cons)	1.666185	1.005898	[0.5103187, 5.440076]
cov(gvcbp,_cons)	-0.0467504	0.025947	[-0.0976056, 0.0041049]
var(Residual)	0.0894068	0.0089317	[0.0735083, 0.1087439]

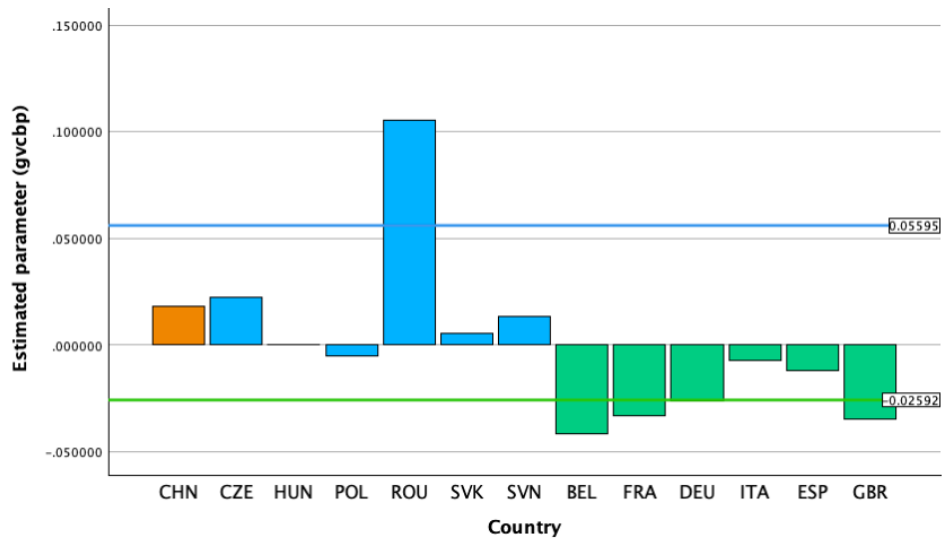


Figure 3: Estimated coefficient for GVC backward participation in the mixed effect model

6 Conclusion and implication

This study examined the relationship between different patterns of GVC participation and to elucidate the underexplored transition from GVC backward participation to forward participation. This transition has major implications for technology upgrading, especially as firms and industries seek to capture a larger share of high value-added activities. While this phenomenon is critical for enhancing the competitiveness and long-term economic growth of emerging and middle-income economies by helping them avoid the middle-income trap, it also bears relevance for advanced economies seeking to maintain their global innovation edge. By comparing China's, CEE's, and WE's automotive industries, this research provides valuable insights into how different levels of economic development, GVC participation patterns, and functional specialization shape distinctive upgrading trajectories. In doing so, it contributes a deeper understanding of GVC dynamics at the industry level and offers direction for both academic inquiry and policy formulation.

From a theoretical perspective, this study advances the literature by integrating FDI-driven functional specialization into the conceptualization of upgrading via GVC participation. Drawing on a framework that posits upgrading hinges on capturing high value-added activities that require capabilities often beyond those acquired through continued backward participation, this research highlights the strategic necessity of shifting toward forward participation. The empirical findings show that for WE's well-developed automotive industries, further expanding GVC backward participation can negatively affect forward participation, likely due to the diversion of resources away from high value-added activities in which these economies already possess comparative advantages. In contrast, CEE's automotive industries exhibit a positive relationship between backward and forward participation. Notably, the threshold effect observed in CEE (an upper limit of approximately 53.25% foreign value-added in domestic production) suggests that over-reliance on imported inputs for domestic production can hinder the sustainable pursuit of forward participation, a finding that is critically relevant for economies at a transitional development stage. An additional theoretical contribution lies in demonstrating that functional specialization moderates the GVC upgrading process. While pre-manufacturing, manufacturing, and post-manufacturing activities all facilitate the transition from backward to forward participation, their relative importance differs across regions. The strongest reliance on manufacturing activities as a key driver for upgrading to

GVC forward participation is observed in China, whereas WE's automotive industry reaps benefits from all three functional segments, reflecting the advantages that high-income economies enjoy in diversifying their value-added portfolio. These disparities underscore the challenges that emerging economies face in broadening their functional capacities beyond manufacturing, emphasizing that upgrading via GVC is not an automatic process and moving up the value chain often requires deliberate policy action.

The findings also underscore the pivotal role of domestic technology upgrading and capability accumulation. In both China and CEE, the development of indigenous capacities and structural upgrading exerts a stronger impact on enhancing forward participation than the mere intensity of backward participation. China, in particular, illustrates how a domestically driven modernization process can catalyze higher-value activities, although WE's automotive sector appears less sensitive to further technological improvements because of its already high capability base. This suggests that the returns to technology upgrading may diminish at advanced stages of industrial development.

Several policy implications emerge from these findings, particularly in light of recent debates on reshoring, industrial policy, and supply-chain resilience. First, policymakers in emerging and middle-income economies should be cautious about relying too heavily on GVC backward participation by deepening assembly or manufacturing roles as a pathway to economic growth. While initial integration into GVC can facilitate knowledge diffusion and build foundational capabilities, excessive dependence on foreign value-added inputs may create a structural lock-in, limiting the transition to higher-value segments of GVCs. To mitigate these risks, policymakers should actively promote reshoring strategies that strengthen domestic supply chains and reduce vulnerability to global disruptions, such as those highlighted by recent global crises. Additionally, promoting domestic R&D, fostering innovation ecosystems, and incentivizing local and foreign firms to engage in pre- and post-manufacturing activities should be central to industrial policy. Second, functional specialization policies should align with the economy's existing industrial structure and its stage of technological development. For countries in a transition stage, such as CEE, there is a critical need to monitor the threshold of foreign input reliance and invest in workforce development, technology transfer, and linkages with global R&D networks. These initiatives not only foster indigenous capabilities but also enhance supply-chain resilience. China's experience suggests that state-led initiatives, structural upgrading of the automotive industry, and strategic joint ventures

between domestic and foreign auto firms can effectively facilitate upgrading via GVC participation. Finally, advanced economies, represented by WE countries, must preserve and extend their comparative strengths in high-value-added activities. Policies should support competitiveness in knowledge-intensive segments through continuous upgrading of research and innovation infrastructures, considering reshoring or nearshoring critical activities to safeguard resilience and maintain technological leadership. Although returns to further technology upgrading may diminish, sustaining an innovation-friendly environment remains crucial to retaining a leadership position in GVCs and ensuring long-term economic vitality.

Overall, this study not only enriches knowledge on GVC participation and upgrading but also furnishes practical guidance for policymakers in designing strategies that enable sustainable growth. By highlighting the interplay between backward and forward GVC participation, functional specialization, and technology upgrading, this research affirms that meaningful economic progress requires holistic and context-specific approaches. As global value chains continue to evolve, countries at various stages of development should calibrate their policies to nurture domestic capabilities and functional specialization in higher-value segments, ensuring a more resilient and upward-oriented path within the global economy.

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Appendix

Table 7: Appendix Table: Index of Technology Upgrading

Category	Component	Quantitative Indicators	Comp. Weight	Cat. Weight	Cronbach's α
Index A: Inten- sity of technol- ogy upgrading	1. Human re- sources and ca- pability	1. Employment share in total economy (Source: OECD iS- TAN, Automotive industry yearbook)	1/7	1/2	0.7002
		2. High-skilled labor percentage in total number of employ- ees (Source: Eurostat KLEMS, Automotive industry year- book)			
		3. High-skilled labor compensation share in total labor com- pensation (Source: WIOD Social Economic Account)			
		4. Hours worked by high-skilled persons share in total hours (Source: WIOD Social Economic Account)			
	2. Production capability	5. Number of ISO 9001 certificate per 1000 vehicles produced (Source: ISO website)	1/7	1/2	
		6. Investment on fixed capital per vehicle produced (Source: OECD iSTAN, Automotive industry yearbook)			
		7. Number of trademarks registered in automotive industry per 1000 vehicles produced (Source: WIPO)			

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Table 7 – *Continued from previous page*

Category	Component	Quantitative Indicators	Comp. Weight	Cat. Weight	Cronbach's α
Index Breadth technology upgrading	3. R&D capability	8. R&D expenditure on automotive industry per vehicle produced (Source: OECD-ANBERD)	1/7	1/2	0.7890
		9. Capital expenditures per vehicle produced if FDI projects on R&D activities (Source: FDI market)			
		10. Number of FDI projects on R&D activities per 1000 vehicles produced (Source: FDI market)			
	B: 4. Infrastructure upgrading	11. Length of motorway per square km of the country area (Source: UNECE)	1/7	1/2	
		12. Road infrastructure investment per square km of the country area (Source: OECD)			
		13. Road infrastructure investment in constant USD per inhabitant (Source: OECD)			
		14. Road infrastructure maintenance per square km of the country area (Source: OECD)			

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Category	Component	Quantitative Indicators	Comp. Weight	Cat. Weight	Cronbach's α
	5. Structural upgrading	15. Degree of self-sufficiency: value added to output ratio (Source: OECD iSTAN, Automotive industry yearbook) 16. Share of passenger cars in terms of total vehicles produced (Source: OICA) 17. CO ₂ emission from transport in tonnes per inhabitant (Source: OECD) 18. CO ₂ emission from transport per one million units of USD GDP (Source: OECD) 19. Percentage of passenger cars powered by petrol and diesel (Source: Eurostat, Automotive industry yearbook)	1/7	1/2	
	6. Industrial Structure	20. Road injury accidents per 1000 vehicles registered (Source: OECD) 21. Value added share of automotive industry in total economy (Source: OECD iSTAN, Automotive industry yearbook)	1/7	1/2	

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Table 7 – Continued from previous page

Category	Component	Quantitative Indicators	Comp. Weight	Cat. Weight	Cronbach's α
Index C: Interaction with global economy	7. Demand up-grading	22. Percentage of firms with more than 100 employees (Source: Orbis)	1/7	1/2	
		23. Motorization: Number of passenger cars per 1000 inhabitants (Source: Eurostat, UNECE)			
		24. First registration of passenger cars per 1000 inhabitants (Source: OECD, China statistic yearbook)			
		25. Consumption preference: percentage of household expenditure for purchase of vehicles in total household expenditure (Source: OECD, China statistic yearbook)			
	8. Capital inflow	26. Number of inward FDI projects on automotive industry per 1000 vehicles produced (Source: FDI Market)	1/3	N.A.	0.8130
		27. Capital expenditure on inward FDI projects on automotive industry per 1000 employees (Source: FDI Market)			
		28. Ratio of jobs created from inward FDI projects on automotive industry to total employees in automotive industry (Source: FDI Market)			

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Table 7 – *Continued from previous page*

Category	Component	Quantitative Indicators	Comp. Weight	Cat. Weight	Cronbach's α
	9. Capital out-flow	29. Number of outward FDI projects on automotive industry per 1000 vehicles produced (Source: FDI Market)	1/3	N.A.	
		30. Capital expenditure on outward FDI projects on automotive industry per 1000 employees (Source: FDI Market)			
	10. GVC Participation	31. Ratio of jobs created from outward FDI projects on automotive industry to total employees in automotive industry (Source: FDI Market)	1/3		
		32. Foreign value added content of gross exports per 1000 employees (Source: TiVA)			
		33. Domestic value added content of gross exports per 1000 employees (Source: TiVA)			
		34. Gross imports of intermediate products per 1000 employees (Source: TiVA)			
		35. Domestic value added embodied in foreign final demand per 1000 employees (Source: TiVA)			