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Is productive service intermediate input a good instrument for enhancing the Global Value Chain participation?☆

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ABSTRACT

Globalization has closely interconnected the production systems of various countries, and gaining a superiority in the Global Value Chain (GVC) has become a strategic imperative for many countries. Warrant attention, the service-based economy has been playing a pivotal role in optimizing and upgrading the GVC. Consequently, based on a sample that consists of 77 countries from 1995 to 2020, this article investigates the promoting effect of productive service intermediate input (PSII) on GVC participation. The findings are consistent with our expectations and are supported by a series of robustness checks and endogeneity handling. Heterogeneity analyses provide partial support for a geographic pattern linking PSII to GVC participation. Mediation analyses confirm that PSII enhances GVC participation through manufacturing servitization, financing constraint alleviation, and efficiency improvements. Finally, moderation analysis indicates that PSII exhibits a "substitution" effect vis-à-vis innovation capacity, implying a more feasible pathway for less developed countries to industrial upgrading.

1. Introduction

The intensification of geopolitical conflicts and trade protectionism after the global financial crisis has underscored the fragility and uncertainty of the international order, suggesting a potential "decoupling" of the global manufacturing production system. Developed countries have begun to reconsider the impacts of globalization, with American and European economies implementing "reindustrialization" strategies to attract manufacturing back to their territories (Capello and Cerisola, 2023). Concurrently, the widespread application of new-generation information technology has facilitated the integration of production processes and the intelligentization of supply chains. This technological advancement has been effective in reducing the number of production stages in manufacturing, lowering the urgent demand for labor, and narrowing the cost gap in processing (Hyvonen, 2008). In this evolving landscape, it has become imperative for economies to adapt effectively to external environmental changes and aim for higher positions within the Global Value Chain (GVC).

Productive services, acting as both "adhesive" and "lubricant", have emerged as crucial intermediate inputs across various production stages in the GVC (Guerrieri and Meliciani, 2004). In recent years, there has been a significant reduction in trade costs, particularly for intangible services, due to the development and application of digital technology. This reduction has allowed for a finer specialization and recombination of tasks within value chains. Furthermore, the rapid development of productive services, positioned at the high end of value chains, has propelled the growth of cross-border investment, making the global production system more interconnected (Szalavetz, 2003).

A clear manifestation of the rapid development of productive services is driving the servitization of manufacturing (Huang et al., 2024; Xiang et al., 2019). The servitization of manufacturing, characterized by the integration of services into the manufacturing process, has become an essential path for the industry's transformation and upgrading (Xiang et al., 2019). While previous research has underscored the benefits of servitization for manufacturing production, the issue lies in the fact that, as can be seen in the following text, servitization is a rather "systematized" concept that highlights the interdependence between the manufacturing and service sectors (Neely, 2008; Liu et al., 2016). It also implies that, although servitization can indeed promote the development of manufacturing, it would be challenging to derive any straightforward policy insights from such a conclusion, as a systematized variable depends not only on individuals.

Emphasis on servitization has left a gap in offering practical tools for policy implementation that leverage these insights to enhance the value chain position of economies. In fact, existing research has suggested that Productive Service Intermediate Input (PSII) play a leading role in

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driving the servitization of manufacturing (Lin et al., 2019). By streamlining manufacturing processes, productive services contribute to operational efficiency, a cornerstone for competitive advantage in the global market (Chesbrough, 2003). Furthermore, they are instrumental in fostering innovation, supporting the development and integration of new technologies that are essential for ascending the value chain and expanding global market presence (Lodefalk, 2013). Beyond operational and innovative enhancements, productive services also facilitate global market integration by improving logistics, ensuring product quality, and aiding in regulatory compliance, thereby enabling countries to not only enter but excel in international markets (Pietrobelli and Rabellotti, 2011). The role of productive services is thus multifaceted, directly influencing countries' ability to compete and thrive within the GVC framework.

Aiming to bridge this gap by providing a nuanced exploration of PSII and elucidating its dual significance in terms of "quantity" and especially "quality", this article conducts empirical studies based on panel data of 77 countries from 1995 to 2020. "Quantity" here refers to the proportion of productive services within the overall input mixture, signifying the extent to which sectors utilize these services. Meanwhile, "quality" relates to the sophistication or complexity of these services, denoting their potential to drive innovation and operational efficiency. Collectively, the two dimensions of PSII play a critical role in countries' abilities to enhance their participation in the GVC, and a series of robustness checks and endogeneity handling corroborate this finding. By distinguishing between types of PSII, this article provides indirect empirical support for the explanatory power of the core–periphery model in shaping the geographic patterns of PSII and GVC participation. Through an in-depth examination and empirical testing of mediating channels, we demonstrate how both the quantity and quality of PSII enhance countries' GVC participation by raising the degree of manufacturing servitization, easing financing constraints, and improving efficiency. Finally, the "substitution" effect exhibited by PSII vis-à-vis innovation capacity underscores the significance of PSII as a feasible pathway for industrial upgrading in less developed countries.

The remainder of this article is structured as follows. Section 2 reviews the literature relating to PSII and GVC participation and identifies existing research gaps. In Section 3, we develop the theoretical framework through which PSII affects GVC participation, including the formation of geographic patterns, the causal channels, and interactions with knowledge inputs. Section 4 describes our research design, including the econometric model and variable specifications. Section 5 reports the baseline regression results along with robustness checks and endogeneity handling. In Section 6, we conduct detailed extension analyses, comprising heterogeneity analyses, mediation effect tests, and moderation analyses. Finally, Section 7 concludes this article, offering policy implications and suggesting directions for future research.

2. Literature review

Rooted in vertical specialization derived from transnational division of labor, specialization in the Global Value Chain is fundamental to shaping competitive advantage, meaning that the emergence of specialization in GVC signifies that different countries assume distinct roles at various stages of the GVC (Guerrieri and Meliciani, 2004). Global commodity chain theory argues that the drivers underpinning value chains can be categorized into producer-driven — based on scale and R&D advantage, and consumer-driven — based on favorable distribution channels and brand effects. Each type of value-chain driver corresponds to a unique competitive advantage (Gereffi, 1999), implying that participation in the GVC is closely tied to such a capacity to "capture value". A country occupying a core manufacturing or leadership position within the GVC can secure a larger value share through cross-border value-chain collaboration.

Traditional trade theory emphasizes how factor endowment and economic structure influence GVC participation (Vandermerwe and Rada, 1988); some studies also incorporate institutional environments into analyses (Acemoglu et al., 2007; Nunn and Trefler, 2013). Within classical theories, industrial upgrading typically proceeds via "inter-industry shifts" — whereby an economy transitions from labor-intensive to capital- or technology-intensive industries (Huang et al., 2024). Driven by labor division and policy liberalization, the nature of GVC participation has evolved, highlighting a strategic shift toward intra-industry upgrading — i.e., upgrading within the value chain itself by moving from low-value-added activities to high-value-added activities (Kadarusman and Nadvi, 2013). Considering the impact of geographic distance on transportation costs and efficiency, the GVC often exhibits regionalization at the regional level, which may align with the formation of a core–periphery geographical pattern (Cigna et al., 2022; Rodríguez-De la Fuente and Lampón, 2020). Moreover, the formation of organizational networks and the provision of digital infrastructure may elevate positions in the international division of labor via micro-level channels — promoting horizontally compatible integration among SMEs or geographically dispersed firms, enhancing technological innovation capacity, and lowering operating costs (Taglioni and Winkler, 2016; Rungi et al., 2023).

Recent studies have further investigated the role of deep integration and collaborative development between manufacturing and services in the GVC specialization process (Baines et al., 2009; Huang et al., 2024). Manufacturing and services can be integrated through the so-called "servitization of manufacturing". Servitization refers to the transformation of innovative firms from providing mere products to delivering product–service systems, or a capability and process that generates economic value (Neely, 2008); alternatively, it embodies the trend of manufacturing firms incorporating more productive service components into their production processes and outputs to create product–service systems (Visnjic and Van Looy, 2013). Servitization can be further divided into two types: "input servitization" and "output" one (Kusiak, 2020). The former implies that manufacturing can embed services within itself through service inputs to achieve "service-enabled" manufacturing (Kin-man To and Leung, 2001). The latter signifies that manufacturing firms extend their business into services, thus realizing the servitization of their manufactured products.

Servitization indeed plays a significant role in the real economy, which has been widely recognized in prior research. It highlights the interdependence between manufacturing and services, showing that services are closely linked to production and form networks that support manufacturing (Heuser and Mattoo, 2017), which systematically enhance manufacturing operational efficiency and core competitiveness (Liu et al., 2020b). Consequently, raising manufacturing servitization is also considered an important means to elevate the value-chain participation status.

However, it should be noted that servitization is defined in terms of product–service "systems" (Huxtable and Schaefer, 2016); which is also measured by " pure consumption" based on the ICIO table, capturing the indirect inputs of services to manufacturing (Lv et al., 2017; Liu, 2016). This means servitization is a systems variable, not merely a function of individual entities; instead, the level of servitization depends on the interdependency among actors within the ICIO network comprising manufacturing and service sectors. Previous research on the relationship between manufacturing service inputs and GVC participation has largely focused on manufacturing servitization. The problem lies in the systemic nature of servitization, implying that conclusions may lack policy relevance, because it is difficult, at least in an intuitive way, to determine how a change at the individual level, e.g., increasing the output of a certain product, can raise the overall system's servitization level.

In contrast, as a crucial input factor in the manufacturing servitization process, production services, spanning IT, logistics, R&D, and other fields, offer innovation oriented toward services, streamline complex management systems, and improve operational efficiency, which implies that Production Services Intermediate Input (PSII) may represent

the key and primary driver for enhancing GVC position (Gereffi and Fernandez-Stark, 2011). Unlike manufacturing servitization, PSII emphasizes production services as individual units, involving direct supply relationships within product–service systems, rather than systemic interdependencies. Starting from PSII as a primitive production input, it also provides a more straightforward policy reference for facilitating dynamic interactions between advanced manufacturing and productive service industries to accelerate industrial upgrading.

3. Theoretical framework and research hypothesis

According to the OECD, Productive Service Intermediate Input can be defined as direct intermediate input into further production activities sold to other firms; or primary intermediate services in manufacturing processes provided by producer-service suppliers primarily to final goods producers or the commercial sector, rather than to individuals or households (Francois and Woerz, 2008). Productive services typically include R&D, ICT, logistics, financial services, and management consulting (Manghnani et al., 2021)

At a macroeconomic level, PSII is typically associated with the servitization of manufacturing by means of resource allocation and specialization, the flow and accumulation of cross-border knowledge and technology, and production-process coordination optimization. First, production services often compensate for technological and resource deficiencies in manufacturing sectors (Dong et al., 2022). By embedding capabilities, management, and professional knowledge outsourcing, production service inputs tend to enhance manufacturing productivity more effectively than physical inputs via "quality effect", "learning-by-doing", and economies of scale and specialization due to greater product variety (Amiti and Konings, 2007). Second, production services foster knowledge and technology spillover and accumulation. They often carry advanced R&D, standardization, and professional training elements, so through project collaboration and outsourcing, production services can provide spillovers to manufacturing, assisting it to upgrade from low-tech to mid- or high-tech functions; this knowledge transfer capacity is essential for transitioning from "manufacturing–export" to "R&D–services + manufacturing" (Criscuolo et al., 2017; Luo et al., 2024). Furthermore, as key "glue" and "lubricant" in cross-border production networks, production services reduce transaction costs, improve time consistency and supply-chain resilience, coordinating logistics, information, and financial flows across geographically dispersed production, which can, in turn, facilitate modular participation in value chains (Taglioni and Winkler, 2016; Manghnani et al., 2021).

At the micro-level, knowledge-intensive service inputs can be integrated into firm-level production activities to reduce costs, improve efficiency, and spur innovation (Balland and Rigby, 2017; Goldar, 2019), thereby enhancing participation in the GVC and driving value-chain upgrading (Linbing et al., 2023; Ma et al., 2022). Introducing PSII into manufacturing can enhance the value and utility of manufactured products (Xiang et al., 2019), integrate dispersed manufacturing resources (Lei et al., 2021), and transition from pure service sets to "service packages". By combining IT and manufacturing technologies, firms can effectively control production, supply, and sales operations, facilitating information sharing and coordinated operations (Dequan et al., 2010). They can alleviate liquidity constraints, reduce transaction costs, and support R&D practice and innovation by developing financial-service (Linbing et al., 2023). Additionally, the "relational embeddedness" between service inputs and products enables continuous and effective exchange of non-market information, sustaining operational continuity and coordination, which allows firms to focus on their core competencies, further encouraging manufacturing firms to externalize services (Patel et al., 2021). Thus, the following hypotheses will be tested:

Hypothesis 1. Productive Service Intermediate Input (PSII) can enhance participation in the Global Value Chain (GVC).

As a "controllable" primary input factor, combining production services with manufacturing activities can more directly bridge the gap between manufacturing and high-value services. The macro-level resource allocation, factor mobility, and production optimization, together with micro-level cost reduction, efficiency gains, and information flow, mean that PSII can powerfully facilitate integrations into and effective participation in the GVC. Simultaneously, it is worth noting that the "quality" rather than the "quantity" of PSII may profoundly impact GVC participation. Recent research has focused on "efficiency improvement and quality enhancement" across goods trade (Kong et al., 2021; Gao and Dong, 2022) and technology and innovation domains (Hu et al., 2020; Wang et al., 2022). This suggests that "complexity" as a proxy for "quality" may contribute more deeply to core competitiveness. Complexity refers to the evolution of advanced, tacit, hard-to-learn, and hard-to-transfer knowledge inputs. These knowledge inputs typically have high barriers, marked industry-level "stickiness", leading to high sunk costs for outsiders, thus conferring high economic value on such products (Balland and Rigby, 2017). Therefore, high-quality PSII may result in productive manufacturing sectors capable of delivering more high-value-added goods, thereby enhancing their global value chain participation. Thus, the following hypothesis will be tested:

Hypothesis 2. Higher quality of PSII will promote participation in the GVC.

Hypothesis 3a. By enhancing the level of servitization of manufacturing, PSII (both "quantity" and "quality" aspects) can improve countries' participation in the GVC.

Hypothesis 3b. PSII (both "quantity" and "quality" aspects) can also enhance GVC participation by mitigating financial constraints and promoting managerial efficiency.

It is also necessary to distinguish domestic PSII from imported PSII, because the domestic integration of PSII with manufacturing, as well as dependency on foreign PSII, may have entirely different economic implications and provide insights into countries' positioning differences within the GVC.

Countries with advanced technical capabilities, well-established institutions, and capital-intensive industries are often associated with independent R&D and high-level PSII export (e.g., R&D support, financing, intermediary consulting, etc.), and typically do not rely heavily on imported PSII. These are usually "core countries" within core–periphery models (Pavlínek, 2022). By domestically integrating PSII and manufacturing, these nations can achieve high output efficiency and technological integration, and outwardly export PSIIIs that shape global standards and rule-setting processes (Antràs and De Gortari, 2020). In contrast, semi-peripheral countries manifest a dual character: on one hand, they import core PSIIs to support domestic manufacturing and service upgrades (Lampón et al., 2024b); on the other hand, they gradually develop local capacity to absorb lower- or mid-level PSIIs with exporting them to peripheral countries, thereby deepening GVC embedding (Chu et al., 2025).

Peripheral countries, which are characterized by resource- or labor-intensive economic structures and relatively low value-added output, tend to rely heavily on imported PSIIs (Lampón et al., 2024a). Within the GVC, these countries may be fronted with "low-end locked" — positioned at the low-value-added nodes of value chains — with strong backward participation but weak forward participation. Lacking domestic service capacity and bargaining power, they are vulnerable to price, institutional, and standards fluctuations (Jones et al., 2019; Lampón et al., 2022). Due to such a lock-in, greater dependence on imported PSIIs and an imbalanced industrial structure further squeezes the space for high-value-added industries, making it more difficult to develop domestic PSIIs and support industrial upgrading. Thus, the following hypothesis will be tested:

Hypothesis 4. Domestic PSII manifests a promoting effect on GVC participation, while imported PSII has a negative effect.

Moreover, innovation capability may significantly enhance GVC participation by introducing factors of knowledge or R&D (Aparicio et al., 2021). The structure and development of manufacturing will be related to productive service with high knowledge- or technology-intensity directly, e.g., R&D services can enhance manufacturing enterprises' capability to develop new products, elevate high-end and facilitate product design (Demircioğlu, 2020; Aparicio et al., 2021; Wilkin and Chenhall, 2020); the industrialization of innovation can be accelerated by integrating by introducing commercialization services of technology, through the path of integrating existing resources (Dmitriev et al., 2014; Brohman and Ward, 2015); and IT services promote the intelligence and innovative development of manufacturing and significantly improve the production and operational efficiency of enterprises (Hyvonen, 2008). The intelligence and innovative development of manufacturing can be promoted, which can, in turn, significantly improve enterprises' production and operational efficiency by developing IT services (Hyvonen, 2008). From the other perspective, the introduction of advanced factors such as knowledge, technology, and information into manufacturing, particularly through "input servitization", is also instrumental in bolstering the manufacturing enterprise's capacity for independent innovation (Hyvonen, 2008; Klumpp and Loske, 2021), assisting industries in ascending to the high-value segments of the value chain. Additionally, servitization introduces modern production processes and new business models to enterprises, thereby enhancing their value-added capabilities (Fransen et al. 2023) (Wang et al., 2023).

While the innovation capability may indeed exhibit the aforementioned "leverage effect" in enhancing GVC participation through PSII, research suggests that R&D and innovation activities may also lead to the crowding out of PSII. Existing studies have indicated such a "crowding out effect" (Liu et al., 2020a; Teng et al., 2020), which is particularly pronounced in corporate green innovation activities under environmental regulation (Liu, 2022; Fang and Shao, 2022; Qu et al., 2023). The demand for resources and displacement caused by R&D and innovation activities are more pronounced than those caused by other production activities. In manufacturing production activities, especially in strategic emerging industries, substantial investments in R&D and innovation are required, which may imply crowding out of PSII. Additionally, higher innovation capability, typically measured by economic or technological complexity at the macro level, may also suggest that the manufacturing sector has already achieved a significant level of integration in up- and down-stream domains with considerable knowledge- or technology-intensity, positioning itself in relatively high-value-added segments of the GVC. At this point, PSII may not be the dominant factor in enhancing competitive advantages. Therefore, once enhancing GVC participation through PSII is involved in innovation activities, a "crowding out effect" may occur, which means that innovation capability will substitute for the role of PSII and exhibit a negative moderating effect on the relationship between PSII and GVC participation. Thus, the following hypothesis will be tested:

Hypothesis 5. Innovation capability can substitute for PSII in enhancing GVC participation, exhibiting a negative moderating effect.

4. Research design

4.1. Explained variable

In previous research, the mainstream methods for measuring GVC primarily followed the approaches outlined by Wang et al. (2017) and Borin and Mancini (2019), which are based entirely on the tripartite decomposition of gross exports within the Inter-Country Input–Output (ICIO) model. However, it is worth noting that GVC metrics derived from traditional trade-based frameworks significantly underestimate global GVC activities, misrepresent participation in key sectors such as services and upstream manufacturing, and exaggerate risks during critical stages like early trade liberalization in large economies. Therefore, this article draws on Borin et al. (2021) approach, conducting measurements of GVC participation by applying the tripartite decomposition method to global production networks, which extend beyond import–export dynamics and encompass international and domestic production relationships. Such an output-related framework encompasses not only the GVC activities traced in value-added and final goods but also all the exchanges of inputs within the intermediate production stages related to GVCs (Borin et al., 2021).

Therefore, in every part of the regressions, this article will first conduct regressions by setting output-related GVC participation as the dependent variable based on the tripartite decomposition of outputs. Additionally, this article will also conduct regressions by setting each of the three components of orGVC — pure backward (orGVC_pb), pure forward (orGVC_pf), and two-sided (orGVC_ts) of output-related GVC participation as dependent variables. The construction details of these four indicators are provided in Supplementary Information.

4.2. Core explanatory variable

According to its definition, and the OECD classification, productive service industries are commonly recognized to be knowledge-intensive, requiring high initial investments (Markusen, 1989), which are usually related to transportation, financial, insurance, information, communication, technology, and other business services (Yang, 2015). Thus, this article quantifies the level of productive services intermediate input by calculating the ratio of intermediate inputs provided by the producer service sectors to total outputs of the service sector, namely:

$$PSII_n = \frac{\sum_i^{g_s}\sum_j^{g_n} Z_{n,ij}}{\sum_i^{g} X_{n,i}} \tag{1}$$

where, $PSII_n$ denotes the level of productive services intermediate input of country n; $Z_{n,ij}$ denotes intermediate inputs of producer service sector (g_s) i to non-producer service sector (g_n) j within country n; $X_{n,i}$ denotes total outputs of service sector (g) i. Measurements on the PSII are also generally based on ICIO data.

In order to realize quantifying the "quality" of PSII, this article adopts the approach proposed by Tacchella et al. (2012) and Sciarra et al. (2020), measuring the "quality" by introducing "complexity":

$$PSIIcomp_c = \left(\sum_{i=1}^{s} \lambda_i^N \left(v_{c,i}^N\right)^2\right)^2 + 2\sum_{i=1}^{s} \left(\lambda_i^N\right)^2 \left(v_{c,i}^N\right)^2 \tag{2}$$

where, $PSIIcomp_c$ denotes the "complexity" of PSII in country c; λ_i and $v_{c,i}$ denote the eigenvalue and eigenvector of proximity matrix stemmed from the country-sector value-added bipartite network, which can be constructed based on the data provided by OECD ICIO table; s denotes the s^{th}-order (s^{th}-largest eigenvalue and corresponding s^{th}-largest eigenvector).

In fact, the method of measuring "quality" (including PSII quality in this article) via the bipartite network framework originates from such an idea: any output data of country c in field p (which may be a product, patent, commodity, etc.) corresponds to a 2 mode data type. Through two types of nodes (country nodes N_c and field nodes N_p) and edges (E) connecting different node types, a bipartite network can be constructed (which can be described via the adjacency matrix M_{cp}).

At that point, the issue of "complicacy" (in this context, helpful for assessing PSII quality) can be settled by examining the "complicacy" of the two node types (denoted X_c and Y_p). Crucially, the complicacies of both types of nodes can be represented as coupled equations: the complicacy of a country node (X_c) depends on the complicacy of field nodes ($Y_1, Y_2, \ldots, Y_t$) and on their relations (M_{cp}); similarly, the complicacy of a field node (Y_p) depends on the complexities of its

country nodes ($X_1, X_2, \ldots, X_c$) and their relations (M_{cp}). The coupled equations can be expressed as:

$$\begin{cases} X_c = f(Y_1, Y_2, \ldots, Y_t, M_{cp}) \\ Y_p = g(X_1, X_2, \ldots, X_c, M_{cp}) \end{cases} \tag{3}$$

By solving Eq. (3) with a specific algorithm, $\hat{X}_c$ and $\hat{Y}_p$ can be obtained, which are referred to as "complexities", distinguishing them from the aforementioned "complicacy" — the latter denotes the attribute of nodes, while the former is the quantification of the latter.

In fact, in this article, we solve for X_c and Y_p using the Fitness and Complexity (FC) algorithm proposed by Tacchella et al. (2012), which sequentially computes the country proximity matrix $N_{cc'}$ and the field proximity matrix $G_{pp'}$. The two matrixes can be expressed as:

$$\begin{cases} N_{cc'} = \frac{\sum_{c'} M_{cp} M_{c'p}}{(s'_p)^2 s_{c'} s_c} \\ G_{pp'} = \frac{\sum_{p'} M_{cp} M_{cp'}}{(s_p)^2 s'_{p'} s'_p} \end{cases} \tag{4}$$

Since the bipartite network actually describes direct relationships between country and field nodes (i.e. output of country c in field p), countries are not directly connected to countries, nor fields to fields. By applying the FC algorithm, the original 2 mode network is decomposed into two 1 mode networks containing only one node type, where nodes (of the same type) are directly linked; in this context, the country proximity matrix $N_{cc'}$ and the field proximity matrix $G_{pp'}$ contain only country nodes or only field nodes, respectively; and countries are directly connected to countries, the same as fields to fields. These matrices describe such a "proximity": similarity in output structure between countries, and similarity in participating countries across fields.

The core idea of this algorithm is: higher country complexity should indicate broader field participation, deeper participation within each field, and participation in fields of higher complexity; similarly, higher field complexity should imply fewer participating countries, deeper country-level participation, and higher complexity of participating countries; all demonstrating mutual dependence between countries and fields.

Finally, the λ_i and $\upsilon_{c,i}$ in Eq. (2) are actually the eigenvalues and eigenvectors of $N_{cc'}$. The PSII quality measurement, i.e., PSIIcomp, derived from Eq. (2), essentially captures the economic value embedded in productive service inputs. A higher PSIIcomp indicates that a country's productive service inputs hold greater economic value, meaning that its productive service sector delivers higher-quality PSII. Drawing on the concept of eigenvector centrality demonstrated in the Matrix-Estimation, and the core logic of the FC algorithm, the quality of PSII as measured by PSIIcomp simultaneously accounts for both "heterogeneity" of output across different productive service industries with "interconnectedness" among these industries. Moreover, through the economic interpretations of this algorithm provided by Mealy et al. (2019) and Zhang (2024), PSIIcomp indeed captures the fact that the higher quality of PSII a country provides (i.e., a higher PSIIcomp value), the broader the range of productive service industries in which it participates, the deeper its engagement in intermediate inputs, and the higher the complexity of these industries; additionally, the indicator implicitly conveys another economic meaning: the higher the PSIIcomp of a country is, the greater its degree of specialization in certain productive service sectors will be, and the closer its output structure with that of other countries with high PSII quality will be.

It is particularly worth noting that, in order to enhance the interpretability of the estimated coefficients of PSII quality in the subsequent analyses, we recompute the annual percentile ranking of PSIIcomp for each country or region based on its absolute value. The percentile ranking of PSIIcomp is then consistently used as the key explanatory variable in the baseline regressions as well as in a series of robustness checks and endogeneity handling. A higher percentile ranking of PSIIcomp indicates that the country or region provides higher-quality productive services intermediate input (see Fig. 1).

4.3. Econometric model and other variable specification

Formally, to investigate the impact of productive service intermediate inputs on GVC participation, this article considers constructing the following econometric model:

$$GVC_{it} = \alpha + \beta PS_{it} + \sum_{k=1}^{K} \gamma_k X_{k,it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{5}$$

where GVC_{it} denotes participation or position of countries in the GVC, and we use 4 indicators aforementioned in specific regressions; PS_{it} denotes productive service intermediate input, and we use "quantity" and "quality" dimension of PSII in specific regressions; $X_{k,it}$ denotes control variables that can affect GVC participation, including labor, human capital, innovation, etc.; λ_t and μ_i denote time fixed effects and individual fixed effects respectively; ε_{it} denotes the error term.

Referring to previous studies, this article considers selecting the following 11 control variables: institutional quality (freedom), human capital (HCI), asset depreciation (depreciate), working hours (work), patent output (patent), fixed capital (GFCF), government expenditure (GFCE), labor force (labor), high-end output (highend), openness of market, and market capitalization. The abbreviations, corresponding names and descriptions of the variables are provided in Supplementary Information.

Considering the presence of missing data in the sample, this article selects a sample period of 26 years from 1995 to 2020 and includes 77 countries as sample individuals. In order to ensure the robustness of the results, this article applies 1% winsorization to each variable, both at the upper and lower tails. The descriptive statistics of these variables are shown in Table 1.

5. Results

5.1. Baseline regression

Table 2 shows the results of baseline regressions estimating the impact of "quantity" and "quality" of PSII on GVC participation.

The results show that all coefficients of PSII and PSIIcomp are significantly positive at the 1% level, which indicates that enhancing productive service intermediate inputs indeed has a positive effect on participation in the GVC, no matter whether in terms of quantity or quality. In fact, across the regressions for each subset of output-related GVC participation — pure backward, pure forward, and two-sided GVC participation — as dependent variables, the coefficients of PSII and PSIIcomp are significantly positive at a sufficiently high level, and there are no significant differences between these groups. It suggests that the enhancement in the "quantity" or "quality" level of PSII roughly equally enhances a country's forward and backward participation in the global value chain, thereby elevating the country's GVC position.

From the perspective of the economic interpretation, the coefficients of PSII and PSIIcomp, with orGVC as the dependent variable, are 1.175 and 0.234, respectively. This indicates that a one-percentage-point increase in the share of Production Service Intermediate Input in total service output (or an equivalent one-percentage-point rise in their quality percentile ranking) is associated with an expected 1.175% (or 0.234%) increase in the value-added of all activities in an intermediate position.[1]

Regarding more detailed subcategories, the coefficient, with orGVC_pb as the dependent variable, shows that a one-point increase in PSII share (or quality percentile) is associated with a 0.910% (or

[1] In the view of its construction, orGVC measures the combined value-added of three subcategories of output processes — forward-related output, backward-related output, and all other intermediate activities involving both directions (i.e., two-sided) within the same value chain.

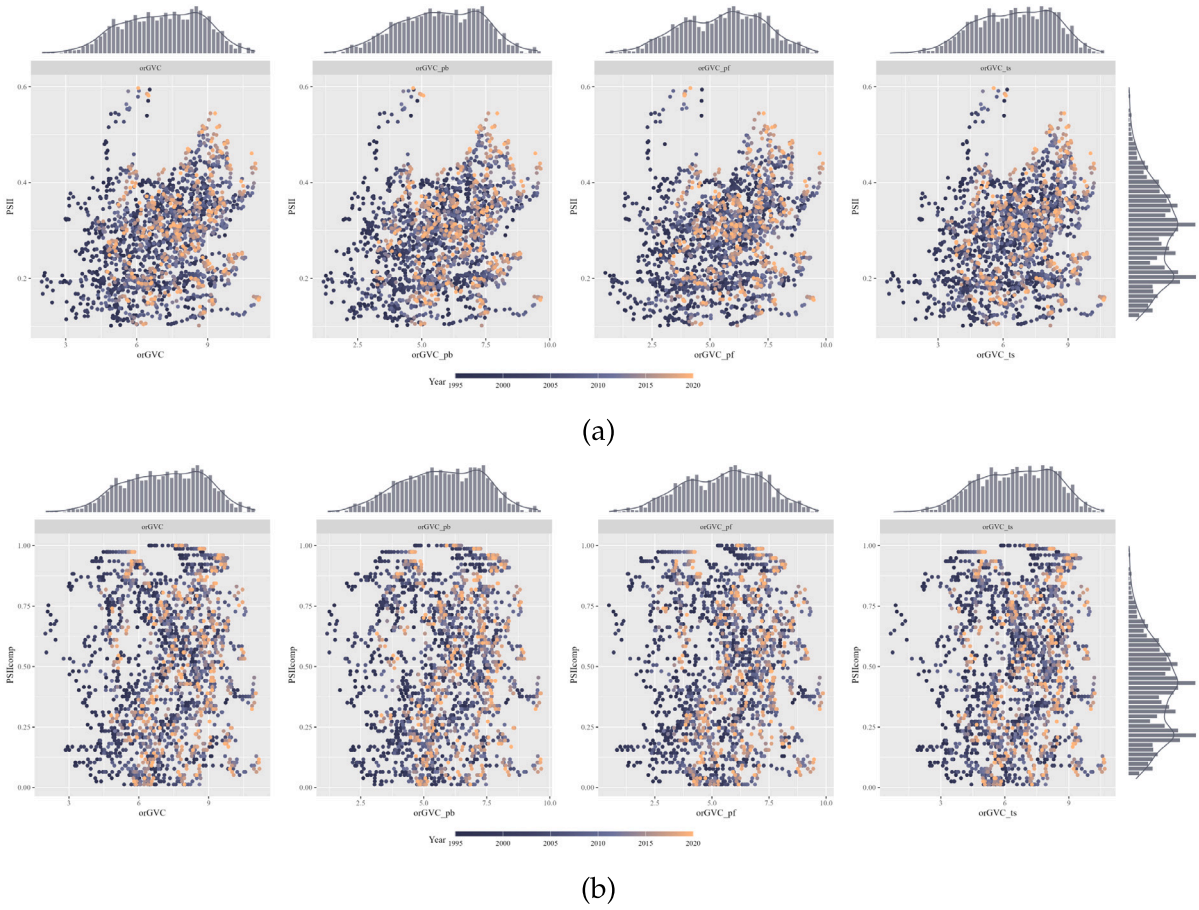

Fig. 1. Scatter plots between GVC participation and Productive Service Intermediate Input.
Note: Sub-figures (a) and (b) show the robustness checks results of PSII and PSIIcomp as the core explanatory variables, respectively.

Table 1
Descriptive statistics of variables.

Statistic	N	Mean	St. Dev.	Min	Max
orGVC	2,002	7.173	1.751	3.129	10.797
orGVC_pb	2,002	5.771	1.653	2.109	9.395
orGVC_pf	2,002	5.609	1.821	1.357	9.289
orGVC_ts	2,002	6.499	1.817	2.200	10.035
PSII	2,002	0.291	0.111	0.101	0.716
PSIIcomp	2,002	0.506	0.289	0.013	1.000
policy	1,598	7.176	0.922	4.441	8.870
HCI	1,900	2.749	0.696	0.000	3.742
depreciate	1,900	0.043	0.010	0.025	0.078
work	1,542	7.547	0.146	7.241	7.847
patent	1,319	2.896	1.033	0.477	5.564
GFCF	1,488	0.229	0.052	0.128	0.404
GFCE	1,472	0.166	0.050	0.051	0.262
labor	1,316	0.609	0.080	0.393	0.821
highend	1,950	0.315	0.152	0.003	0.719
openness	1,931	0.466	0.349	0.098	1.950
capitalize	1,358	0.709	0.922	0.011	7.264

0.245%) increase in value-added tied to backward production processes.[2] Each one-point increase in PSII share (or percentile rank), with orGVC_pf as the dependent variable, corresponds to a 1.108% (or 0.193%) rise in value-added associated with forward production processes.[3] Finally, with orGVC_ts as the dependent variable, a one-percentage-point increase in PSII share (or quality percentile) is linked

[2] The backward process here measures the value-added generated when domestic economic sectors import intermediate inputs and subsequently produce final goods or exports within the same value chain.

[3] The forward process measures value-added from domestic output that is exported and then re-exported within the same value chain.

Table 2
Results of baseline regressions.

Variable	GVC participation							
	orGVC		orGVC_pb		orGVC_pf		orGVC_ts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PSII	1.175***		0.910***		1.018***		1.276***	
	(0.246)		(0.219)		(0.257)		(0.284)	
PSIIcomp		0.234***		0.245***		0.193***		0.230***
		(0.057)		(0.062)		(0.054)		(0.069)
policy	0.208***	0.208***	0.183***	0.180***	0.299***	0.299***	0.178***	0.178***
	(0.027)	(0.025)	(0.028)	(0.026)	(0.030)	(0.028)	(0.026)	(0.025)
HCI	0.346***	0.287***	0.419***	0.363***	0.174***	0.125***	0.351***	0.291***
	(0.042)	(0.044)	(0.034)	(0.032)	(0.035)	(0.042)	(0.049)	(0.051)
depreciate	5.731	8.363	11.881*	14.095**	6.505	8.757	3.982	6.772
	(7.019)	(7.161)	(6.227)	(6.223)	(6.610)	(6.826)	(7.798)	(7.898)
work	−0.200	−0.255	0.189	0.146	0.005	−0.042	−0.409*	−0.467**
	(0.183)	(0.189)	(0.204)	(0.204)	(0.233)	(0.247)	(0.209)	(0.211)
patent	0.115***	0.096***	0.027	0.012	0.139***	0.123***	0.115***	0.095***
	(0.021)	(0.020)	(0.028)	(0.028)	(0.025)	(0.023)	(0.020)	(0.019)
GFCF	2.184***	2.214***	3.548***	3.554***	0.591**	0.619**	1.996***	2.035***
	(0.200)	(0.228)	(0.208)	(0.236)	(0.247)	(0.261)	(0.223)	(0.246)
GFCE	−1.150	−0.776	0.529	0.897	−2.172***	−1.861**	−1.264	−0.888
	(0.809)	(0.840)	(0.802)	(0.832)	(0.711)	(0.746)	(0.850)	(0.881)
labor	−0.060	−0.010	−0.731**	−0.636*	0.862***	0.897***	−0.078	−0.045
	(0.282)	(0.312)	(0.322)	(0.342)	(0.326)	(0.341)	(0.287)	(0.326)
highend	0.148	0.196	0.103	0.138	0.034	0.075	0.256	0.308*
	(0.163)	(0.151)	(0.139)	(0.128)	(0.167)	(0.159)	(0.176)	(0.164)
openness	0.538***	0.519***	0.488***	0.471***	0.132*	0.116	0.644***	0.624***
	(0.069)	(0.074)	(0.068)	(0.072)	(0.068)	(0.072)	(0.071)	(0.075)
capitalize	−0.082***	−0.080***	−0.043***	−0.040***	−0.058***	−0.055***	−0.097***	−0.094***
	(0.017)	(0.016)	(0.015)	(0.015)	(0.011)	(0.011)	(0.019)	(0.018)
Observation	841	841	841	841	841	841	841	841
Adj. R^2	0.307	0.288	0.359	0.352	0.230	0.216	0.261	0.239
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓	✓	✓

Note: *p < 0.1; **p < 0.05; ***p < 0.01. Values within "()" denotes Clustered Heteroskedasticity-Robust Standard Errors; and the same as the following.

to a 1.276% (or 0.230%) upswing in value-added relating to two-sided production processes.[4]

5.2. Robustness check

To ensure the robustness of the baseline regression results, this article conducts a comprehensive series of robustness checks. The specific implementation methods for each category of robustness test are as follows:

- Explained variable replacement. As noted earlier, the output-related indicators of GVC participation are derived using the tripartite decomposition method applied to total sectoral output, which is originally designed to account for GVC-related export activities. Accordingly, in this section, we replace the explained variable by the traditional trade-based GVC participation indicator (trGVC) with its three sub-indices: pure backward (trGVC_pb), pure forward (trGVC_pf), and two-sided bilateral (trGVC_ts) trade-based GVC. Then, this article re-conducts regressions separately using both PSII and PSII_comp as explanatory variables.
- Time-lag effect test. Given the time-lagged nature of fluctuations in sectoral production reflected in input–output tables, the impact of productive service sectors adjusting intermediate inputs from non-production services to output also incurs delays. Additionally, the output of intermediate goods and import/export dynamics tend to exhibit inertia; hence, any increase in GVC participation resulting from sectoral production changes should demonstrably carry time-lag effects. Accordingly, we replace the core explanatory variables PSII and PSIIcomp with their lagged 1 term (PSII_lag 1 and PSIIcomp_lag 1) and lagged 2 term (PSII_lag 2 and PSIIcomp_lag 2), to test the time-lag effect of productive service intermediate inputs on GVC participation.
- Additional control variables. Although the baseline regression already includes a substantial number of control variables to mitigate confounding factors, omitted-variable bias may still exist. Here, we include further covariates to assess whether the baseline adequately controls for confounders indirectly. Additional control variables comprise: education expenditure (education),[5] infrastructure investment (railline),[6] governance effectiveness (governance),[7] law and order situation (law),[8] exchange rate volatility (exchange),[9] and accountability (account).[10]
- Additional interaction fixed effect. While the baseline model includes time and individual fixed effects to eliminate time-invariant and entity-invariant unobservables, multidimensional unobserved factors may still exist, e.g., a shock in one period may affect different countries differently. To further control for

[4] orGVC_ts covers all other intermediate-position activities within the same value chain that involve both forward and backward processes, including combinations of cross-border intermediate imports and final exports, as well as the pairing of domestic intermediate inputs with cross-border exports and re-exports.

[5] This variable measures government education spending as a share of GDP.

[6] Measured by total carrying capacity of rail lines used in goods transportation (million ton-km).

[7] Measured by point estimates of perception of public service quality with its independence from political pressures.

[8] Measured by assessments of the completeness of legal frameworks and the stability of social order.

[9] Measured by annual variance in daily official exchange rate versus the USD.

[10] Measured by evaluations of government transparency and responsiveness to public demands.

residual bias, this article introduces stricter interaction fixed effects. Given the geographic clustering often observed in the coevolution of PSII and GVC positioning — particularly within regions — this article introduces the region-year interaction fixed effect to control for unobserved factors at the region-year level.

- Period adjustment. Our baseline regression utilizes data from 1995–2020; however, significant global economic shocks during this period (e.g., the 2008–2009 financial crisis) could result in biases. Thus, this article adjusts the sample period in three ways, conducting regressions on each modified dataset: (1) excluding all data prior to 2000 to account for the Asian financial crisis of 1997 and its aftermath; (2) removing data from 2008–2010 to isolate effects of the global financial crisis with its aftermath; and (3) excluding all data beyond 2015 to account for impact from the launch of China's "Belt and Road" Initiative (BRI) and the establishment of the Asian Infrastructure Investment Bank (AIIB).
- Country adjustment. The data used in baseline regressions includes 77 countries. Recognizing the substantial heterogeneity in economic development, this article adjusts the sample in 4 approaches and re-conducts regressions accordingly: (1) excluding the last 20 countries in average GVC participation from 1995–2020, which may be "locked in" low-end value chains for this characteristics of industrial structure and factor endowment[11]; (2) excluding the top 20 countries in GVC participation, which may have advanced industrial structures and deep integration of manufacturing and service sectors; (3) excluding the bottom 20 countries in PSII; and (4) excluding the top 20 countries in PSII.

The results of each robustness test are displayed in Fig. 2, focusing on the coefficients of PSII and PSIIcomp across different robustness tests. Complete results are available in the Supplementary Information.

Results show that nearly all coefficients of PSII and PSIIcomp remain positive and statistically significant at the 10% level at least across nearly all robustness checks, lending strong support to the reliability of baseline findings. Several aspects of these robustness analyses merit further discussion.

First, while replacing trGVC, trGVC_pb, trGVC_pf, and trGVC_ts as the explained variables, the coefficients on PSII and PSIIcomp remain positive and significant. Notably, as anticipated, traditional trade-based GVC measures tend to overestimate participation in sectors like services and upstream manufacturing. The generally higher coefficients observed across regressions corroborate such a bias. In particular, the coefficients of PSII underscore this phenomenon most distinctly in regressions where pure backward GVC (trGVC_pb) is the explained variable. Here, both PSII and PSIIcomp coefficients exceed those in the baseline model, highlighting how conventional backward metrics often overstate backward linkages.

Second, the tests for the time-lag effect confirm that productive service intermediate input exerts a lasting influence on GVC participation over time. The coefficients on the lagged terms of PSII and PSIIcomp (lagged 1 and lagged 2) are significantly positive, indicating that improvements in PSII lead to sustained increases in GVC engagement over extended periods. However, these coefficients gradually diminish in magnitude as the lag lengthens, consistent with the notion that the influence of PSII, while persistent, tapers.

Third, even after including additional variables as well as additional interaction fixed effects, the coefficients of the PSII or PSIIcomp remain unchanged, which further implies that the baseline regressions have effectively accounted for potential confounding influences and unobserved factors.

Fourth, the period adjustments yield PSII and PSIIcomp coefficients nearly identical to those in the full-sample regression. This consistency suggests that major economic shocks across the long sample period did not distort the relationship between PSII and GVC participation. Moreover, country adjustments further affirm the generalizability of baseline findings, which indicates that the influence of PSII on GVC participation is broadly homogeneous across most countries, regardless of their development status or production-service input levels.

5.3. Endogeneity handling

In previous regressions, this article introduced the two-way fixed effect to mitigate the endogeneity issues caused by omitted variables, which are time- or individual-invariant and cannot be observed to some extent. However, the effectiveness of the two-way fixed effect is still limited, and the problem of reverse causality between the dependent and explanatory variables cannot be ignored. As mentioned above, a country can promote its participation in the GVC by improving productive service intermediate inputs. However, the improvement in a country's participation in the GVC may also lead to an increase in productive service intermediate inputs due to the development of related industries it drives or leads.

Therefore, this article considers adopting Two-Stage Least Squares (TSLS) estimation by selecting three sets of eligible instrumental variables. The TSLS model can be represented as:

$$orGVC_{it} = \alpha^{2sls} + \beta^{2sls}\widetilde{PSII}_{it} + \sum_{k=1}^{K}\gamma_k^{2sls}X_{k,it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{6}$$

where $\widetilde{PSII}_{it}^{lag_1}$ meets:

$$\widetilde{PSII}_{it}^{lag_1} = \hat{\alpha}^{iv} + \sum_{j=1}^{J}\hat{\beta}_j^{iv}IV_{j,it} + \sum_{k=1}^{K}\hat{\gamma}_k^{iv}X_{k,it} + \hat{\lambda}_t + \hat{\mu}_i + \hat{\varepsilon}_{it} \tag{7}$$

First, in the first set, this article considers using language and geographic factors as the primary tools in constructing instrumental variables. Regarding the language factor, this article employs the Common Language index (CL), which is a binary indicator based on linguistic proximity (Melitz and Toubal, 2014). This measure draws on the approach used by Laitin (2000) and Fearon (2003), which estimates linguistic distances based on classifications in the Ethnologue database—spanning language families, branches, and sub-branches. With respect to geography, this article uses internal distance as an alternative to the CL index. Internal distance is computed based on a country's land area, as per CEPII methodology (Mayer and Head, 2002), and reflects the average distance between producers and consumers within the country (Mayer and Zignago, 2011). Empirically, both language and geographic factors are almost exogenous — language reflects deep-rooted socio-historical stability and geography is spatially invariant; and at the same time, they will also be effective. First, since productive service sectors are knowledge-intensive and often require international expertise, sharing a common language with other countries may facilitate the transfer of high-value knowledge, thereby enhancing GVC positioning through the development of productive service inputs. Second, internal distance determines the internal provision and utilization costs of intermediate inputs, thus influencing PSII levels.

To further ensure variation in both time and individual dimension, this article introduces the global weighted average tariff as the second tool in constructing instrument variables. Weighted average tariffs at the global level are generally exogenous because tariff schedules result from multilateral negotiations or agreements and tend to remain stable within certain policy periods. Moreover, average tariffs are not significantly influenced by the economic performance of any single country. From a theoretical standpoint, higher tariffs restrict the cross-border flow of resources and factors, thereby reducing the inputs of productive services. Accordingly, this article multiplies the global weighted average tariff with (a) a country's average linguistic distance

[11] Measured by the average rankings of GVC participation over 1995–2020.

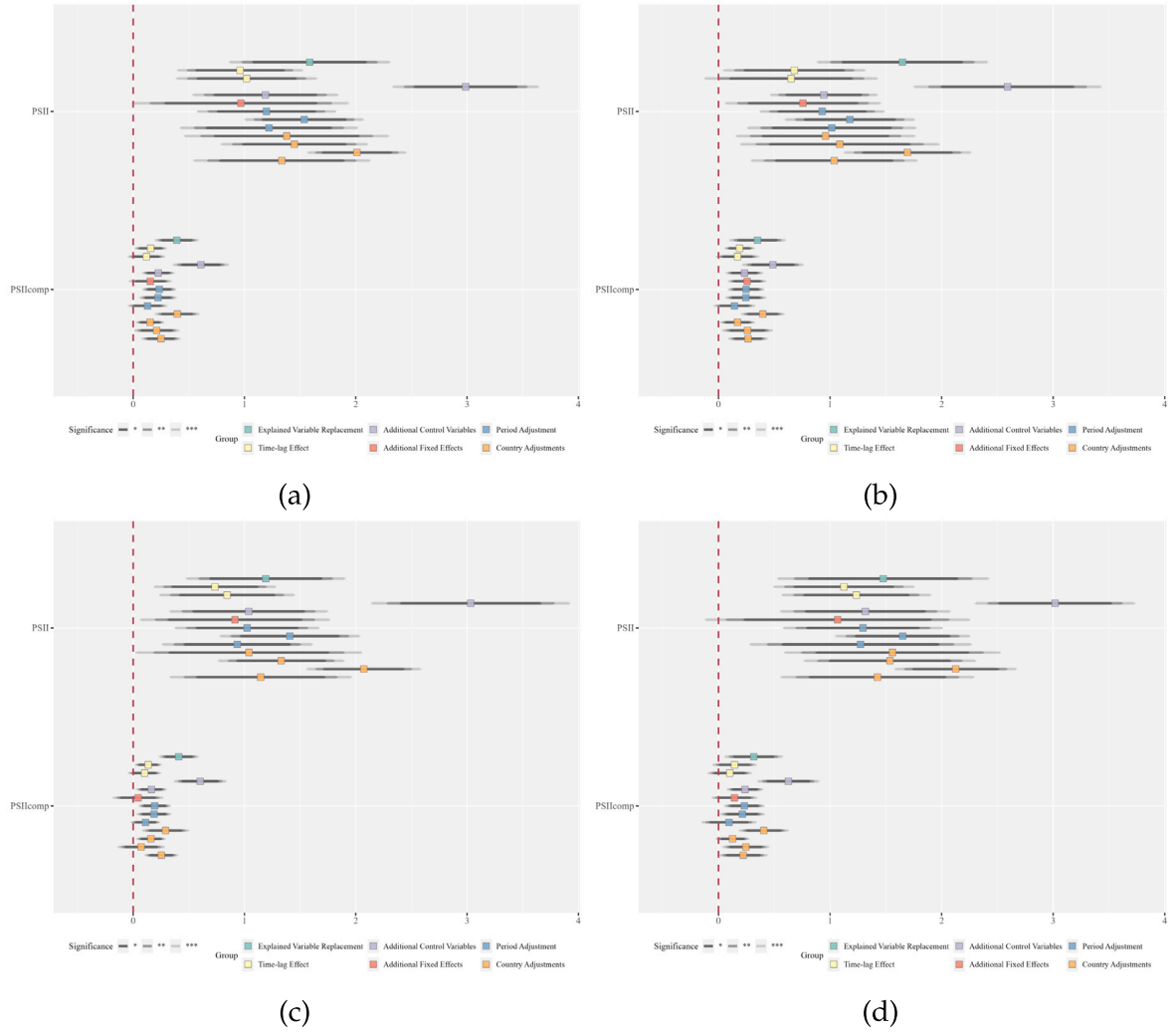

Fig. 2. Results of robustness checks.
Note: Sub-figures (a) to (d) show the robustness checks results of orGVC, orGVC_pb, orGVC_pf, and orGVC_ts as the explained variables, respectively.

to other countries,[12] which is abbreviated as "language", and (b) the country's internal distance, abbreviated as "intdis". These two constructed variables serve as instrument variables for PSII and PSIIcomp in TSLS estimations.

Second, in the second set, this article follows the method outlined by Goldsmith-Pinkham et al. (2020) to construct a Bartik IV equivalent to the shift-share IV. This instrument variable is formed by the interaction of a country's PSII share at the global level and the aggregate growth of PSII at the global level, as shown below:

$$B_{it} = \frac{z_{i0}}{\sum_i z_{i0}} \times \left(\frac{\sum_i z_{i,t}}{\sum_i z_{i,t-1}} - 1 \right) \tag{8}$$

where $z_{i,z}$ denotes the total PSII of country i in period t, and $\frac{z_{i0}}{\sum_i z_{i0}}$ represents its initial share at the global level. $\frac{\sum_i z_{i,t}}{\sum_i z_{i,t-1}} - -1$ measures global PSII growth. This instrument variable is plausibly exogenous because both the country's share and global growth shocks depend on worldwide conditions rather than the country's own economic fluctuations.[13] Furthermore, both a larger initial PSII share and stronger global growth indicate a higher exposure to productive service inputs in the economy.

Third, this article employs the lagged 3 term of PSII and PSIIcomp as additional instrument variables, serving as a robustness check alongside the two aforementioned sets. The TSLS regression results of all three sets are presented in Table 3.

Across all specifications, the coefficients of both fitted PSII and PSIIcomp remain positive and statistically significant at conventional levels. This robustness suggests that our baseline results hold even after accounting for potential endogeneity. Additionally, 1st stage regressions, weak IV diagnostics, and overidentification tests all support the validity of each set of instrument variables.[14] The exogeneity tests applied to the first two sets confirm that baseline regressions suffer from substantive endogeneity — explaining observed differences between OLS and TSLS estimates. Conversely, the lagged term form of

[12] Measured by reversed Max–Min standardized CL index

[13] Borusyak et al. (2022) note that as long as the shock component is exogenous, even if the share is somewhat endogenous, the Bartik IV estimator remains consistent.

[14] See Supplementary Information for detailed test results.

Table 3
Results of TSLS regressions (2nd stage).

Variable	GVC participation					
	Set I		Set II		Set III	
	(1)	(2)	(3)	(4)	(5)	(6)
PSII (fitted)	2.766**		2.843***		1.420***	
	(1.143)		(0.643)		(0.367)	
PSIIcomp (fitted)		1.203***		2.416***		0.182**
		(0.372)		(0.796)		(0.064)
Observation	822	822	841	832	841	841
Adj. R^2	0.807	0.234	0.330	−0.319	0.376	0.357
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

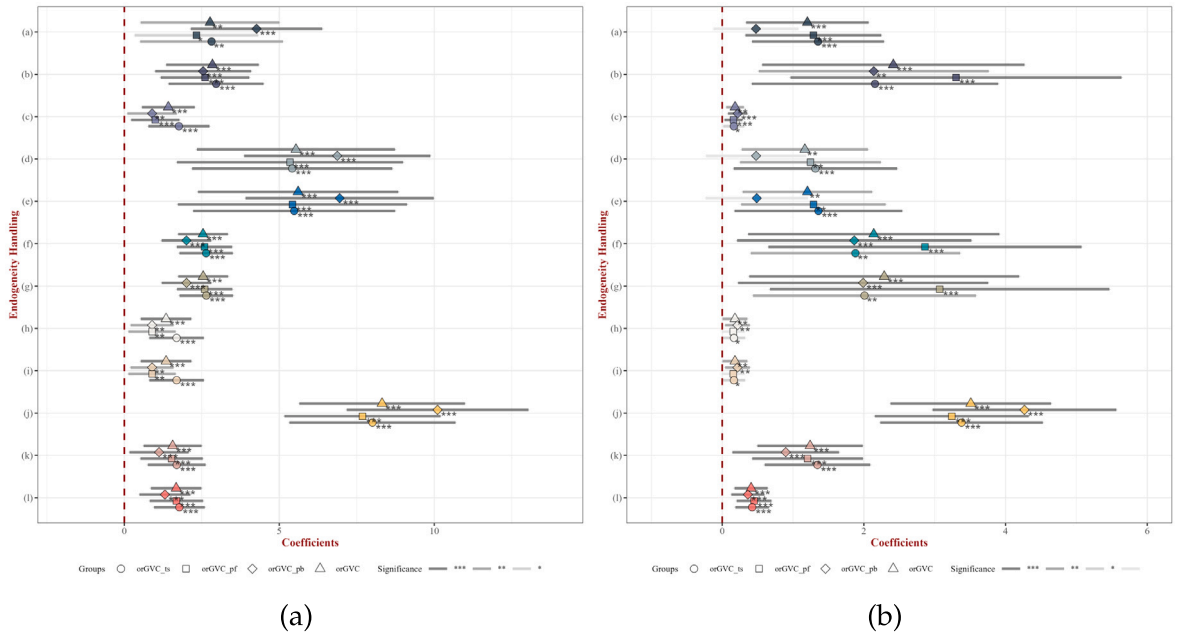

Fig. 3. Results of robustness checks. *Note:* Sub-figures (a) and (b) show the results of PSII and PSIIcomp as the core explanatory variables, respectively.

IV specification does not reject exogeneity, producing results closely aligned with the baseline.

To further bolster estimation reliability, this article also conducts Limited Information Maximum Likelihood (LIML) estimation, Fuller-K estimation, and two-step system GMM with forward orthogonal deviations (FOD) based on the aforementioned three sets of instrument variables. Results are presented in Fig. 3, which confirms that both PSII and PSIIcomp coefficients remain robust, reinforcing our conclusion that enhanced PSII is critical for strengthening a country's position in the GVC.

6. Extended analysis

6.1. Heterogeneity of PSII type

One of the requirements for achieving industrial upgrading and moving towards high-value-added industries is to improve the development level of the domestic tertiary industry. It aligns with enhancing domestic productive service inputs, which means that domestic PSII enhancement should exhibit a positive effect on promoting participation in the GVC. The relationship between domestic PSII and productive service imports may be substitutive. For countries with relatively low levels of development in the service sector, pullulation of productive service industries that require high initial investment may face the "hold-up" or investment inadequacy issues (Antras and Helpman, 2004). Additionally, the "low-locked" path reliance limits the effectiveness of productive service inputs (Cheng, 2008). These countries may rely more on importing productive services. Conversely, higher levels of domestic PSII imply easier achievement of functional and intersectoral upgrading, thereby helping to enhance GVC participation (Gereffi et al., 2005). Therefore, in this section, in addition to examining the impact of domestic PSII (PSII_dom), this article also aims to investigate the impact of foreign PSII imports (PSII_imp) on GVC participation, both from perspectives of "quantity" and "quality".

The results are presented in Table 4 indicates the promoting effect of domestic PSII on GVC participation, because all coefficients of domestic PSII, no matter whether in terms of "quantity" or "quality", are significantly positive at the 1% level. While coefficients of PSII_imp are almost significantly negative at the 1% level at least, and those of PSIIcomp_imp are all insignificant even at the 10% level. This implies that there is not enough evidence to believe that PSII imports have a positive impact on GVC participation; moreover, to some extent, PSII imports may indeed signify a lack of domestic capacity to develop productive service industries, thereby hindering the improvement of GVC participation.

6.2. Servitization of manufacturing

As described above, this article aims to identify actionable policy tools beyond servitization to enhance a country's participation in the

Table 4
Results of heterogeneity analyses.

Variable	GVC participation			
	Domestic PSII		Imported PSII	
	(1)	(2)	(3)	(4)
PSII_dom	1.696***			
	(0.231)			
PSIIcomp_dom		0.311***		
		(0.058)		
PSII_imp			−1.084**	
			(0.383)	
PSIIcomp_imp				−0.029
				(0.095)
Observation	841	841	841	841
Adj. R^2	0.392	0.367	0.356	0.351
Year FE	✓	✓	✓	✓
Country FE	✓	✓	✓	✓

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

GVC. As one of the critical processes for enhancing GVC participation, considerable research has examined the positive effects of servitization (Xiang et al., 2019; Lei et al., 2021). This article also aims to examine whether productive service inputs can enhance GVC participation by enhancing the servitization of manufacturing through the test of the mediating effect.

However, mediating effects often face numerous endogeneity issues, especially in testing by setting the mediating variable as the explanatory variable and introducing it into the baseline regression. Even so, a considerable amount of literature has already fully considered the endogeneity between the servitization of manufacturing and GVC participation. Therefore, this article will not conduct extensive econometric regressions but will directly regress servitization on PSII and PSIIcomp to examine whether the level of productive service inputs promotes servitization. Furthermore, to further avoid reverse causality issues, this article directly conducts TSLS based on two sets of instrumental variables at this point.

For measurements on servitization of manufacturing, calculating the "complete consumption" based on the OECD-ICIO table is an often-used method (Lay, 2014; Lv et al., 2017). Specifically, servitization can be measured by the degree of interdependence between service g_s and manufacturing sectors g_m:

$$servitization_{n,g_n} = \sum_{i}^{g_s} s_{i,g_n} + \sum_{i}^{g_s}\sum_{j}^{g_s} s_{i,j}s_{j,g_n} + \cdots + \sum_{i}^{g_s}\sum_{j}^{g_s}\cdots\sum_{z}^{g_s} s_{i,j}\ldots s_{z,g_n} \quad (9)$$

Where s_{i,g_n} denotes the ratio of intermediate inputs, delivered from service sector i to manufacturing sector g_n, to total inputs of g_n. In this case, ***servitization*** represents the "complete consumption" of manufacturing sectors by productive service sectors. Compared to "direct consumption", it can more comprehensively reflect the interdependence among sectors.

To compute the "complete consumption" of the manufacturing sector on the service sector, the common practice is to take a weighted average of various industries or consider both the manufacturing and service sectors as single entities. However, the issue arises when treating the manufacturing sector as a whole, as it may overestimate the level of servitization based on "complete consumption". This is because the final demand portion, as "external dissipation", is internalized, significantly affecting the computation of complete consumption calculated through the adjacency matrix.

One solution is to calculate the consumption of the manufacturing sector on the service sector based on the "hitting probability":

$$servitization_{\phi,ij} = \frac{\left(\sum_{m=0}^{\infty}(\boldsymbol{M}^m)\right)_{ij}}{\left(\sum_{m=0}^{\infty}(\boldsymbol{M}^m)\right)_{ii}\left(\sum_{m=0}^{\infty}(\boldsymbol{M}^m)\right)_{jj}} \quad (10)$$

where $\boldsymbol{M}$ is the Markov Transition Matrix transferred from the OECD ICIO table.

Calculating the "hitting probability" is intuitive because "first hitting" can be seen as the moment when the manufacturing sector consumes intermediate inputs provided by the service sector. Once these intermediate inputs are consumed, their mission — servitized in manufacturing — is accomplished. Although the subsequent flow from the manufacturing sector to other industries is computed as "complete consumption", considering it as part of servitization is inappropriate. Therefore, this article calculates the level of servitization based on the "hitting probability" and uses it as the dependent variable for TSLS. The details of variable construction are provided in Supplementary Information. The regression results are presented in Table 5; it is worth mentioning that only the results of orGVC are presented due to the limitation of the table width. The results show that PSII can significantly enhance the servitization of manufacturing, no matter whether in terms of "quantity" or "quality", which also implies that increasing productive service intermediate inputs can enhance participation in the GVC by the approach of improving the servitization of manufacturing.

6.3. Financial constraints

Participating in the international trade and labor division in the GVC indeed requires substantial capital, and the ease of accessing funds greatly influences the development of manufacturing (Becker et al., 2013). However, financial constraints pose a barrier in the credit accommodation and allocation process, restraining financing capabilities and inhibiting export expansion and improvements in the GVC status (Reddy and Sasidharan, 2021). The productive service inputs, especially financial services, can reduce information asymmetry, lowering enterprise financing costs (Linbing et al., 2023), and contribute to enhancing capital-intensive products and intermediate inputs, thus altering industry factor structures (Bas and Berthou, 2012).

Therefore, it is reasonable to believe that the role of PSII in enhancing GVC participation may be related to financial constraints; further, enhancing productive service inputs may help alleviate financial constraints. However, due to endogeneity issues, this article aims to test such a mechanism by grouped regressions instead of testing its mediating channel. If the hypothesis above holds, then the reduction of financial constraints by productive service inputs should be significant; in addition, in situations of high financial constraints, the improvement in GVC participation due to productive service inputs should not be significant.

Thus, according to the definition provided by the IMF, this article considers adopting the aggregate risk-based capital ratios, namely, the ratio of regulatory capital to risk-weighted assets, which is the most common indicator of capital adequacy, to measure the financial constraints. Then, this article conducts grouped regressions using two partitioned sub-samples of low and high constraints based on their mean value.

Table 5
Results of mediating effect tests.

Variable	Servitization					
	IV Set I		IV Set II		IV Set III	
	(1)	(2)	(3)	(4)	(5)	(6)
PSII (fitted)	3.388**		2.076**		2.539*	
	(1.256)		(0.973)		(1.193)	
PSIIcomp (fitted)		1.879***		0.848***		0.570***
		(0.515)		(0.130)		(0.148)
Observation	410	410	412	419	419	419
Adj. R^2	0.878	0.761	0.651	−0.329	0.920	0.950
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

Table 6
Results of grouping regressions based on financial constraints.

Variable	Constraint		GVC participation			
			Low constraint		High constraint	
	(1)	(2)	(3)	(4)	(5)	(6)
PSII	0.258***		−0.765		0.599*	
	(0.061)		(0.506)		(0.318)	
PSIIcomp		0.083***		−0.388***		0.345***
		(0.024)		(0.096)		(0.096)
Observation	577	577	191	191	386	386
Adj. R^2	0.478	0.479	0.584	0.611	0.331	0.339
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

Results shown in Table 6 indicate that productive service indeed alleviates the financial constraints for the significant negative coefficients at a high enough level. From the view of grouped regressions, the coefficients of PSII and PSII_comp are both significantly positive within the low constraints sub-sample while being both insignificant even at the 10% level in the high constraints sub-sample, which is exactly consistent with our expectation.

6.4. Efficiency improvement

Productive service is a key enabler that can reduce management and production costs, stimulate service-oriented innovation, and improve production and operational efficiency, thereby facilitating the integration of firms into the GVC (Goldar, 2019; Ma et al., 2022). On the other hand, productive service inputs facilitate human capital accumulation, enhancing the capacity for technology absorption and knowledge diffusion, thereby indirectly improving production and operational efficiency (Yameogo and Jammeh, 2019; Wu et al., 2021).

Therefore, following the approach in the preceding text, this article aims to examine the mechanism of the impact of production and operational efficiency through grouped regressions. The article measures production and operational efficiency using welfare-relevant Total Factor Productivity (TFP) levels at current PPPs. Then, this article partitions the original sample into low and high efficiency sub-samples and conducts grouped regressions.

Table 7 demonstrates that productive service significantly improves production and operational efficiency. Meanwhile, insignificant and significantly negative coefficients of PSII and PSIIcomp within the low-efficiency sample, and significant positive coefficients within the high one, imply that our expectation of production and operational efficiency affecting the promoting effect of PSII on GVC participation is reasonable.

6.5. Moderating effect of innovation

As mentioned earlier, technological innovation capability may significantly moderate the impact of productive service inputs on promoting participation in the GVC. Innovation capability may act as a "lever", positively reinforcing the relationship between the latter two; however, the improvement in innovation capability may lead to "crowding out" of other intermediate inputs, thereby weakening the promotion effect of productive service inputs on GVC participation. Therefore, this article constructs moderation effect models to examine whether and how the promotion effect of productive service inputs on GVC participation is significantly moderated by innovation capability.

This article will continue to measure innovation capability by introducing "complexity". Knowledge complexity is often considered a prominent indicator of technological innovation capability, representing the amount of complex knowledge encompassed within a country's patents across various fields. Following the approach of Balland and Rigby (2017) and Zhang and Zhang (2024), this article calculates the knowledge complexity (GPYC) based on the country-patent bipartite network, using patent data provided by OECD. Besides that, economic complexity also implies a country's innovation capability. A higher economic complexity indicates higher economic value and technological content of commodities, suggesting sufficient technological innovation capabilities. Therefore, following Tacchella et al. (2012) and Sciarra et al. (2020), this article indirectly measures the innovation capability by calculating the economic complexity (GENEPY) based on the country-commodities bipartite network, using trading data provided by TiVA. The details of variable construction are provided in Supplementary Information, and the moderating effect models constructed in this article are as follows:

$$orGVC_{it} = \alpha + \beta PSII_{it} + \gamma GPYC_{it} + \delta PSII_{it} \times GPYC_{it} + \sum_{k=1}^{K} \theta_k X_{k,it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{11}$$

$$orGVC_{it} = \alpha + \beta PSII_{it} + \gamma GENEPY_{it} + \delta PSII_{it} \times GENEPY_{it} + \sum_{k=1}^{K} \theta_k X_{k,it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{12}$$

Table 7
Results of grouping regressions based on efficiency.

Variable	Productivity		GVC participation			
			Low productivity		High productivity	
	(1)	(2)	(3)	(4)	(5)	(6)
PSII	0.258***		−0.765		0.599*	
	(0.061)		(0.506)		(0.318)	
PSIIcomp		0.083***		−0.388***		0.345***
		(0.024)		(0.096)		(0.096)
Observation	577	577	191	191	386	386
Adj. R^2	0.478	0.479	0.584	0.611	0.331	0.339
Year FE	✓	✓	✓	✓	✓	✓
Country FE	✓	✓	✓	✓	✓	✓

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

Table 8
Results of tests on the moderating effect.

Variable	GVC participation			
	GPYC		GENEPY	
	(1)	(2)	(3)	(4)
PSII	2.454***		2.435***	
	(0.733)		(0.463)	
PSIIcomp		0.499***		0.394***
		(0.128)		(0.120)
GPYC	1.229***	0.829***		
	(0.283)	(0.158)		
PSII×GPYC	−2.177**			
	(0.909)			
PSIIcomp×GPYC		−0.547***		
		(0.177)		
GENEPY			2.584***	1.792***
			(0.238)	(0.140)
PSII×GENEPY			−3.105***	
			(0.595)	
PSIIcomp×GENEPY				−0.507**
				(0.238)
Observation	825	825	841	841
Adj. R^2	0.449	0.415	0.503	0.464
Year FE	✓	✓	✓	✓
Country FE	✓	✓	✓	✓

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

Table 8 shows the results of moderating effect models, which indicate that regardless of whether innovation capability is measured by knowledge complexity or economic complexity, the multiplicative terms of innovation capability and PSII, as well as PSIIcomp, are significantly negative at the 1% level. It suggests that higher innovation capability weakens the promotion effect of a country's productive service inputs on GVC participation, which may mean that innovation capability "crowds out" productive service inputs. However, the coefficients of GPYC and GENEPY being significantly positive imply another fact: the promotion effect of innovation capability on GVC participation may be "substitutive" for productive service inputs. Therefore, for developing countries, enhancing technological innovation capability with higher sunk costs and more incredible development difficulty may face the dilemma of excessive resource occupation. In contrast, it may be more feasible to prioritize the development of productive service sectors to enhance their position in the GVC through the international division of labor.

7. Concluding remark

7.1. Research conclusion

Globalization has forged a "world without borders" (Robertson and White, 2007). Whoever secures a greater advantage in international specialization, i.e., a higher rung within the GVC, stands to gain most from globalization. Amid escalating geopolitical conflicts and trade protectionism, advanced economies have reasserted their "reindustrialization" strategies to preserve their positions in the GVC. In this context, the rapid growth of productive service intermediate input has significantly propelled the servitization of manufacturing, emerging as a cornerstone of industrial transformation (Xiang et al., 2019).

Therefore, this article investigates whether optimizing productive service intermediate input will enhance countries' capabilities in participating in the GVC, and which factors play pivotal roles in such a relationship. Based on panel data covering 77 countries from 1995 to 2020, our empirical analyses suggest that PSII indeed significantly boosts GVC participation of countries, which holds under a series of robustness tests and endogeneity handling; tests for the time-lag effect further reveal that enhancements in PSII persistently and effectively strengthen GVC participation over time. Extended analyses show that domestic, rather than imported, PSII accounts for most of the effect, supporting a regional pattern consistent with the core–periphery framework. Mediation analyses indicate that PSII accelerates manufacturing servitization, alleviates financing constraints, and improves efficiency, thereby raising GVC participation. Finally, this article also uncovers the "substitution" effect of PSII on innovation capability.

7.2. Theoretical and policy implications

This article has made multiple contributions to the literature concerning the GVC participation and productive service, and provided empirical evidence through systematic testing:

- First, this article clearly identifies PSII as a critical driver of industrial upgrading and transformation, examining its role in elevating the GVC position. By employing output-related value-added based on tripartite decomposition for measuring the GVC positioning, this article offers a relatively precise reference for assessing the causal effect of PSII.
- Second, based on the bipartite network framework, we differentiate between the "quantity" and "quality" dimensions of productive services, and separately examine the heterogeneous impacts of each on GVC positioning.
- Third, this article incorporates the core–periphery model into the theoretical framework, and the heterogeneous effects of PSII on GVC participation, with regarding to both "quantity" and "quality" aspects, can be seen to be served as some representation — whether a country tends to move toward the "core' of the GVC network or remains in the "semi-periphery" or "periphery". In this sense, our findings offer a practical approach to using the core–periphery framework not merely as a conceptual tool but as a criterion to classify and evaluate countries' positions within the GVC.
- Final, we also propose two primary pathways through which productive PSII affects GVC participation, and explore potential interactions between PSII and complex knowledge; our systematic empirical tests support these hypotheses.

The findings of this article also carry policy relevance and practical implications:

- First, the positive effects of both the quantity and quality of PSII suggest that securing a more advantageous position in the GVC requires accelerating the development of productive service sectors and equipping manufacturing with the requisite service inputs to achieve deep domestic integration between manufacturing and service industries. In fact, compared with the systems-level concept of manufacturing servitization, PSII, as a primary input factor, will be more conducive to policy implementation, since increasing the share of intermediate inputs is more feasible than elevating the entire "servitization" at the system level.
- Second, while refining the tertiary-industries structure, it is also necessary to cultivate an enabling institutional environment, reinforce market regulation, and establish information dissemination and feedback mechanisms, which will help decrease information asymmetries, alleviate financing constraints, foster human-capital accumulation, and thereby amplify the competitive advantages arising from integration between manufacturing and services.
- Moreover, the geographic pattern of GVC participation suggests that countries with abundant and high-quality PSII are more likely to upgrade their industrial structure and thus consolidate a core position, whereas countries with limited or low-quality PSII tend to be confined to peripheral segments. This observation invites us to reflect more profoundly on the reorganization and reform of GVC structures. On the one hand, the heterogeneous effects of PSII on GVC participation allow us to adjust and reassess our understanding of specific countries' positions within the global production system. On the other hand, the geographic pattern of PSII's influence on GVC participation can also serve as an important tool for classifying national development strategies. Building on the recognition and evaluation of these patterns, countries can identify more suitable strategies to enhance their GVC positioning.
- finally, for countries positioned at the low end of the GVC and lacking indigenous innovation and R&D capacity, prioritizing the development of productive service sectors through specialized division of labor may be more feasible than massive investment in high-technology R&D, which offers a more realistic pathway to enhance their GVC participation.

7.3. Direction for future research

This article also leaves room for further refinement, with unresolved questions awaiting future research. First, although this article partly explains the geographic patterns in PSII with GVC participation using the core–periphery model, the empirical tests only provide indirect support rather than directly examining the heterogeneity between peripheral versus core and semi-peripheral countries. Second, our examination of the pathways through which PSII enhances GVC participation and its interaction with other factors is relatively narrow; future research could explore and validate additional channels or mechanisms to yield more valuable policy insights into maximizing the potential of PSII and increasing GVC participation. Last, this article treats PSII in isolation, but in practice, PSII often involves cross-national cooperation, especially in the globalization era, which emphasizes cross-border resource allocation and transnational production division. Thus, further investigation into the positive role of PSII cooperation would also be beneficial.

CRediT authorship contribution statement

Sin-Som (Sergio) Tsiong: Writing – review & editing, Writing – original draft, Software, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Hongsong Liu:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Conceptualization.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.strueco.2025.10.002.

Data availability

Data will be made available on request.

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