Exploring knowledge spillovers and GVC participation to understand double counting in GVCs: A case study of Japan*

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Abstract

As global value chain (GVC) participation and knowledge spillovers have arguably become more crucial for countries, it is still challenging to measure their real value for countries. The complexity comes from the trade in intermediate goods as part of GVCs and the inability to track their coupling with additional components and services. The result is double counting and lack of clarity about the real value of GVCs for countries. This paper assesses how GVC participation and knowledge spillovers influence double counting and transitively the innovation and value added growth in GVCs for the case of Japan. The empirical evidence suggests that expanding production fragmentation within GVCs and diversifying foreign suppliers in production stages foster innovation and maximize knowledge diffusion, leading to enhanced value added output. Thus, knowledge spillovers and feedback effects within and between countries at bilateral and multilateral integration levels affect the GVCs. The paper sheds light on the intricate nature of intermediate goods flows in GVCs and the link between double counting and knowledge spillovers in GVCs.

Keywords: double counting, global value chains, knowledge spillover, value added

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1. Introduction

As multinational companies expand globally, global value chain (GVC) participation becomes more crucial but challenging to measure. The complex nature of trade in intermediate goods and the inability to track their coupling with additional components and services hinder accurate measurement. Disaggregating integrations at the level of the enterprise or the production stage proves difficult because of the multidirectional trade flows of intermediate goods. The high volume of sector-country transactions raises questions about accurately tracing production value and origins because of the unavailability of data sources to show where the goods are coupled with additional components and services. Consequently, at the heart of GVC measurement challenges lies the issue of double counting, i.e. intermediate goods being repeatedly traded among countries during the production process, distorting traditional trade statistics. This double counting is leading to an overestimation of economic activity and a skewed perception of each country's actual contributions to GVCs (de Gortari, 2019; Johnson, 2018; Kee and Tang, 2016).

Intermediate product flows in GVCs present both double-counting challenges and opportunities for knowledge transfer among countries collaborating on and specializing in specific production stages for traded goods. Participation in GVCs, particularly through importing commodities, serves as a valuable avenue for knowledge exchange, facilitating the transfer of production techniques and fostering both imitation and innovation outcomes. Despite the possibility of some double counting in the production process, the concept of the knowledge spillover effect, driven by production stages achieved through vertical integration, underscores international production fragmentation as a means of knowledge transfer (Keller, 2010). For example, scholars have found compelling evidence of the integration between patent flows and value added production within GVCs (Zolas and Lybbert, 2022), resulting in significant international knowledge spillovers (Constantinescu et al., 2019; Piermartini and Rubínová, 2021).

The complexity of measurements in GVCs requires a novel approach to understanding GVC dynamics and value creation in international trade. This approach needs to take into account the intermediate product flow between countries and incorporate a perspective on vertical integration. Neglecting the double-counting issue in GVCs when estimating the optimal impact of production stages leads to biased estimates. Empirical estimates need to both address double-counting issues regarding direct contributions and emphasize the significance of knowledge spillovers in GVC participation. Thus, the main research question guiding this study is, how does the concept of knowledge spillovers address double-counting, influence GVCs and, in turn, affect the potential for innovation and value added growth in GVCs in the case of Japan?

To estimate the optimal value added (VA) and its spillover effect among sectors and sector-country pairs within GVCs, the study uses the Global Trade Analysis Project version 10 Multi-Region Input-Output (GTAP-MRIO) and the patent panel data sets derived from the United States Patent and Trademark Office. Incorporating additional information from a structured patent panel data set can enhance the analysis of technology diffusion, considering the vertical integration of subsequent production stages. This approach,[1] leveraging the GTAP-MRIO and patent panel data sets, provides more precise information than traditional input-output data, contributing to a better understanding of GVC involvement and its impact on knowledge transfer among sector-country pairs within GVC. Empirical evidence indicates that sector-country pair integration, measured by the trade among nations as spillovers, significantly contributes to VA while occasionally introducing double-counting issues, estimated at approximately 1.5 per cent.[2] Also, expanding production fragmentation within GVCs leads to increased innovation; thus, considering the knowledge spillover effect, tradable commodities being reexported or reimported in production stages, such as crossing borders at the initial stage or reaching their full potential within GVC, contribute from 2.5 per cent to as much as 154 per cent.

Accurate estimation of VA in GVCs requires developing robust accounting frameworks and methodologies to address double counting, as cross-border product flows with knowledge spillover effects significantly boost value added output. Also, empirical evidence emphasizes the role of countries with a global market concentration and diverse intermediate goods in the production process in driving knowledge accumulation. In essence, developing robust techniques, promoting GVC participation, strengthening trade relationships and facilitating knowledge exchange emerge as critical policy considerations for unlocking the potential of GVCs in driving value added growth. These policy measures empower economies to harness innovation, bolster productivity and enhance resilience, ultimately leading to sustainable value added output.

The paper contributes to the literature and practice in various ways. The research aligns with existing literature, highlighting the positive effects of technology spillover among nations during the production stages within GVCs (Alfaro et al., 2019). Firms engaged in GVCs often experience greater productivity, a phenomenon commonly

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[1] This paper draws inspiration from works such as Alfaro et al. (2019), de Gortari (2019) and Zolas and Lybbert (2022). For instance, Zolas and Lybbert (2022, p. 471) emphasize "…increasing the flow of intermediate and final goods and catalyzing knowledge spillovers across sectors and regions".

[2] The fragmentation of GVCs has concentrated activity in specific regions. "Factory East Asia", including Japan, contributes 38 per cent of global industrial output, followed by Factory North America (19 per cent) and Factory Europe (20 per cent) (Li et al., 2019). Notably, these findings are particularly relevant in the context of this paper, providing a nuanced understanding of the dynamics specific to the Japanese scenario within the broader GVC framework.

referred to as “GVC-driven innovation” (Pietrobelli and Rabellotti, 2011), resulting in productivity gains estimated at approximately 1.6 per cent (Constantinescu et al., 2019). To illustrate, the decoupling of GVCs through the removal of intermediate input trade can lead to output and welfare reductions ranging from 1 per cent to 70 per cent (Caliendo and Parro, 2015; Eppinger et al., 2021). These findings underscore the pivotal role of intermediate goods trade within the GVC framework. Moreover, by addressing this issue, policymakers can make well-informed decisions that promote resilience and drive sustainable value added output. This study delves into the complexities of measuring double counting in GVCs, presents examples of two-country and n-country models, and overcomes challenges through empirical analysis. Also, it explores vertical integration, uncovering spillover and feedback effects within and between countries at the levels of bilateral and multilateral integration. In doing so, the study sheds light on the intricate nature of intermediate goods flows in GVCs, revealing the link between double counting and knowledge spillovers in GVCs.

The rest of this paper is organized as follows: section 2 provides a review of the relevant literature; section 3 presents the empirical modeling and analysis for two approaches – double counting and knowledge spillovers in GVC; and the concluding section summarizes the key findings of this study, along with policy implications.

2. Literature review

GVC participation extends beyond traditional trade by encompassing the exchange of intermediate inputs and services across various production stages such as roundabout models (Caliendo and Parro, 2015), spider models (Antràs et al., 2017; Baldwin and Venables, 2013), snake models (Antràs and de Gortari, 2020), and hybrid “sniker” models (Antràs et al., 2023). A growing body of recent literature explores the trade channels of (i) knowledge transfer dynamics linked to imports and exports (Atkin et al., 2017; Buera and Oberfield, 2020) and (ii) value added double-counting in GVCs (Borin and Mancini, 2019; Hummels et al., 2001; Johnson and Noguera, 2012 and 2017).

Participation in GVCs necessitates collaboration and coordination among countries, each specializing in specific production stages for globally traded goods and services. This collaboration facilitates knowledge transfer and the exchange of know-how among GVC participants, encompassing mechanisms such as import-driven spillovers (Halpern et al., 2015; Nabeshima et al., 2018) and vertical specialization in productivity (Blalock and Veloso, 2007; Constantinescu et al., 2019). Notably, tradeable (intermediate) commodities, integrated into sector-country pairs, significantly drive value added output (Halpern et al., 2015; Keller, 2010), highlighting the positive impact of knowledge embedded in tradeable goods on sectoral productivity (Tajoli and Felice, 2018; Zolas and Lybbert, 2022). Their findings also indicate a link between increasing knowledge flows and higher levels of value added output, underscoring the importance of knowledge flows in driving sectoral innovation and economic performance within GVCs.

Specifically, GVCs play a crucial role as channels for knowledge spillovers that drive innovation through strong interactions between foreign firms and domestic suppliers (Piermartini and Rubínová, 2021; World Bank, 2020) and efficient production of outsourced inputs, eventually consumed by foreign outsourcing firms (Baldwin and Lopez-Gonzalez, 2015). This is supported by research indicating that engaging in specific production stages within GVCs stimulates innovation (Alfaro et al., 2019; de Gortari, 2019; Tajoli and Felice, 2018) and that utilizing foreign intermediate inputs enhances plant productivity (Halpern et al., 2015). In this context, this paper integrates the concept of knowledge spillover effects within GVC participation to estimate the production stage and its impact on VA.

Nevertheless, the intricate dynamics of intermediate product flows in GVCs pose both opportunities for knowledge transfer among collaborating countries and double-counting challenges; thus, estimating the optimal impact of GVCs by production stages would result in biased estimates if the double-counting issue in GVCs is ignored. The literature on VA has explored various dimensions, including the location of VA creation (Koopman et al., 2014; Wang et al., 2013), the upstream effect of VA (Alfaro et al., 2019; Antràs et al., 2012; Fally, 2012), measuring of double-counting rates (World Bank, 2020), VA exchange rates (Bems and Johnson, 2017), factor content (Trefler and Zhu, 2010), international inflation spillover (Auer et al., 2019), and bias estimate of both domestic value added (DVA) and foreign value added (FVA) (Bems and Kikkawa, 2021; Johnson, 2018; Kee and Tang, 2016).

Koopman et al. (2014) and Wang et al. (2013) extended the gross export decomposition methodology introduced in Koopman et al. (2010) by introducing distinct definitions for “domestic value added in exports” and “domestic content in exports”. These differentiated measures provided a deeper understanding of the trade in value added concept. In addition, Johnson (2018) and Los et al. (2016) proposed analytical frameworks such as the GDP decomposition framework and the production of final goods decomposition framework. These frameworks enable the separation and analysis of fragmented production chains. Specifically, they shed light on the re-exportation of intermediate goods and their subsequent absorption in home countries, importers and third countries. These methodologies offer insights into the destinations of products and identify the countries and sectors participating in GVCs.

One limitation of these studies is that the double-counting estimates rely on two-way or three-way gross exports among n-way (Koopman et al., 2014; Los et al., 2016; Wang et al., 2013). GVC participation, when considering multi-country export content, treats third parties as a single country and segments product portions on the basis of DVA and FVA. The literature lacks an approach that accounts for n-way (multinational) intermediate inputs trade within a multi-country setting. In addition, Blaum (2019) demonstrates that export-oriented firms tend to be more reliant on imports (Amiti et al., 2014). This implies that trade in DVA is overestimated in terms of GVC involvement because of the lack of consideration for heterogeneity in export-import intensity between firms within clustered sectors (Bems and Kikkawa, 2021).

In contrast, this paper highlights the complexities arising from the inclusion of aggregated third economies in trade beyond two- or three-way interactions. The integration of cross-border trade at a multilateral level is a complex process, and estimations of GVCs heavily rely on assumptions regarding the observation of foreign goods in destination or exporter countries, as noted by Borin and Mancini (2019) and Koopman et al. (2014). Consequently, the complex nature of these integrations in VA estimation manifests as seemingly simple mathematical equations that are inherently unpredictable, giving rise to what is referred to as the "paradox of intertwined trade".

In summary, this study contributes to the deeper understanding of GVC dynamics by exploring the positive spillover effects of vertical integration within GVCs. Nonetheless, overlooking double counting in GVCs during the estimation of the optimal impact of production stages may introduce bias. Thus, this paper not only underscores the importance of accounting for double-counting effects in evaluating the impact of intermediate goods within GVCs but also delves into the intricate dynamics of knowledge flows within GVC networks (de Gortari, 2019; Pietrobelli and Rabellotti, 2011; Tajoli and Felice, 2018), elucidating the link between double counting and knowledge spillovers in GVCs. While drawing from previous works by Koopman et al. (2014) and Wang et al. (2013), this paper differentiates itself by utilizing the average of aggregate value added instead of separately derived DVA and FVA. This addresses the issue of undervaluation of downward GVC participation, as discussed in the literature (Bems and Kikkawa, 2021;[3] Johnson, 2018; Kee and Tang, 2016). Notably, this research advances GVC-related measurements by introducing a novel model that incorporates the vertical integration of production stages to calculate the optimal contribution of knowledge flow to overall outcomes within GVCs.

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[3] The researchers discovered that sectoral input-output tables introduce bias in value added (DVA and FVA) estimates owing to firm-level heterogeneities, leading to an undervaluation of downward GVC participation (for firm-level evidence in China, see Kee and Tang (2016)).

3. Empirical analysis

3.1 Double counting in production stages

This subsection explores the impact of supply chain trade on cross-border production measures, building on the works of Antràs and Chor (2018), and Baldwin and Lopez-Gonzalez (2015). The issue arises with the potential double counting of VA, as tradeable commodities cross borders multiple times, resulting in measurement bias (Los et al., 2016; Johnson, 2018). The extent of this double counting and its effect on VA depends on a country's role as a hub for goods in process within GVCs. To address this, the study incorporates value added embodied in intermediate goods export, introducing complexity to VA integration and potentially leading to double counting from the perspective of final demand.

The analysis then delves into the phenomenon of re-exportation and reimportation of intermediate products within production activities, shedding light on the intricate challenge of bias estimation in GVCs. This investigation is motivated by the inherent complexities arising from the unavailability of a methodological framework and a reliable data source for tracking double counting. Specifically, the analysis focuses on the potential bias introduced in GVC estimation by the inability to systematically monitor the re-exportation and reimportation of intermediate goods in the assembly process.

3.2 DVA and FVA in a multi-country setting

To simplify the understanding of DVA and FVA, we use a three-country set-up model, designating the countries as r, s and the rest of the world l.[4] In this model, the Japanese market is considered as r, as the country of primary interest at the country level, taking into account its interactions with s and l. DVA in country r[5] can be written as follows:

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[4] The algebras and calculated matrix are available upon request.

[5] In the context of the model, the subscripts r and s are used to index countries, where $1 \leq r, s \leq S$. Similarly, the subscripts i and j are used to index industries, where $1 \leq i, j \leq J$. When a pair of superscripts is used, the left superscript refers to the source or selling country-industry, while the right superscript refers to the destination or buying country-industry. By decomposing the Leontief inverse matrix ($B = B^{rr} + B^{rs}$) into two components, namely (i) the domestic effect (D^{rr}) and intra-country feedback effect ($F^{rr} = B^{rr} - D^{rr}$), and (ii) the multilateral spillover effect (B^{rs}) and bilateral spillover effect (L^{rs}), we gain insights into the intricate interactions within GVCs. The feedback spillover effect from multilateral integration is represented by $F^{rs} = B^{rs} - L^{rs}$. The downstream effect shows how products in country r are stimulated by multilevel integration from country s ($D^{rr}A^{rs}B^{sr} = \lambda^{rs}$), while the upstream effect reveals how products in country s are stimulated by multinational integration from country r ($F^{rr}A^{rs}B^{sr} = \delta^{rs}$). Briefly, $D^{rr} = (I - A_{ij}^{rr})^{-1}$ captures the local equilibrium conditions that each country satisfies. Also, $L^{rs} \cong D^{rr}A^{rs}D^{ss}$ represents the matrix of the bilateral spillover effect. For more details, see Biyik (2022).

$$DVA^r = v^r B^{rr} E^{rs} + v^r B^{rr} \sum_{l \neq r,s}^{S} E^{rl}$$

$$\begin{aligned} DVA^r = {} & v^r [D^{rr} + F^{rr}] \left(\hat{Y}^{rs} + \sum_{l \neq r,s}^{S} \hat{Y}^{rl} \right) \\ & + v^r \{\lambda^{rs} + L^{rs} + \delta^{rs} + F^{rs}\} \left(A^{rs} X^{ss} + A^{rs} X^{sr} + \sum_{l \neq r,s}^{S} A^{rs} X^{sl} \right) \\ & + v^r \left(\sum_{l \neq r,s}^{S} \{\lambda^{rl} + L^{rl} + \delta^{rl} + F^{rl}\} \right) \left(\sum_{l \neq r,s}^{S} \left[A^{rl} X^{ll} + A^{rl} X^{lr} + A^{rl} X^{ls} \right.\right. \\ & \left.\left. + \sum_{t \neq r,s,l}^{S} A^{rl} X^{lt^*} + \cdots + \sum_{t \neq r,s,l}^{S} \sum_{v \neq r,s,l,t}^{S} \ldots . \sum_{x \in S} A^{lx} X^{x^*} \right] \right) \end{aligned} \tag{1}$$

FVA in r can be written as follows:

$$FVA^r = v^s B^{sr} E^{rs} + \sum_{l \neq r,s}^{S} (v^l) \sum_{l \neq r,s}^{S} (B^{lr} E^{rl})$$

$$\begin{aligned} FVA^r = {} & v^s (L^{sr} + F^{sr}) (\hat{Y}^{rs} + A^{rs} X^s) \\ & + \left(\sum_{l \neq r,s}^{S} (v^l) \sum_{l \neq r,s}^{S} (L^{lr} + F^{lr}) \right) \left(\sum_{l \neq r,s}^{S} \hat{Y}^{rl} + \sum_{l \neq r,s}^{S} A^{rl} X^{l^*} + \sum_{l \neq r,s}^{S} \sum_{t \neq r,s,l}^{S} A^{rl} X^{lt} \right) \end{aligned} \tag{2}$$

Where ($\hat{Y}^{rs}$ and $\sum_{l \neq r,s}^{S} \hat{Y}^{r}$) final goods in r are exported to s and third partners (ROW) l. Note that the trade flows of intermediate goods have different processes. While ($A^{rs} X^{ss}$) and ($\sum_{l \neq r,s}^{S} A^{rs} X^{sl}$) intermediated goods in r are absorbed in s and l, intermediated products of ($A^{rs} X^{sr}$) are processed and exported back to r, as a form of products embodied in the semi-final $[A^{sr} X^{r}]$ or final products ($\hat{Y}^{sr}$). Likewise, $\sum_{l \neq r,s}^{S} A^{rl} X^{lr}$ and $\sum_{l \neq r,s}^{S} A^{rl} X^{ls}$ are processed and exported back to r and exported to s from l. This process is relatively straightforward because it involves the bilateral relationships between a single country and other countries.

The distribution of exports from third countries to partners (r and s) and within their own borders is a crucial aspect to consider in the context of complex and continuous production processes of multi-level integration. The literature suggests that direct trade between third partners is often absent, as they tend to rely on aggregated third countries instead. However, this paper's extension introduces a novel perspective by considering the DVA^l of third countries in export content, thereby promoting continuous trade integration. Specifically, describing $\sum_{l \neq r,s}^{S} A^{rl} X^{ll}$, which represents intermediate goods domestically absorbed in l, presents a challenge that this research seeks to address. The challenge arises because the imported intermediate products undergo processing to produce semi-final and final products, which are then exported to r ($\sum_{l\neq r,s}^{S} A^{rl}X^{lr}$), s ($\sum_{l\neq r,s}^{S} A^{rl}X^{ls}$), l ($\sum_{l\neq r,s}^{S} A^{rl}X^{ll}$), as well as distributed within trade partners ($\sum_{l\neq r,s}^{S}\sum_{t\neq r,s,l}^{S} A^{rl}X^{lt}$) in t. The challenge lies in comprehending $\sum_{l\neq r,s}^{S}\sum_{t\neq r,s,l}^{S} A^{rl}X^{lt^*}$, which represents the processed and exported intermediate goods absorbed in (*S*-4) countries originating from l countries (*S*-3).

This concept highlights the paradox of intertwined trade in multi-country relations. It acknowledges the complex trade integration between countries, including r, s, l, t and (*S*-4) countries, where each has trade connections with the others. This concept aligns with the findings of de Gortari (2019), Fally (2012), Alfaro et al. (2019) and Antràs et al. (2012), who emphasize the role of multiple production stages and vertical integration. Within this framework, intermediate commodities traverse sector-country pairs, eventually contributing to the production of final goods. These final goods are subsequently shipped and consumed in country x. Stated differently, this process is repeated until intermediate commodities complete their route to becoming final goods that are delivered and sold to final consumers in country x as $\sum_{l\neq r,s}^{S}\sum_{t\neq r,s,l}^{S}\sum_{k\neq r,s,l,k}^{S}\cdots.\sum_{x\in S} A^{lx}X^{x^*}$ (box 1).

Whereas previous research (e.g. Borin and Mancini (2019) and Koopman et al. (2014)) explains methods to identify and eliminate double counting, this study is unable to provide a definitive estimation method to address the returning-home part, given the iterative nature of product movements across borders for assembly. Specifically, equations (1) and (2) highlight the challenge of identifying the origins of intermediate goods exports and their commodities in multi-country trade. Constructing comprehensive equations to explain the flow of intermediate goods across sector-country pairs is complex. However, a technique exists to address double counting in two-way global trade when intermediate goods cross borders twice, as demonstrated by the example of spider models in Baldwin and Venables (2013).

In sum, addressing double counting and determining the origins of intermediate goods in multi-country trade pose significant challenges. The paper aims to develop an optimal approach using an inverse matrix to empirically eliminate double counting based on the number of times goods return to their source economies. To be specific, this study evaluates the impact of sector-country integration on overall output and utilizes the spillover effect as a measure of products crossing international borders within GVCs.

Box 1. Sector-country pairs in GVC participation

To estimate the stage of the production process, this paper modifies the integration of intermediate goods trade flow. It defines r as a country ($r, s, ..x, .. \in \mathcal{S}$), i as a sector ($i, j \in \mathcal{J}$) and k as sector-country pairs { $k[r(i), s(j)] \in \mathrm{K}$ }. The intermediate goods trade flow at sector-country pairs is denoted as $\zeta^{\dagger}(k^{\dagger-1}, k^{\dagger-2}, \ldots k^{1}, x)$, where inputs are sold from $k^{\dagger-1}$ to the sequence $k^{\dagger-2} \rightarrow k^{\dagger-3} \rightarrow \cdots \rightarrow k \rightarrow x$. This concept illustrates how intermediate goods flow at sector-country pairs, and it helps explain how many times inputs are sold from $k^{\dagger-1}$ to x. For example, produced products in $k^{\dagger-2}$ are sold to $k^{\dagger-3}$, and so on and so forth, until the products arrive at k^{1} and are put into final goods that are shipped and sold to final consumers in x. To illustrate sector-country pairs in GVC participation at bilateral integration in the last two stages, VA can be written as follows:

$$VA = \sum_{\dagger=2}^{\infty} \ldots . \sum_{k \in \mathrm{K}} VA^{\dagger}\left(k^{\dagger-1} | k^{2}, k, x\right)$$

However, the complexity increases when intermediate inputs flow within a multilateral integration setting. Theoretical frameworks of highly stylized sequential production do not characterize asymmetries across production stages (see Alfaro et al. (2019)). This is because the production activities of transactions among countries are not easily observed. Nevertheless, de Gortari (2019) suggests that this challenge can be addressed by specializing inputs, as exemplified by the roundabout model involving Canada, Mexico and the United States.

3.2.1 Data source

The input-output data set provides detailed information about sectoral and sector-country pair integration, allowing for the direct mapping of DVA and FVA. This paper utilizes input-output databases to examine GVC participation through an aggregated data set. The study develops a GTAP-MRIO table using the methodology of Walmsley et al. (2014) and the GTAP-MRIO version 10 database, released in 2019. This database covers 65 sectors in 141 economies, countries and regions, with 2014 as the reference year (Aguiar et al., 2019). The methodology can be adapted to various input-output tables, considering their specific data restrictions and advantages. The aggregated data analysis focuses on the Japanese market across four sectors to estimate the single-country variable r in the model set-up, as shown earlier (appendix table A1).

3.2.2 Results and discussion

The empirical analysis examines the optimal double-counting coefficients, which represent the percentage contribution of sectoral or total average output. By predicting sector-country pair integration using an empirical approach, the paper addresses the challenges by accurately disentangling double-counting elements in the vertical production stages, which could lead to estimation bias. The analysis sheds light on the impact of sectoral interconnections on overall output growth. The following paragraphs present the findings derived from the Japanese market.[6]

Table 1 shows that the interconnections within domestic industries have a significant impact on their respective sectoral outputs (see column 2, domestic effect). Industries with strong trade relationships with their partners exhibit a notable supplier effect through multilevel integration. For instance, in the Japanese context, the manufacturing sector benefits from bilateral integration as a direct effect, leading to a 3.13 per cent increase in its sectoral output as VA (see column 5, on bilateral effect). In addition, the feedback effect from multilevel integration as an indirect effect contributes an additional 0.56 per cent to the manufacturing sector's output

Table 1. Contribution of sectoral integration to sectoral outcome in Japan (Percentage)

	Trade at bilateral and multinational levels					
	Within market			Spillover effect		
Sector	**Domestic effect**	**Feedback effect**	**Total effect**	**Bilateral effect**	**Feedback effect**	**Total effect**
Agriculture	99.79	0.03	99.82	0.15	0.03	0.18
Mining	99.49	0.10	99.59	0.36	0.06	0.41
Manufacturing	95.65	0.66	96.31	3.13	0.56	3.69
Services	98.51	0.22	98.73	1.09	0.18	1.27
Sectoral average	98.18	0.28	98.46	1.32	0.23	1.54

Source: Author's estimation, based on GTAP-MRIO version 10 database.

Note: The Leontief matrix results at the multinational level are presented as *Within market* (B^{rr})) and *Spillover effect* (B^{rs}). *Within market* is divided into domestic effects (D^{rr}) and (intra–country) feedback effect ($F^{rr} = B^{rr} – D^{rr}$). The *Spillover effect* includes bilateral (L^{rs}) spillover effect and a feedback spillover effect from multilateral integration ($F^{rs} = B^{rs} – L^{rs}$). Detailed estimations of these matrices are available upon request

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[6] The analysis is based on a three-country sample in our model framework, with a particular focus on the Japanese market. This estimation does not depend on the specific nature of Japan's relationships with China or other countries, as it controls for country-specific effects by estimating the weighted average spillover effect among countries.

(see column 6, on feedback effect). This implies that a significant increase in global trade would particularly benefit Japan's manufacturing industry, contributing to growth in output of 3.69 per cent (3.13 + 0.56 per cent) (see last column, total effect).

The growing involvement of GVCs in regions such as East Asia and North America raises concerns about biased estimates in VA caused by the complex nature of international trade in production networks, such as the form of spiders or snakes (Antràs and de Gortari, 2020; Baldwin and Venables, 2013). Specifically, the issue arises when commodities cross a border multiple times or return to the source country, resulting in additional VA generated through interconnected trade. These interconnected trade flows can occur through both direct and indirect integration among countries (Antràs et al., 2023). The implications of these phenomena highlight the need for careful consideration when estimating VA to accurately capture the full impact of GVCs.

This research, consistent with previous studies (Bems and Kikkawa, 2021; Johnson, 2018; Kee and Tang, 2016), focuses on the overall or average contribution rather than on each sectoral contribution of DVA/FVA. The novelty of this subsection lies in its empirical estimates, which reveal that the double counting arising from the back-and-forth movement of intermediate products in trade contributes about 1.3 per cent at the bilateral level and 1.5 per cent at the multilateral level of integrations (see row 5, the sectoral average, in table 1). These findings align with the World Bank's (2020) forecast of a 1.7 per cent contribution in Germany, which serves as a representative developed country. These findings highlight the significance of accounting for double-counting effects when measuring the impact of intermediate goods in GVCs. By considering these calibrations, readers can gain valuable insights into the contribution of production stages to average growth, as well as the interplay of knowledge flows within GVC networks discussed in the next subsection, within the context of bilateral and multilateral interactions.

Overall, while some studies shed light on the re-exportation of intermediate goods and their subsequent absorption in home countries, importers and third countries (e.g. Koopman et al., 2014), this paper raises the challenge of where intermediate goods go within GVCs. Specifically, the presence of re-exported or reimported products between trading partners poses challenges in accurately disentangling double-counting elements within GVCs (de Gortari, 2019), leading to potential estimation bias (Bems and Kikkawa, 2021; Johnson, 2018; Kee and Tang, 2016). Accurate estimation of VA is crucial for understanding the impact of intermediate goods in GVCs. Addressing the challenges of double counting elements in the vertical production stages, consistent with the literature (Antràs et al., 2023; Baldwin and Venables, 2013), is essential to avoid estimation bias (de Gortari, 2019).

3.3 Knowledge spillovers and GVC participation

The intricate nature of intermediate product flows in GVC challenges related to double counting, as elucidated earlier. Simultaneously, these complexities create opportunities for knowledge transfer among collaborating countries that specialize in specific production stages for traded goods. This subsection further contributes to a deeper understanding of GVC dynamics by delving into the positive spillover effects of vertical integration within GVCs, adding a nuanced perspective to the scholarly discourse.

This paper adopts a two-step approach to analyse the dynamics of knowledge flow within GVCs. The first step involves the introduction of a knowledge flow model that captures the exchange and diffusion of knowledge among sector-country pairs participating in GVCs. In the second step, the knowledge flow model with sector-country pair integration is integrated, represented in a matrix form. This combination enables us to assess the impact of knowledge flows on sector-country pair interconnections and their contributions to value added output.

In the first step, the knowledge flow model based on the work of Bottazzi and Peri (2003), is represented by equation (3):

$$\sum \eta_{ij}^{rs} = \sum X_{ij}^{rs} \prod_{s \neq r} IMP_{ij}^{rs} \tag{3}$$

where η_{ij}^{rs} represents the knowledge flow, which is influenced by the distribution probability of importing and exporting, IMP_{ij}^{rs} is the international knowledge spillovers embodied in tradable goods and X_{ij}^{rs} is the other variables that have an impact on knowledge flow in regions, such as distance and languages.

Equation (3) plays a vital role in shaping the concept of knowledge flow within the production process among sector-country pairs in multilateral integration. I assume that the distributional impact of knowledge flow is jointly determined by the production stages of continuous inputs. I represent this effect as a percentage contribution[7] denoted by $\zeta_{r(i)s(j)}^{\dagger}$, which accounts for the products that are being re-exported or reimported multiple times between economies to be assembled.

$$\zeta_{r(i)s(j)}^{\dagger} = \begin{bmatrix} \sum_{\dagger \neq 1}^{\infty} \left(\eta_{ij}^{rs}\right)^{\dagger - 1}, & \sum \eta_{ij}^{rs} \neq 0 \\ 1, & \sum \eta_{ij}^{rs} = 0 \end{bmatrix} \tag{4}$$

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[7] This logic aligns with the findings regarding the relationship between the logarithm of patent citations and import value, as illustrated later.

The distribution of the joint probability[8] is formulated as $\left(\eta_{ij}^{rs}\right)^{1} + \left(\eta_{ij}^{rs}\right)^{2} + \cdots \left(\eta_{ij}^{rs}\right)^{\dagger-1} + 1$, where $\dagger - 1$ accounts for the number of times a product crosses a border during the production process across sector-country pairs (box 1). $\zeta^{\dagger}_{r(i)s(j)} = 1$ signifies products that fully complete their GVC participation within the destination country and have no direct impact on export content or production chain in export. Thus, under the assumption of symmetry in country characteristics, the sum of the $\zeta^{\dagger}_{r(i)s(j)}$ is equal to $1 + (\dagger - 1)x\left(\eta_{ij}^{rs}\right)$, which can be interpreted as the maximum potential of knowledge flow reaching 100 per cent within GVC. This formulation captures the cumulative effect of knowledge spillover as it propagates through sector-country pairs (Baqaee and Farhi, 2019).

In the second step, the knowledge flow model was integrated with GVC participation using the approach proposed by Koopman et al. (2010) and Trefler and Zhu (2010). To achieve this, equations (1) and (2) were adjusted by introducing the term $\zeta^{\dagger}_{r(i)s(j)}$, represented by an n-by-n diagonal matrix, and combining it with both sides in equation (5). This function describes the knowledge flow coefficients in a location that makes it inherently sequential.

$$\zeta^{\dagger} T_v^{E} = \begin{bmatrix} \zeta_r^{\dagger} & 0 & \cdots & 0 \\ 0 & \zeta_s^{\dagger} & \ldots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \zeta_n^{\dagger} \end{bmatrix} \begin{bmatrix} v^r B^{rr} E_{k*}^{r} & v^r B^{rs} E_{k*}^{s} & \cdots & v^r B^{rn} E_{k*}^{n} \\ v^s B^{sr} E_{k*}^{r} & v^s B^{ss} E_{k*}^{s} & \ldots & v^s B^{sn} E_{k*}^{n} \\ \vdots & \vdots & \ddots & \vdots \\ v^n B^{nr} E_{k*}^{r} & v^n B^{ns} E_{k*}^{s} & \cdots & v^n B^{nn} E_{k*}^{n} \end{bmatrix}$$
$$= \begin{bmatrix} \zeta_r^{\dagger} v^r B^{rr} E_{k*}^{r} & \zeta_r^{\dagger} v^r B^{rs} E_{k*}^{s} & \cdots & \zeta_r^{\dagger} v^r B^{rn} E_{k*}^{n} \\ \zeta_s^{\dagger} v^s B^{sr} E_{k*}^{r} & \zeta_s^{\dagger} v^s B^{ss} E_{k*}^{s} & \ldots & \zeta_s^{\dagger} v^s B^{sn} E_{k*}^{n} \\ \vdots & \vdots & \ddots & \vdots \\ \zeta_n^{\dagger} v^n B^{nr} E_{k*}^{r} & \zeta_n^{\dagger} v^n B^{ns} E_{k*}^{s} & \cdots & \zeta_n^{\dagger} v^n B^{nn} E_{k*}^{n} \end{bmatrix} \tag{5}$$

Briefly, equation (5) provides insights into the location of knowledge spillover and its interaction with production activities that directly affect exports. An accurate assessment of the contribution of knowledge spillover to value added in exports can be achieved by calibrating the technological influence of sector-country pairs. The primary goal of this approach is to utilize the global input-output matrix to effectively determine the dissemination of know-how through the intermediate goods utilized in various production stages. In this regard, modifications have been applied to DVA and FVA regarding the disaggregated export value of

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[8] The jointly cumulative effect aligns with sectoral value-added propagation length through vertical integration in supplier and consumer relationships (see Antràs et al. (2012) and Dietzenbacher et al. (2005) for further details on average propagation lengths).

$\sum_{s\neq r}^{S}\sum_{i,j=1}^{J}\sum_{f=1}^{F}E_{i,j,f}^{rs} = \left[\sum_{s\neq r}^{S}\sum_{i,j=1}^{J}\sum_{f=1}^{F}\left(\hat{Y}_{i,j,f}^{rs}\right) + \sum_{s\neq r}^{S}\sum_{i,j=1,1}^{J}\left(A_{i,j}^{rs}X_{j}^{s}\right)\right]$.[9] This modification considers the diversity of products involved in the production process across different sector-country pairs. DVA and FVA can be written as follows:

$$
\begin{aligned}
DVA^{r} = {} & v^{r}[D^{rr} + F^{rr}]\left(\sum_{s\neq r}^{S}\sum_{i,j=1}^{J}\sum_{f=1}^{F}\left(\zeta_{\mathrm{r(i)s(j)}}^{\dagger}\right)\left(\hat{Y}_{i,f}^{rs}\right) + \sum_{l\neq r,s}^{S}\sum_{i,j=1}^{J}\sum_{f=1}^{F}\left(\zeta_{\mathrm{r(i)l(j)}}^{\dagger}\right)\left(\hat{Y}_{i,f}^{rl}\right)\right) \\
& + v^{r}\{\lambda^{rs} + L^{rs} + \delta^{rs} + F^{rs}\}\left(\sum_{i,j=1,1}^{J}\left(\zeta_{\mathrm{r(i)s(j)}}^{\dagger}\right)\left[A_{i,j}^{rs}X_{j}^{ss}\right] + \sum_{i,j=1,1}^{J}\left(\zeta_{\mathrm{r(i)s(j)}}^{\dagger}\right)\left[A_{i,j}^{rs}X_{i}^{sr}\right]\right. \\
& \left. + \sum_{l\neq r,s}^{S}\sum_{i,j=1,1}^{J}\left(\zeta_{\mathrm{r(i)s(j)}}^{\dagger}\right)\left[A_{i,j}^{rs}X_{j}^{sl}\right]\right) \\
& + v^{r}\left(\sum_{l\neq r,s}^{S}\{\lambda^{rl} + L^{rl} + \delta^{rl} + F^{rl}\}\right)\left(\sum_{l\neq r,s}^{S}\sum_{i,j=1,1}^{J}\left(\zeta_{\mathrm{r(i)}l\mathrm{(j)}}^{\dagger}\right)\left[A_{i,j}^{rl}X_{j}^{ll}\right]\right. \\
& + \sum_{l\neq r,s}^{S}\sum_{i,j=1,1}^{J}\left(\zeta_{\mathrm{r(i)}l\mathrm{(j)}}^{\dagger}\right)\left[A_{i,j}^{rl}X_{j}^{lr}\right] + \sum_{l\neq r,s}^{S}\sum_{i,j=1,1}^{J}\left(\zeta_{\mathrm{r(i)}l\mathrm{(j)}}^{\dagger}\right)\left[A_{i,j}^{rl}X_{j}^{ls}\right] \\
& + \sum_{l\neq r,s}^{S}\sum_{t\neq r,s,l}^{S}\sum_{i,j=1,1}^{J}\left(\zeta_{\mathrm{r(i)}l\mathrm{(j)}}^{\dagger}\right)\left[A_{i,j}^{rl}X_{j}^{lt}\right]\ldots \\
& \left. + \sum_{l\neq r,s}^{S}\sum_{t\neq r,s,l}^{S}\sum_{v\neq r,s,l,t}^{S}\ldots.\sum_{x\in S}\left(\zeta_{l\mathrm{(i)}x\mathrm{(j)}}^{\dagger}\right)\left[A_{i,j}^{lx}X_{j}^{x^{*}}\right]\right)
\end{aligned}
\tag{6}
$$

$$
\begin{aligned}
FVA^{r} = {} & v^{s}(L^{sr} + F^{sr})\left(\sum_{f=1}^{F}\zeta_{s(j)r(i)}^{\dagger}\left(\hat{Y}_{f}^{rs}\right) + \sum_{i,j=1,1}^{J}\zeta_{s(j)r(i)}^{\dagger}\left[A_{ij}^{rs}X_{j}^{s}\right]\right) \\
& + \left(\sum_{l\neq r,s}^{S}\left(v^{l}\right)\sum_{l\neq r,s}^{J}\left(L^{lr} + F^{lr}\right)\right)\left(\sum_{l\neq r,s}^{S}\sum_{f=1}^{F}\zeta_{l(j)r(i)}^{\dagger}\left(\hat{Y}_{f}^{rl}\right) + \sum_{l\neq r,s}^{S}\sum_{i,j=1,1}^{J}\zeta_{l(j)r(i)}^{\dagger}\left[A_{ij}^{rl}X_{j}^{l*}\right]\right. \\
& \left. + \sum_{l\neq r,s}^{S}\sum_{t\neq r,s,l}^{S}\sum_{i,j=1,1}^{J}\zeta_{l(j)r(i)}^{\dagger}\left[A_{ij}^{rl}X_{j}^{lt}\right]\right)
\end{aligned}
\tag{7}
$$

To summarize, this research aims to enrich our understanding of GVC participation by investigating the effect of knowledge spillovers in vertical interactions. By thoroughly analysing continuous trade and its spillover effects within GVCs, it provides valuable insights into estimating tradable intermediate products and

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[9] This represents the sum of the (aggregated) gross export in country r of (i) final goods $\sum_{s\neq r}^{S}\sum_{i,j=1}^{J}\sum_{f=1}^{F}\left(Y_{i,j,f}^{rs}\right)$, which account for the sum column of households, governments and investments, and (ii) intermediate goods $\sum_{i,j=1,1}^{J}\left(A_{i,j}^{rs}X_{j}^{s}\right)$, which accounts for the sum column of n-by-n industries.

their technological spillover impact on sector-country pair interconnections at the national and international levels. Importantly, the study emphasizes the diversity and heterogeneity of input products, leading to distinct knowledge spillover effects on trade in both bilateral and multilevel integrations. Overall, the model significantly contributes to comprehending global trade dynamics and the critical role of knowledge flows within GVCs.

3.3.1 Data source and econometric model

The number of patent citations is commonly used as a reliable indicator of knowledge flow (Nabeshima et al., 2018). In this study, to estimate the knowledge flow coefficient, patent citation data between 2001 and 2010 were collected from the United States Patent and Trademark Office.[10] In addition, import trade data at the 4-digit level of the International Standard Industrial Classification was obtained from the United Nations Comtrade database.[11] To quantify the spatial information of Japanese trading partners, variables such as distance, language and border were acquired from CEPII GeoDist.[12] To establish the connection between patent knowledge flow and trade goods industries, I merged the knowledge flow classification of patents with the industry classifications of trade goods. This merging process was based on the concordance table documented by Schmoch et al. (2003).

To ensure the consistency of the technological spillover effect, the trade data are linked with patent citation data. In addition, my research aligns with Bottazzi and Peri (2003), who established that knowledge spillovers tend to decrease with distance. To examine these dynamics, the data set comprises trade and patent citation information from 14 Asian economies: Brunei Darussalam, Cambodia, China, Hong Kong (China), Indonesia, Japan, the Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, the Republic of Korea, Singapore, Thailand and Viet Nam. These countries were selected on the basis of data availability and the presence of significant trade flow and industrial networks within the region.[13] Knowledge diffusion is estimated for Japan as a single-country analysis.

This research adopts the empirical approach proposed by Nabeshima et al. (2018) to investigate the connection between patent citations and import values. By solving the log linearizing system in equation (3), an approximate relationship between patent citations and import values can be derived, as follows:

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[10] "Patent application data", Bulk Data Storage System, https://bulkdata.uspto.gov (accessed 14 April 2019).

[11] https://comtradeplus.un.org (accessed 10 February 2020).

[12] http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp (accessed 20 February 2020).

[13] Unbundling in GVCs has concentrated GVC involvement in specific regions, leading to more efficient knowledge transfer within specific regions (Piermartini and Rubínová, 2021).

$$ln\left(\sum \eta_{ijt}^{rs}\right) = \beta_0 + \beta_1 ln\left(IMP_{ijt}^{rs}\right) + \beta_2 \boldsymbol{X}_{ijt}^{rs} + \delta_i + \lambda_t + \varepsilon_{ijt}^{rs} \quad (8)$$

$$ln\left(\sum \eta_{ijt}^{rs}\right) = \exp\left[\beta_0 + \beta_1 ln\left(IMP_{ijt}^{rs}\right) + \beta_2 \boldsymbol{X}_{ijt}^{rs} + \delta_i + \lambda_t\right] + \varepsilon_{ijt}^{rs} \quad (9)$$

where $ln\left(\sum \eta_{ijt}^{rs}\right)$ represents the natural logarithm of the number of patent citations, representing the knowledge flow from country r to country s in an industry i to j for a specific year t, as a percentage of knowledge flow. Similarly, $ln\left(IMP_{ijt}^{rs}\right)$ denotes the natural logarithm of bilateral trade flow of imports. The control variables, $\boldsymbol{X}_{ijt}^{rs}$, account for the logarithm of the distance between each country's capital, along with dummy variables for language and border (appendix table A2). Sector-fixed effect δ_i and year-fixed effect λ_t are also considered. Lastly, the error term ε_{ijt}^{rs} accounts for unobserved factors.

In the analytical framework, the study employs a set of models for rigorous analysis. Panel data analysis involves random-effects, fixed-effects, Poisson random-effects and Poisson fixed-effects models. For pooled data, ordinary least squares, negative binomial regression and Poisson pseudo-likelihood regression with multiple levels of fixed effects are employed. These models, selected based on the non-negative nature of patenting data, ensure a comprehensive understanding of the intricate relationships between patent citations and imports across diverse sector-country pairs.

3.3.2 Results and discussion

Empirical research has demonstrated that international trade facilitates the exchange of knowledge across borders, particularly in production techniques, leading to improved productivity outcomes (Nabeshima et al., 2018). This study, centered on the Japanese market as a representative single economy, examines the knowledge flow embodied in imported goods between trading partners. Since the dependent variable (patent citations) is expressed in logarithms, the coefficients obtained correspond to elasticities, representing the percentage changes in productivity resulting from learning-by-exporting or -importing.

Table 2 provides panel and pooled data analysis for the relationship between patent citations and imports (refer to equation 9), with heteroskedasticity-robust standard errors and fixed effect. The coefficients denote the knowledge flow, expressing the percentage increase in knowledge associated with a corresponding percentage increase in imports. Columns 1 to 4 present the analysis for all sectors, while columns 5 to 7 focus on agriculture, mining and manufacturing, respectively. The coefficient estimates for imports are statistically significant and positively associated with knowledge flow.

Table 2. Japanese knowledge diffusion (Percentage)

	Panel result						
	All sectors				Agriculture	Mining	Manufacturing
Estimator	**RE** (1)	**FE** (2)	**Poisson RE** (3)	**Poisson FE** (4)	**RE** (5)	**RE** (6)	**RE** (7)
ln(Import+1)	0.547*** (0.051)	0.530*** (0.075)	0.314 (0.470)	0.259*** (0.021)	0.372*** (0.032)	0.317 (0.000)	0.580*** (0.054)
Constant	39.064*** (2.381)	0.354 (0.222)	8.836 (59.702)		23.957 (16.459)	35.880 (0.000)	40.718*** (2.281)
Observations	5 280	5 280	5 280	2 060	240	120	4 800
R^2	0.034	0.617	0.000	0.000	0.031	0.005	0.038

	Pooled result						
Estimator	**OLS** (1)	**PPML** (2)	**PPML** (3)	**NBReg** (4)	**NBReg** (5)	**NBReg** (6)	**NBReg** (7)
ln(Import+1)	0.574*** (0.056)	0.415*** (0.029)	0.340*** (0.024)	0.615*** (0.036)	0.561*** (0.178)	1.016 (0.000)	0.619*** (0.036)
Constant	36.645*** (2.223)	8.286*** (0.818)	10.458*** (0.765)	6.209*** (0.883)	15.786 (9.796)	7.705 (0.000)	6.054*** (0.892)
Observations	5 280	5 040	5 280	5 280	240	120	4 800
R^2/Pseudo R^2/chi^2	0.561	0.555	0.486	0.107	0.158	0.207	0.109
Year dummy	Yes	Yes	No	No	No	No	No
Sector dummy	Yes	Yes	No	No	No	No	No
X (Control variables)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster/Robust	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Author's estimations.

Note: The empirical distribution of dependent and independent variables is based on ln(citations+1) and ln(import+1). This is because the data distribution exhibits a prevalence of 0 values; to avoid omitted observations, as ln(0) is undefined, 1 is incorporated to ensure ln(1) equals 0. Panel data analysis includes RE, FE, Poisson RE and Poisson FE models. Pooled data analysis involves OLS, PPML and NBReg (see columns 1 to 7). The control variables (X) are distance, language and border. Sector-classified product codes 1-2 for agriculture, 9 for mining, 3-8 and 10-44 for manufacturing and 5 for service are not presented as the the relationship between patent citations and imports for the services sector in Japan could not be estimated, because of the standard deviation of 0 (min and max 0). ***,**,* represent significance at the 1 per cent, 5 per cent and 10 per cent level, respectively. Standard errors in parentheses. FE = fixed effects, NBReg = negative binomial regression, OLS = ordinary least squares, PPML = Poisson pseudo-likelihood regression with multiple levels of fixed effects, RE = random effects.

In the panel data, coefficients for all sectors range from 0.259 per cent to 0.547 per cent (see columns 4 and 1). In the pooled data, coefficients for all sectors range from 0.340 per cent to 0.615per cent (see columns 3 and 4). Breaking down by sector, agriculture, mining and manufacturing show coefficients of 0.561 per cent, 1.016 per cent (insignificant result) and 0.619 per cent, respectively (see columns 5 to 7 in the pooled data result). Notably, the representative model for Japan reveals an overall knowledge flow coefficient of 0.615 per cent. These results emphasize the pivotal role of imports as a significant channel for knowledge exchange.

Using the two-step approach (explained in subsection 3.2), the knowledge flow is calculated in production stages, capturing the cumulative effect of knowledge spillovers. Subsequently, this knowledge flow is combined with sector-country pair interconnections to assess its contribution to VA as a potential GVC impact. The key findings of the study reveal that products that undergo the final stages of production in destination countries and subsequently across borders as final goods make a significant contribution to value added output. The estimated contributions range from 2.5 per cent to as much as 154 per cent,[14] depending on factors such as crossing borders at the initial stage or reaching their full potential within the GVC. These findings highlight the vital role of intermediate goods trade within GVCs, where these goods across international borders multiple times to be assembled, assuming various forms, as exemplified by the spider, snake and hybrid "sniker" models (Antràs et al., 2017; Antràs et al., 2023; Baldwin and Venables, 2013).

The findings of this study align with established theoretical frameworks and empirical evidence. Firms operating within GVCs have exhibited increased productivity, often referred to as "GVC-driven innovation" (Baldwin and Yan, 2014; Pietrobelli and Rabellotti, 2011). Constantinescu et al. (2019) highlight the significant impact on average productivity of using imported inputs for export production, with gains of approximately 1.6 per cent. Also, Alfaro et al. (2019) found that more-productive firms tend to integrate a higher number of inputs within GVCs. Although the methodological approach differs in terms of estimating the direct and indirect effects of intermediate goods trade on output, for example, the concept of decoupling GVC, explored in roundabout models (Caliendo and Parro, 2015), demonstrates that no-intermediate-input trade can lead to reduced output and welfare, with impacts ranging from 1 per cent to 70 per cent (Eppinger et al., 2021).

In summary, this subsection explored the optimal contribution of re-exported or reimported products within GVCs. It highlighted their significant impact on knowledge flow and output growth, underlining the importance of knowledge spillovers through sector-country pair integration and international trade for driving economic output within GVCs.

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[14] Note that the coefficient of 0.615% accounts for knowledge flow (η_{ij}^{rs}) for the Japanese market. In the first step, the term $\zeta_{r(i)s(j)}^{\dagger}$ represents the cumulative effect of knowledge spillovers in production stages, calculated as $1+(0.615)^1+(0.615)^2+\cdots+(0.615)^{\dagger-1}$ (see equation (4) in subsection 3.2). We can interpret this as the knowledge flow crossing borders at the initial stage, denoted as $1+(0.615)^1=\mathbf{1.615}\%$, or reaching its full potential, denoted as $(0.615)^1+\cdots+(0.615)^{\dagger-1}+1=(\dagger-1)\,x\,(0.615)+1=100\%$. By merging the two-step approach – the knowledge spillover with sectoral integration, expressed as $\sum_{r\neq s}^{S}\sum_{i,j=1,1}^{J}\left(\zeta_{r(i)s(j)}^{\dagger}B_{ij}^{rs}\right)$ (see subsection 3.2) – tradable commodities in the production stages can contribute from 2.5% (1.615 x 1.54) to 154% (100 x 1.54) to overall output (see tables 1 and 2 for 1.54 and 0.615%, respectively).

4. Conclusions and policy implications

This study offers two significant contributions to literature. First, it unravels the double-counting mystery by elucidating production fragmentation through re-exported or reimported intermediate inputs. Second, it emphasizes the importance of knowledge spillover effects and introduces optimal GVC participation strategies. In short, the research shows that considering different forms of value added with knowledge flow effects provides more accurate integration information at the sectoral and regional levels, along with an optimal estimation technique.

The research highlights country-sector pairs benefiting from production fragmentation in GVCs, emphasizing the importance of accurate value added estimation. More specifically, the findings indicate that integration among country-sector pairs, represented by the export/import coefficient, significantly contributes to VA while occasionally causing double-counting issues, estimated at approximately 1.5 per cent at the country level. Furthermore, considering the knowledge spillover effect, tradable commodities being re-exported or reimported in production stages, such as crossing borders at the initial stage or reaching their full potential within GVCs, significantly contribute to value added output, in a range from 2.5 per cent to as much as 154 per cent.

The paper also has important policy implications. Overall, developing robust methods for analysis is important for developing robust policy recommendations. Promoting GVC participation requires strengthening trade relationships between different countries and regions. At the same time, fostering knowledge exchange is a pivotal policy consideration for unlocking the potential of GVCs to drive knowledge spillover and value added growth. In line with this paper's contribution, the paper calls for the development of robust accounting frameworks and methodologies to address double-counting effects in trade, ensuring accurate estimation of VA in GVCs. This is vital for informed policymakers who are striving to promote resilience and sustainable value added growth. Second, it underscores the paramount importance of recognizing the potential of GVC participation in driving VA growth. By embracing GVCs and actively engaging in global trade networks through processing trade policies,[15] countries can gain access to new markets, harness technological advancements and foster knowledge exchange (Pietrobelli and Rabellotti, 2011).

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[15] Prioritizing initiatives to promote bilateral integration and strengthen multilateral trade relationships enhances supplier effects, enables the smooth movement of intermediate goods, and fosters overall VA (Constantinescu et al., 2019; Razeqa, 2022). In GVCs, reducing trade costs, especially tariffs, is crucial since components often cross borders multiple times, magnifying the impact of trade costs on final prices.

Adopting more tailored trade policies becomes crucial for ensuring that GVC participation leads to higher value capture (Baldwin and Lopez, 2015; Pietrobelli et al., 2021; Van Assche and Gangnes, 2019). Policymakers should prioritize efforts to reduce cross-border transaction costs for local firms, enhance connectivity and attract GVC partners. For instance, studies by Nabeshima and Obashi (2021) and Nabeshima et al. (2021) show that differences in regulations can result in decreased bilateral trade volume and reduced diversity of traded goods. Streamlining regulations, promoting harmonization or achieving mutual recognition of regulations among major trading partners through plurilateral agreements may be ways to reduce the transaction costs to firms of complying with varying regulations, thereby facilitating greater participation by firms in GVCs.

There is concern about market concentration, where a few superstar firms often reap outsized benefits from intangible-related advancements (Autor et al., 2020), underscoring the negative impacts of globalization on certain groups, especially in smaller cities and among unskilled workers (Côté et al., 2020). But the rise of GVCs has produced an intricate trade policy landscape, with the COVID-19 pandemic underscoring the extensive impacts of global supply chain disruptions (Antràs et al., 2023; Eppinger et al., 2021; Van Assche and Brandl, 2021), thereby emphasizing the necessity for supranational reforms in GVCs. Thus, countries should prioritize GVC-oriented policies aligned with market facilitation, connectivity and sector-specific strategies. A key policy implication is that tailoring strategies to their unique contexts and objectives is essential, as a one-size-fits-all approach will not suffice. Policymakers should analyse their industry structures and GVC capabilities so as to design customized policies that leverage strengths and opportunities, promoting economic growth, job creation and innovation. In addition, fostering a collaborative approach through international cooperation, policy coordination and partnerships among governments, businesses and civil society is crucial for effective GVC participation.

The study acknowledges limitations, such as challenges in quantifying foreign-owned firms' participation and potential estimation bias. These important points should be taken into consideration for further research. Moreover, considering the increasing significance of digital technologies in the global economy and the evolving role of services within GVCs, particularly in light of the impact of service digitization on global production networks, investigating the influence of such technologies on the structure and functioning of GVCs emerges as a crucial domain for future research.

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Appendix

Appendix table A1. GTAP-MRIO Data: Sectors and economies, countries or regions

Sectors

Agriculture	Paddy rice; wheat; cereal grains, nec; vegetables, fruit, nuts; oilseeds; sugar cane, sugar beet; fish; sugar; plant-based fibers; fish; vegetable oils and fats; dairy products; crops, nec; bovine cattle, sheep and goats, horses; animal products, nec; raw milk; wool, silkworm cocoons; forestry.
Mining	Coal; oil; gas; mineral products, nec; petroleum, coal products.
Manufacturing	Metal products; manufacturers, nec; textiles; motor vehicles and parts; transport equipment, nec; machinery and equipment nec; bovine meat products; meat products, nec; processed rice; ferrous metals; metals, nec; food products, nec; beverages and tobacco products; wearing apparel; leather products; computer, electronic and optical products; electrical equipment; wood products; paper products, publishing; chemical products; basic pharmaceutical products; rubber and plastic products; bovine meat products; meat products, nec; vegetable oils and fats; dairy products; processed rice; sugar; food products, nec; beverages and tobacco products; other extraction (formerly other manufacturing) minerals, nec.
Services	Gas manufacture, distribution; construction; trade; accommodation, food and service activities; real estate activities; business services, nec; insurance; warehousing and support activities; transport, nec; communication; water transport; air transport; financial services, nec; electricity; water; recreational and other services; public administration and defense; education; human health and social work activities; dwellings.groups. The groups available for organizations to select were Children, Migrants, Women, Refugees and Other vulnerable populations.

Economies, countries or regions

Africa: Central Africa (Central Africa), East Africa (the Democratic Republic of the Congo, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Uganda, the United Republic of Tanzania, Zambia, Zimbabwe, rest of East Africa), North Africa (Egypt, Morocco, Tunisia, rest of North Africa), South African Customs Union (Botswana, Namibia, South Africa, rest of the South African Customs Union), West Africa (Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, rest of West Africa)

Americas: North America (Canada, Mexico, United States of America, rest of North America), South America (Argentina, the Bolivarian Republic of Venezuela, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, the Plurinational State of Bolivia, Uruguay, rest of South America), Central America (Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, rest of Central America), Caribbean (the Dominican Republic, Jamaica, Puerto Rico, Trinidad and Tobago, rest of the Caribbean)

Asia: East Asia (China, Hong Kong (China), Taiwan Province of China, Japan, Mongolia, the Republic of Korea, rest of East Asia), South Asia (Bangladesh, India, Nepal, Pakistan, Sri Lanka, rest of South Asia), South-East Asia (Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic, Malaysia, the Philippines, Singapore, Thailand, Viet Nam, rest of Southeast Asia), Western Asia (Armenia, Azerbaijan, Bahrain, Georgia, the Islamic Republic of Iran, Israel, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Türkiye, the United Arab Emirates, rest of Western Asia)

Europe: East Europe (Albania, Belarus, the Russian Federation, Ukraine, rest of East Europe), European Free Trade Association (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Kingdom of the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, Norway, rest of the European Free Trade Association), rest of Europe, former Soviet Union (Kazakhstan, Kyrgyzstan, Tajikistan, rest of Former Soviet Union)

Rest of the world: Oceania (Australia, New Zealand, rest of Oceania), rest of the world

Source: Author's aggregation, based on the GTAP-MRIO version 10 database.
Note: For more information on the geographic and sectoral coverage details in GTAP, see Aguiar et al. (2019, pp. 22–24).

Appendix table A2. Summary statistics for key variables in patent panel data

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
Log of Patent citation	68 060	0.432	2.076	0.000	19.873
Log of Import value	68 060	2.042	2.239	0.000	10.544
Log of Distance	68 060	7.672	0.616	5.754	8.664
Language	68 060	0.116	0.320	0.000	1.000
Border	68 060	0.148	0.356	0.000	1.000

Source: Author’s estimations.

Note: Countries listed in the summary report include Brunei Darussalam, Cambodia, China, Hong Kong (China), Indonesia, Japan, the Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, the Republic of Korea, Singapore, Thailand and Viet Nam.