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Economic Consequences of Trade and Global Value Chain Integration

A Measurement Perspective

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Abstract

This paper presents a new approach to measuring Global Value Chain (GVC) participation, essential for informed policy-making. It introduces a tripartite classification of GVC involvement—backward, forward, and two-sided—extending beyond trade to include production data. GVCs, vital for global economic growth, are networks through which companies internationally produce goods and services. The advanced framework accurately assesses how different combinations of domestic output, trade, and GVC integration correlate with growth and output stability. The paper finds that traditional trade-based GVC metrics significantly underestimate global GVC activity and misrepresent participation in key sectors like services and upstream manufacturing. They also exaggerate risks during critical stages like early trade liberalization in large economies. Additionally, it shows that traditional backward-forward classifications overestimate backward linkages. The new metrics, applied to established models, effectively predict trade disruption impacts, indicating that GVC participation increases exposure to external shocks but also enhances overall output stability by mitigating local shocks. Furthermore, GVC participation is a key driver of the positive trade-income growth correlation. The complete dataset of these new measures is available on the World Bank's WITS Platform, and it is regularly updated, providing a key resource for GVC analysis.

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Economic Consequences of Trade and Global Value Chain Integration: A Measurement Perspective

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1 Introduction

Securing market access and promoting exports are since long considered as primary drivers of economic growth and prosperity. The emergence of Global Value Chains (GVCs), which encompass production processes whose stages are spread across different countries, industries, and firms, complicate policy-making decisions. Global Value Chains introduce new opportunities and risks compared to traditional trade. On the one hand, GVC-led growth strategies feature additional gains from specializing in specific tasks or components and securing better access to inputs, technology, and skills through repeated firm-to-firm interactions (World Bank, 2019 and Antràs, 2020). On the other hand, GVC participation presents countries with greater challenges, including more income inequality and heightened exposure to imported shocks and risks (due for example to dependencies on foreign partners, sourcing challenges, market concentration of critical inputs or stages of production, and new types of technology and intellectual property vulnerabilities).

Governments today recognize that opportunities and challenges differ between approaches that place a different empahsis on domestic production, traditional trade, and GVC engagement. Yet to find the appropriate policy mix, it is essential that they can rely on rigorous, comprehensive, and unbiased measurement of all these forces. This paper addresses this precise need. It develops enhanced accounting measures at the country-sector level using inter-country input-output (ICIO) data and targets two fundamental questions: how much do countries and industries participate to traditional trade and to GVCs? And in what different ways?

This paper argues that a statistically rigorous and theory-consistent approach to measuring trade and GVC participation is needed to answer these questions. It requires a decomposition into three components: pure backward participation, pure forward participation, and a two-sided engagement strategically positioned between the extremes, involving elements of both backward and forward participation. Furthermore, the paper advocates for a comprehensive assessment of the role of GVC participation on the domestic economy by applying GVC concepts to both output metrics and trade metrics. This approach deviates significantly from conventional metrics that decompose participation in backward and forward linkages and focus exclusively on trade measures.

When applied to the data, the new measures provide an intuitive, theory-consistent, comprehensive, and statistically accurate assessment of international economic integration, and - importantly - they unearth several valuable new insights, exemplified by the following four examples. First, the new metrics unveil a significant oversight in understanding global value chains. In the context of the year 2019, at a global scale, approximately half of GVC production, amounting to roughly USD 10 trillion, remains unaccounted for when solely focusing on traditional GVC trade metrics. Second, mismeasurement is industry-specific. We found a particularly severe bias in those sectors that do not export much directly but exploit domestic chains to export indirectly, such as services and upstream manufacturing. Underestimating their contribution to GVCs, both in terms of risks and opportunities, may lead to misguided decisions in industrial and trade policies. Third, the new measures cast a new light on concerns relevant to low and middle income countries that have liberalized trade in recent decades. For example, the risks associated with a country's involvement in GVCs during the initial phases of trade liberalization can often be exaggerated. This occurs when a country's exports are heavily dependent on GVCs while forming only a minor portion of its total domestic output. Such a scenario was seen in early liberalizing China, for example. Measuring GVC participa-

tion against domestic output, in addition to trade, reveals that economies at such junctures are more shielded from international disturbances than previously thought. The significance of an export sector deeply integrated into GVCs needs therefore to be evaluated within this broader context. Fourth, middle-positioned GVC production matters. Contrary to conventional measures that categorize participation as either backward or forward, most GVC-related production is positioned neither at the beginning nor at the end of the chain, but in the middle.

The above facts have economic significance. To gauge more comprehensively the extent to which the new metrics constitute valuable tools for exploring the relationship between trade and development, we use them in model based simulations and empirical analysis.Specifically, we propose three separate exercises to highlight the different ways in which GVCs contribute to shaping global and local economic dynamics. In all three cases, we use well-known modelling and empirical frameworks, so to focus the attention of the reader on the significance of introducing the new measures. The first exercise uses a workhorse quantitative trade model (Caliendo and Parro, 2015 and Antràs and Chor, 2019) and simulations to show that GVC participation is positively correlated with imported trade disruptions and negatively with domestic ones. The value of this is that a correctly measured GVC participation is a strong predictor of different dimensions of exposure to risk. The second exercise, confirms the above result empirically, further showing that despite making output more vulnerable to foreign shocks, GVC participation enhances overall income stability because it offers greater market diversification. In the third and final exercise, we show that greater GVC participation is positively associated with higher per capita income growth, a result which we obtain by introducing the new measures in a classical growth equation. In all cases, the measures are more accurate and offer higher explanatory power than more traditional measures of openness or GVC participation.

The rest of the paper is structured as follows: Section 2 provides a short literature review. Section 3 describes the tri-partite decomposition of GVC trade and it applies these concepts to GVC-related output. Section 4 shows how these metrics allow an intuitive, clear and comprehensive description of GVC participation. Section 5 shows the relevance of these measures for characterizing economic growth and development. Section 6 concludes underscoring the importance of comprehensive and clear GVC measurement for informed policy decisions and for formulating economic development strategies. The full methodology describing the accounting framework is available in the Online Technical Appendix and the full set of new measures, provisioned from all major ICIO databases is available on the World Bank's WITS Platform and described in Appendix A.

2 Related Literature

Rigorous measures of GVC participation are needed to inform questions relevant to economic growth and development. Among these questions, there are two of primary importance: firstly, the extent of GVC involvement by different countries and industries; and secondly, the nature of their participation. In essence, good measures of GVC participation are needed to discern the importance of a given country's involvement for the domestic economy, and whether it primarily manifests itself as input supply to downstream nations and industries, as utilization of foreign inputs, or as a combination of both.

Assessing the extent to which the production and exchange of goods and services is interconnected globally is, however, a complex task. The most accurate and thorough approach requires data at the individual company level from numerous countries, especially when aiming

for a global perspective. Obtaining such extensive and specific data poses a major hurdle, since very few countries generate the required data (Bems & Kikkawa, 2021). Owing to the shortage of such data, researchers have dedicated significant effort over the past twenty-five years to methodically combine transaction data from customs with national aggregate production data. They have developed accounting measures at the country-sector level based on global databases of inter-country input-output (ICIO) relationships. This approach ensures a scientific rigor in their analysis, despite well-known limitations due to assumptions in terms of homogeneity, proportionality and aggregation that such data require, as discussed by de Gortari (2019), Antràs (2021) and Bems and Kikkawa (2021) among others. The resulting country-sector level measures have allowed to quantify the extent to which production processes have become global in the past decades, and how countries and sectors participate in GVCs, together with other features of participation, such as direct and indirect supply and demand inter-linkages. The study by Antràs (2020) calls this body of work "the broad view of GVC participation" while Antràs and Chor (2022) define it as the "macro-approach" to GVC measurement.

A number of studies have laid the groundwork in understanding and quantifying production sharing and trade in value added following such "macro-approach". Key contributions include Hummels et al. (2001), Johnson and Noguera (2012), Koopman et al. (2014), and Borin and Mancini (2015). These have been instrumental in conceptualizing this field and in developing sound measurement methodologies, that are now accepted as standard in the literature. In particular, Hummels et al. (2001) introduced a fundamental idea, suggesting that a minimal condition for trade to be considered GVC-related, is that it must cross at least two country borders. This concept offers a minimal GVC-participation measure, that circumvents the empirical challenges of ICIO-based measures in telling apart GVC-trade from conventional trade when flows cross only one border but involve stages of an internationally fragmented production process.[1]

Early measures have tended to concentrate on specific aspects of the trade-GVC relationship, providing foundational estimates of participation, which have been refined in later research for greater comprehensiveness, accuracy and statistical rigor. The 'vertical specialization' index by Hummels et al. (2001), which gauges the import content of a country's exports, was widely popular. However, as noted by the authors, it measures participation only partially, accounting for backward but not forward linkages. Koopman et al. (2014) introduced an accounting method to decompose a country's gross exports by the source and final destination of their embedded value added. This approach, which is highly used in the literature, quantifies the extent of a country's production included in other nations' exports. It presents however two limitations: it does not trace whether exports undergo further processing in the importing or downstream countries, nor it allows for a fully-consistent decomposition of flows (see the Online Technical Appendix for further details). Another notable contribution is Johnson and Noguera (2012), which defined the value-added exports to gross exports ratio (VAX). The complement of this measure $(1 - VAX)$ has been interpreted in some cases as a measure of the share of trade involved in GVCs. While changes in this indicator align closely with variations in international production fragmentation, especially globally (Johnson

[1] In theory, value-added generated in the final stages of an internationally fragmented production process should be regarded as related to Global Value Chains (GVC), even if it only crosses one border. However, in practical terms, this segment cannot be distinguished from conventional trade using standard inter-country input-output (ICIO) tables. Due to this empirical constraint, the study Hummels et al. (2001) and all other macro-level measures (that is, at the country-sector level) of GVC-related trade in the wider literature concentrate on the "minimal" criterion for GVC trade, namely, crossing at least two borders.

and Noguera, 2017), the indicator in levels tends to underestimate the significance of GVCs in trade, a point elaborated in Antràs and Chor (2022).[2]

Building on the definition by Hummels et al. (2001), Borin and Mancini (2015) showed how to calculate GVC-related trade using global input-output tables in a way that aligns with the original concept established by Hummels and co-authors in 2001. The accounting framework proposed by Borin and Mancini was the first to provide a quantitative assessment of trade crossing at least two borders. The method ensured that the measure of GVC-trade corresponds to the sum of two established metrics of cross-border GVC linkages: forward GVC participation (producing and exporting inputs for further re-export by the trading partner) and backward GVC participation (utilizing imported inputs for goods exported abroad). More recently, Borin and Mancini (2023) proposed a comprehensive methodology for value-added accounting of trade flows at the aggregate, bilateral, and sectoral levels, aligning different accounting perspectives to the economic questions they address best.

All the above-mentioned concepts and measures are now commonly accepted in academic and policy research. The study by Antràs and Chor (2022), part of the *Handbook of International Economics*, surveys these methods, offering a critical evaluation of the differences between them. These are summarized in Figure 1, which reproduces Figure 3 of Antràs and Chor (2022). The line "*GVC trade*" in the figure corresponds to the measure proposed by Borin and Mancini (2015) and further discussed in Borin and Mancini (2023). It shows that GVC trade accounted for about 42% of gross trade globally in 1990, reaching a peak of 52% in 2008, and retrenching to about 48% by 2015. All other measures also show that cross-border GVC activity rose steadily from the mid-1990s until the late 2000s, slightly ebbing after the Global Financial Crisis. The line "$1 - VAX/GX$" corresponds to the complement of the "VAX" measure proposed by Johnson and Noguera (2012), while the line "VS", i.e. "$1 - DVA/GX$", corresponds to the measure of vertical specialization proposed by Hummels et al. (2001).[3] Both measures understate the degree of GVC participation by around 20 percentage points, as they do not account for forward linkages.[4] Lastly, "$1 - DAVAX/DVA$" is a close counterpart to "*GVC trade*", assessing the importance of domestic value-added that crosses more than one border.

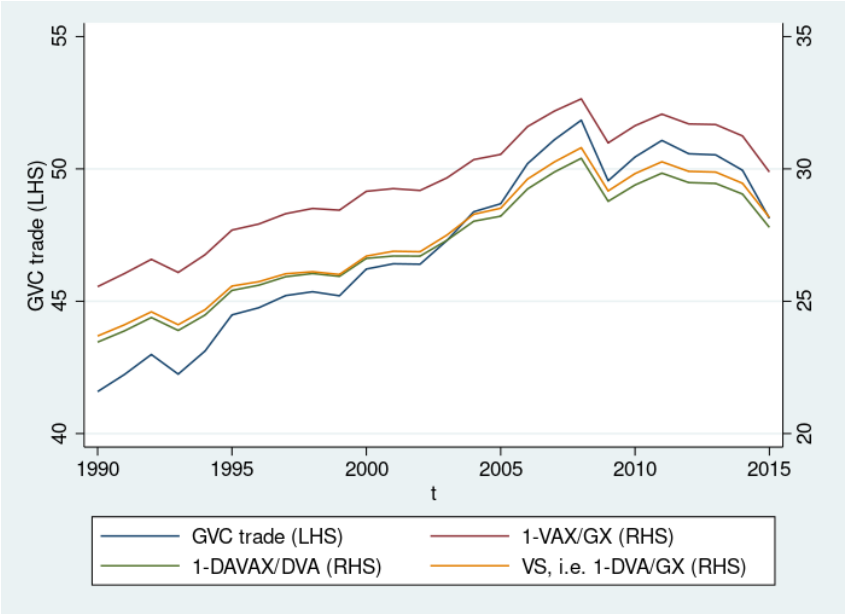
We argue that all the above measurement approaches suffer from three limitations, that the methodology discussed in this paper (Section 3) allows to overcome. First, they do not provide a formulation for forward linkages consistent with the original definition in Hummels et al. (2001). Second, they do not separate pure backward participation from two-sided engagement in GVCs, leading to a systematic exaggeration of the backward component compared to the forward component, and to the oversight of the role of two-sided participation in understanding GVCs. Third, they focus exclusively on trade flows. This practice leads simultaneously to problems of underestimation and overestimation: it tends to underestimate the *absolute* levels of GVC participation through the systematic exclusion of the contribution by industries not directly engaged in exporting activities despite being important suppliers of GVC-oriented industries; and it exaggerates the *relative* exposure for countries whose traded sector is mostly GVC-related, but it constitutes a small share of overall domestic output.

[2] This comes from the fact that only a sub-portion of $\mathbf{VAX}$ is not GVC-related - see the Online Technical Appendix for further details.

[3] Note that Antràs and Chor (2022) do not separately plot the ratio of domestic value added in gross exports "DVA/GX", which Koopman et al. (2014) have emphasized in their work, since the vertical specialization measure by Hummels et al. (2001) is exactly equal to "$1 - DVA/GX$" at the country level.

[4] See the Online Technical Appendix for further details.

Figure 1: Comparison among different GVC measures.



Source: Antràs and Chor, 2022

When one applies the methodology proposed by this paper to the data (Section 4), it is possible to achieve a more comprehensive and statistically rigorous evaluation of the extent and modalities of countries' and sectors' engagement in trade and GVC activities. By improving the measurement of GVC exposure, the measures proposed in this paper are also well suited for discussions about GVC riskiness and resilience, two themes very current in discussions, and for exploring the relationship between trade and countries' growth and development (see Section 5 for further discussion).

3 Methodology

This section presents an accounting framework that allows for a tri-partite decomposition and the use of output-based measures of GVC participation - in addition to trade-related ones. The tri-partite decomposition allows to develop precise, intuitive, and statistically rigorous measures of how countries and industries participate in traditional trade and GVC-related activities. The application of these metrics to both trade and output data allows to capture more comprehensively the extent of participation, as mentioned shortly in the Introduction and at the end of Section 2. The discussion of this Section is streamlined for ease of understanding, and the main concepts are illustrated through diagrams. These latter have a direct correspondence with the underlying algebraic forms, whose full exposition, inclusive of definitions, adopted conventions, and mathematical derivations, is available in the Online Technical Appendix accompanying this paper.

3.1 Tripartite decomposition of GVC-related trade

Characterizing linkages as either forward or backward fails to capture an important empirical regularity: GVC participation encompasses many activities that are linked simultaneously backward and forward to entities abroad. In Section 4 we will show that activities interlinked with both upstream suppliers and downstream buyers internationally could represent as much as two-thirds of all production related to GVCs, highlighting their substantial role. These activities may be critical drivers of economic growth and development, as suggested in Baldwin and Lopez-Gonzalez (2015), under the concept of I2E (import to export), underscoring their significance in the literature on international trade and development.

To more accurately represent international interdependencies, this paper introduces a nuanced accounting framework that identifies three separate modes of participation: *pure forward participation* to describe activities that occur at the start of the value chain, where primary inputs are converted in intermediate goods; *pure backward participation* to characterize activities at the end of the chain, which pertains to the final transformation of these goods into final products; and *two-sided or mixed participation* for activities that are positioned in the intermediary stages of the chain.

Taking the perspective of the exporting sector, in this section we demonstrate the method for identifying the proportion of any trade flow that can be linked to global value chains and how to operate the above-mentioned tri-partite decomposition. In the next section (Section 3.2) we show how these concepts can be applied to output data too.

3.1.1 Definition of GVC-trade

Consider a standard Inter-Country Input-Output (ICIO) model with G countries and N sectors. Given the $N \times 1$ vector of gross exports from country s to country r, which we call $\mathbf{E}_{sr}$, the level of GVC-trade at the sectoral level is:

$$\mathbf{GVC}_{sr} = \mathbf{E}_{sr} - \mathbf{DAVAX}_{sr} = \mathbf{E}_{sr} - \left(\widehat{\mathbf{V}_s\mathbf{L}_{ss}}\mathbf{Y}_{sr} + \widehat{\mathbf{V}_s\mathbf{L}_{ss}}\mathbf{A}_{sr}\mathbf{L}_{rr}\mathbf{Y}_{rr}\right), \tag{1}$$

where $\mathbf{V}_s$ is the $1 \times N$ vector that incorporates the value-added shares embedded in each unit of gross output produced by country s, $\mathbf{L}_{ss}$ is the $N \times N$ *local* Leontief inverse matrix taking into account only the domestic chains, i.e. $(\mathbf{I} - \mathbf{A}_{ss})^{-1}$, with $\mathbf{A}_{ss}$ being the direct requirements matrix of country s inputs in its own productions, $\mathbf{Y}_{sr}$ is the $N \times 1$ vector of final goods and services produced by country s and absorbed in country r.[5]

The term in equation (1) we subtract from gross exports E_{sr} corresponds to the $\mathbf{DAVAX}_{sr}$ – directly absorbed value-added in exports – which identifies, for each country s and sector $n \in N$ of exports, the 'traditional' type of exports to country r, as opposed to the international shipments that take place under the global sharing of production ('GVC-related trade'). Traditional trade $\mathbf{DAVAX}_{sr}$ is the simplest form of trade between countries. In alignment with the concept established by Hummels et al. (2001), it traces the amount of value that crosses just one border, that is the one between the exporter and the importer. It consists of two types of flows: (i) the value of final goods produced entirely at home and consumed abroad ($\widehat{\mathbf{V}_s\mathbf{L}_{ss}}\mathbf{Y}_{sr}$); and (ii) the value of intermediate inputs (entirely) produced at home and used

[5] The hat notation is a standard way to transform a generic $1 \times N$ vector into its diagonal $N \times N$ form. Further details are reported in the Online Technical Appendix.

by the importing country to produce final goods for its internal market ($\widehat{\mathbf{V}_s\mathbf{L}_{ss}}\mathbf{A}_{sr}\mathbf{L}_{rr}\mathbf{Y}_{rr}$).

Accordingly, the measure of 'GVC-related trade', $\mathbf{GVC}_{sr}$, includes all traded items that cross at least two international borders, i.e. that are re-exported at least once before being absorbed in final demand.[6]

Characterizing $\mathbf{GVC}_{sr}$ as in Equation (1) presents two desirable features: *i*) once divided by gross exports, i.e. $\mathbf{GVC}_{sr} \oslash \mathbf{E}_{sr}$, the indicator is bound between 0 and 1, since it traces the *share* of a trade flow value related to GVC activity; *ii*) the indicator $\mathbf{GVC}_{sr}$ is also additive along all dimensions and levels of aggregation (or disaggregation) of trade flows.[7] It should be noted that the broad definition in Equation (1) aligns with a definition initially presented in Borin and Mancini (2015) and discussed in Borin and Mancini (2023). The innovation of this paper is to divide it into the three distinct modes of participation discussed above, i.e. 'pure forward', 'two-sided', and 'pure backward'.[8]

3.1.2 Pure forward GVC-trade participation

'Pure forward' is close to the origin of the chain. It comprises the exports of sector n of value-added generated within the domestic chains, which are then re-exported by the partner.

$$\mathbf{GVC}PureForw_{sr} = \widehat{\mathbf{V}_s\mathbf{L}_{ss}}\mathbf{E}_{sr} - \mathbf{DAVAX}_{sr}. \tag{2}$$

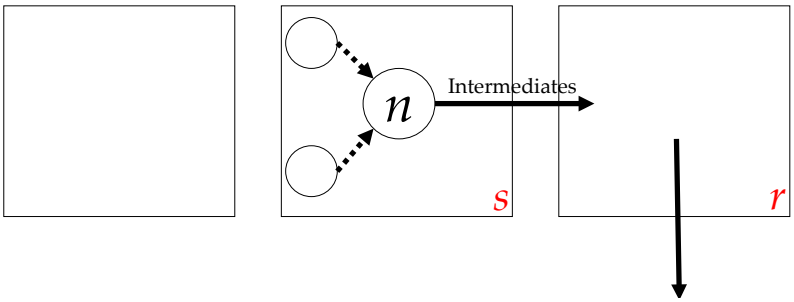
The pure forward participation is simply the difference between the entire domestic value-added that is exported ($\widehat{\mathbf{V}_s\mathbf{L}_{ss}}\mathbf{E}_{sr}$) and the one that is directly absorbed by the importer ($\mathbf{DAVAX}_{sr}$). Schematically one can represent this as in Diagram 1

[6] In principle, also value-added produced in completion stages of the production process, even if it crosses only one border, should be labeled as GVC trade. However, it cannot be singled out using standard ICIO tables. Due to this empirical limitation, it is not considered as part of GVC trade, neither in this paper nor in any macro (country-sector level) measure of GVC trade discussed in the broader literature. Such convention is in line with the initial conceptualization and definition by Hummels et al. (2001).

[7] This means that the indicator can be aggregate in multiple ways and at different levels of aggregation in order to obtain the desired GVC participation measure i.e. exports and its portions (traditional trade, GVC trade, components of GVC trade) at world-level, and at country, country-pair, country-group level, for all industries, for groups of industries, and for individual sectors) by simple summation of the relevant elements

[8] The mapping of these measures with previous ones is as follows: "pure forward participation", corresponds one-to-one to what Belotti et al. (2021) and Borin and Mancini (2017) label as "forward participation". Instead, the sum of "pure backward" and "two-sided" participation corresponds to backward participation in those papers. See the Online Technical Appendix for further discussion.

Diagram 1: Pure-forward GVC-trade - Origin of the chain: first exporting sector



Notes: letters denote either countries (red) or sectors (black) traced by our accounting framework. Boxes represent countries while sectors are identified by circles. Arrows indicate sales, direct ones (solid arrows), or direct and indirect ones (dashed arrows).

The rest of GVC-related trade is given by the sum of the *pure* backward participation and the *two-sided* participation. This is what Hummels et al. (2001) call vertical specialization, i.e. the import content of exports. We discuss it, as well as its two components, in the next paragraphs.

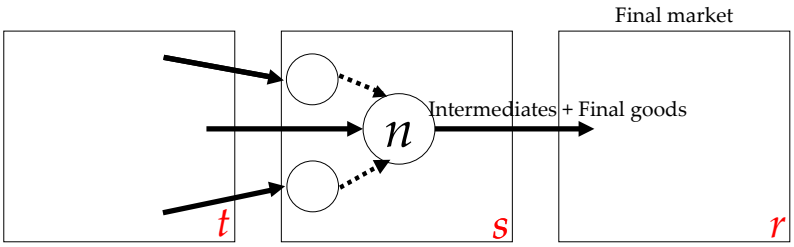
3.1.3 Pure backward GVC-trade participation

'Pure backward' is the portion of the import content of exports closer to the end of the chain:

$$\mathbf{GVC}PureBack_{sr} = \sum_{t \neq s}^{G} \widehat{\mathbf{u}_N \mathbf{A}_{ts} \mathbf{L}_{ss}} \left(\mathbf{Y}_{sr} + \mathbf{A}_{sr} \mathbf{L}_{rr} \mathbf{Y}_{rr} \right), \tag{3}$$

where $\mathbf{u}_N$ is the $1 \times N$ unit row vector whose purpose is to reduce the dimension of the matrices. Pure backward GVC-trade consists of imported inputs bought by sector n in country s directly from the foreign country t or indirectly through domestic chains and exported by the same sector to the final market r, as final products $\left(\sum_{t \neq s}^{G} \widehat{\mathbf{u}_N \mathbf{A}_{ts} \mathbf{L}_{ss}} \mathbf{Y}_{sr} \right)$ or intermediates $\left(\sum_{t \neq s}^{G} \widehat{\mathbf{u}_N \mathbf{A}_{ts} \mathbf{L}_{ss}} \mathbf{A}_{sr} \mathbf{L}_{rr} \mathbf{Y}_{rr} \right)$, as shown schematically in Diagram 2.

Diagram 2: Pure-backward GVC-trade - End of the chain: last exporting sector



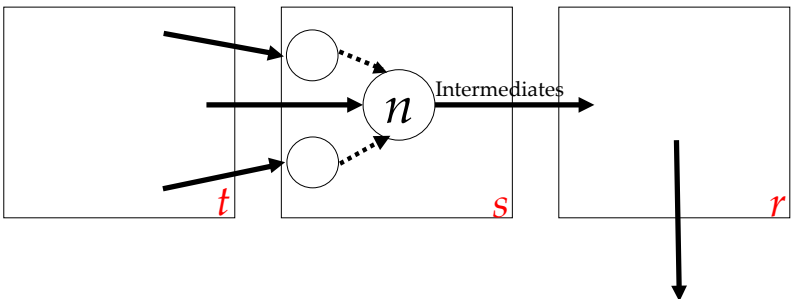
Notes: letters denote either countries (red) or sectors (black) traced by our accounting framework. Boxes represent countries while sectors are identified by circles. Arrows indicate sales, direct ones (solid arrows), or direct and indirect ones (dashed arrows).

3.1.4 Two-sided GVC-trade participation

Finally, the two-sided participation is given by all imported inputs embedded in the re-export of the bilateral partner. The measure represents a measure of both backward and forward participation. It consists of imported inputs in a country's exports that are further re-exported by the bilateral partner (Diagram 3). It clearly excludes the value added captured by pure backward participation – i.e. imported inputs for a country's exports to final markets - and the one captured by pure forward participation – i.e. exports of inputs produced with domestic value added and then re-exported by the bilateral partner.

$$\mathbf{GVC}TwoSided_{sr} = \sum_{t \neq s}^{G} \widehat{\mathbf{u}_N \mathbf{A}_{ts} \mathbf{L}_{ss}} \left(\mathbf{A}_{sr} \mathbf{L}_{rr} \sum_{j \neq r}^{G} \mathbf{E}_{rj} \right) \tag{4}$$

Diagram 3: Two-sided or intermediate position: other sectors have already exported the item, others will re-export it



Notes: letters denote either countries (red) or sectors (black) traced by our accounting framework. Boxes represent countries while sectors are identified by circles. Arrows indicate sales, direct ones (solid arrows), or direct and indirect ones (dashed arrows).

3.2 GVC Concepts and Measures Applied to Output

Traded activities represent the most visible manifestation of cross-country production linkages. However, global production networks extend beyond import-export dynamics and encompass both international and domestic production relationships.

3.2.1 Definition of GVC-related output

The approach to measure GVC-related output mirrors the method used for GVC-related trade in Section 3.1. Also in this case, we focus on the three key moments that define a sector's role in the supply chain: its contributions at the initial stage, its role in the intermediary phases, and its impact at the end of the production process. Here the emphasis is on the sector of production, not on the sector of exports, as in Section 3.1. Accordingly, we identify as "pure forward participation" the very first link of a chain, i.e. the activities related to the creation of value-added that will be exported by any sector and then re-exported by a direct trade partner. Activities related to the assembly of the final goods or services will instead fall in the "purely backward related participation", as they represent the last link of a chain. Final goods that are not exported will fall into this category too, if they are assembled using inputs that

have previously crossed at least two borders. Everything in between, i.e. all the activities that encompass both buying and selling of inputs, will be categorized as two-sided participation.

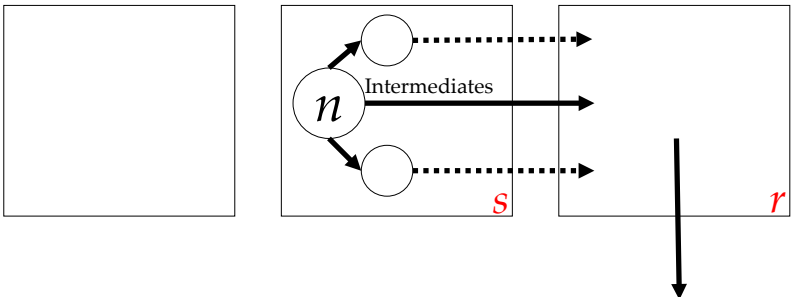
3.2.2 Pure forward GVC participation in output

Pure forward GVC output consists of value-added produced by sector n that is sold abroad – directly by n, or indirectly through other sectors that are part of the same domestic value chains – and subsequently re-exported by the partner country r, hence crossing two borders or more. Formally,

$$\mathbf{GVC}PureForw_s^X = \widehat{\mathbf{V}_s} \sum_{r \neq s}^{G} (\mathbf{A}_{sr}\mathbf{X}_r^{exp} + \mathbf{A}_{ss}\mathbf{L}_{ss}\mathbf{A}_{sr}\mathbf{X}_r^{exp}), \tag{5}$$

where $\mathbf{X}_r^{exp}$ is the output of country r further re-exported. The first term $(\mathbf{A}_{sr}\mathbf{X}_r^{exp})$ represents direct sales to foreign country r by sector n, while the second term $(\mathbf{A}_{ss}\mathbf{L}_{ss}\mathbf{A}_{sr}\mathbf{X}_r^{exp})$ indirect sales through domestic chains. Pure-forward participation is illustrated in Diagram 4.[9] Therefore, GVC pure forward participation in output corresponds to value-added crossing at least two borders traced in the sector of its origin.[10]

Diagram 4: Pure-forward GVC-Output - Origin of the chain: sector where the value-added originates



Notes: letters denote either countries (red) or sectors (black) traced by our accounting framework. Boxes represent countries while sectors are identified by circles. Arrows indicate sales, direct ones (solid arrows), or direct and indirect ones (dashed arrows).

3.2.3 Pure backward GVC participation in output

Pure backward GVC output is defined as imported inputs bought by a sector n directly from abroad or indirectly through domestic chains that are embedded in sector n's final goods production. If imported inputs cross more than one border before being used by n, they are part of pure backward GVC output even if they are sold to domestic consumers as final goods (Diagram 5). Instead, if imported inputs cross only one border before being used by n, they are part of pure backward GVC output only if they are sold abroad as final goods (Diagram 6). This distinction is a crucial one. It makes sure that overall pure backward GVC output

[9] Pure forward GVC participation in output can also be obtained by subtracting the portion of value added that is never exported and the one that crosses only one border from the total value added of a sector, as discussed in Borin and Mancini (2015).

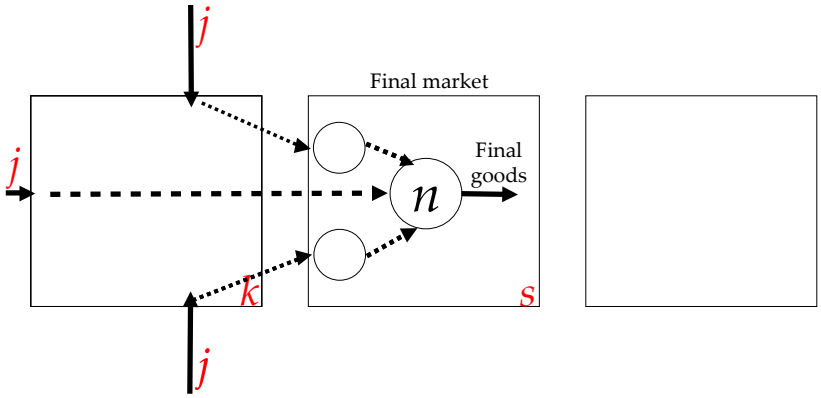
[10] See the Online Technical Appendix for a broader discussion.

adheres to our broad definition of GVCs, i.e. items crossing at least two borders. It is defined as:

$$\mathbf{GVC}PureBack_s^X = \sum_j^G \widehat{\mathbf{V}_j\mathbf{L}_{jj}\sum_{k\neq j}^G \mathbf{A}_{jk}\mathbf{B}_{ks}} \sum_z^G \mathbf{Y}_{sz} - \sum_{j\neq s}^G \widehat{\mathbf{V}_j\mathbf{L}_{jj}\mathbf{A}_{js}\mathbf{L}_{ss}}\mathbf{Y}_{ss}, \tag{6}$$

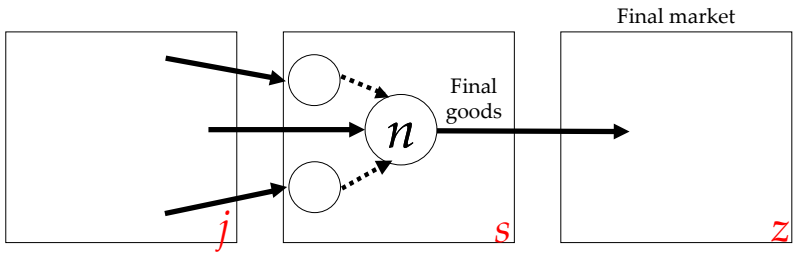
where $\mathbf{B}_{ks}$ is the *global* Leontief inverse matrix. Intuitively, the first term identifies imported intermediates embedded in final goods production carried on by sector n, while the second one excludes from the first term those intermediates crossing just one border. Therefore, $\mathbf{GVC}PureBack_s^X$ consists only of imported intermediates that are embedded in final goods and cross at least two borders.[11]

Diagram 5: Pure-backward GVC-Output - End of the chain: case in which the good is completed and sold in the domestic market



Notes: letters denote either countries (red) or sectors (black) traced by our accounting framework. Boxes represent countries while sectors are identified by circles. Arrows indicate sales, direct ones (solid arrows), or direct and indirect ones (dashed arrows).

Diagram 6: Pure-backward GVC-Output - End of the chain: case in which the good is completed and sold to foreign markets



Notes: letters denote either countries (red) or sectors (black) traced by our accounting framework. Boxes represent countries while sectors are identified by circles. Arrows indicate sales, direct ones (solid arrows), or direct and indirect ones (dashed arrows).

3.2.4 Two-sided GVC participation in output

While pure forward and pure backward GVC output pertain to activities at the origin – value-added creation – or at the end – final goods production – of a value chain, two-sided GVC

[11] See the Online Technical Appendix and Wang et al. (2017).

output is found in all the other activities in an intermediate position. Intuitively, it consists of two terms. First, intermediates bought abroad (backward) and exported as intermediates (forward). This case is illustrated in Diagram 7. Second, domestic inputs bought from other sectors in the domestic market (backward), exported as intermediates, and further re-exported by the bilateral partner (forward), as per Diagram 8. Both terms share the usual property ('crossing at least two borders') but they are computed in different ways. The first term can be computed by subtracting the inputs originating from a direct trade partner and not re-exported, and those being part of pure backward GVC output, from the total imported inputs. The second term instead follows the same rationale of GVC pure forward output in (5), but it is applied to domestic inputs instead of value-added. Formally, we write the corresponding equations as follows:

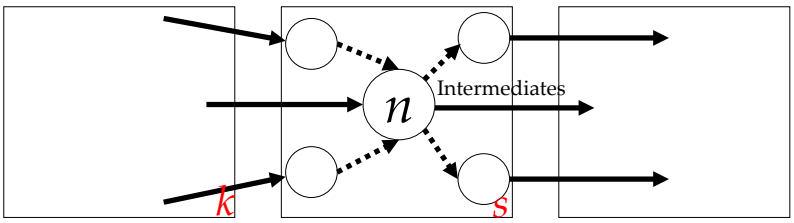
$$\mathbf{GVC}TwoSide_s^{ImpInp} = \sum_j^G \widehat{\mathbf{V}_j\mathbf{L}_{jj}\sum_{k\neq j}^G \mathbf{A}_{jk}\mathbf{B}_{ks}}\mathbf{X}_s - \sum_{j\neq s}^G \widehat{\mathbf{V}_j\mathbf{L}_{jj}\mathbf{A}_{js}\mathbf{L}_{ss}}\mathbf{L}_{ss}\mathbf{Y}_{ss} - \mathbf{GVC}PureBack_s^X, \tag{7}$$

where $\mathbf{X}_s$ is the $N \times 1$ vector of gross output produced by country s, and

$$\mathbf{GVC}TwoSide_s^{DomInp} = \widehat{\mathbf{V}_s\mathbf{L}_{ss}\mathbf{A}_{ss}}\sum_{r\neq s}^G \left(\mathbf{A}_{sr}\mathbf{X}_r^{exp} + \mathbf{A}_{ss}\mathbf{L}_{ss}\mathbf{A}_{sr}\mathbf{X}_r^{exp}\right).^{12} \tag{8}$$

Therefore, two-sided GVC participation in output will be equal to $\mathbf{GVC}TwoSide_s^X = \mathbf{GVC}TwoSide_s^{ImpInp} + \mathbf{GVC}TwoSide_s^{DomInp}$.

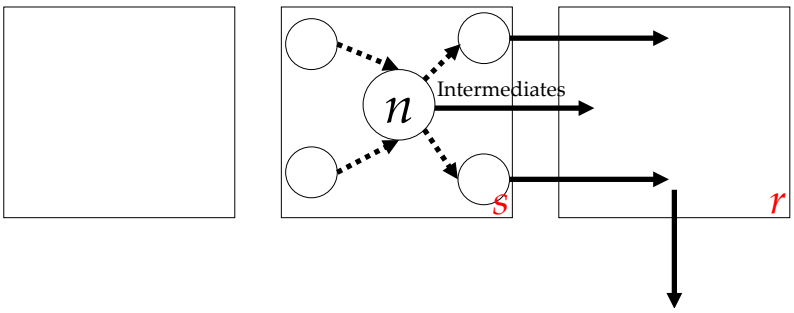
Diagram 7: Two-sided GVC-Output - sector buying foreign inputs and selling intermediates



Notes: letters denote either countries (red) or sectors (black) traced by our accounting framework. Boxes represent countries while sectors are identified by circles. Arrows indicate sales, direct ones (solid arrows), or direct and indirect ones (dashed arrows).

[12] More technical details can be found in the Online Technical Appendix.

Diagram 8: Two-sided GVC-Output - sector buying domestic inputs and selling intermediates



Notes: letters denote either countries (red) or sectors (black) traced by our accounting framework. Boxes represent countries while sectors are identified by circles. Arrows indicate sales, direct ones (solid arrows), or direct and indirect ones (dashed arrows).

3.3 Derived Measures: Aggregations, Complements of GVC Activity, and Forwardness Indices

The above accounting decompositions for trade and output can be manipulated in three useful ways: they can be aggregated to allow different empirical applications; they can be used to look at the complement of GVC-related trade and output, i.e. domestic production and traditional trade; and they can be used to compute an index of relative participation in GVC-trade and GVC-output centered at zero, that we call *forwardness*.

3.3.1 Aggregation across industries, countries and modes of participation

Depending on the empirical application, it could be useful to consider broad measures of participation instead of pure ones. The accounting framework allows to aggregate by simple summation across all dimensions of the indicators, i.e. participation modes, industries, countries. More specifically:

- Broad measures of participation can be computed by simply summing up the three modes of participation into an overall measure of GVC-related trade or GVC-related output, respectively:
  - $\mathbf{GVC}_{sr} = \mathbf{GVC}PureForw_{sr} + \mathbf{GVC}PureBack_{sr} + \mathbf{GVC}TwoSided_{sr}$
  - $\mathbf{GVC}_{s}^{X} = \mathbf{GVC}PureForw_{s}^{X} + \mathbf{GVC}PureBack_{s}^{X} + \mathbf{GVC}TwoSided_{s}^{X}$
- The overall indicators of GVC-related trade and GVC-related output, and their forward, backward and two-sided components can be computed by summation at any level of country-sector aggregation.
- At the aggregate world level, i.e. summing across exporters s, importers r and sectors n, the 'GVC pure backward-related trade' is equal to the 'GVC pure forward-related trade', i.e. $\sum_{s,r\neq s}^{G} \mathbf{u}_N \mathbf{GVC}PureBack_{sr} = \sum_{s,r\neq s}^{G} \mathbf{u}_N \mathbf{GVC}PureForw_{sr}$. The same property holds for GVC-related output, i.e. $\sum_{s}^{G} \mathbf{GVC}PureForw_{s}^{X} = \sum_{s}^{G} \mathbf{GVC}PureBack_{s}^{X}$.

3.3.2 Regional GVC trade

The GVC-related trade measures presented above can also be computed so to distinguish between intra-regional and extra-regional value chain participation. The same holds for its sub-components, i.e. pure forward, pure backward and two-sided participation presented in equations (2), (3) and (4).

More specifically, given a country s, member of a region K, for each exporting sector n, intra-regional value-chain participation is defined as the sum of : *i*) domestic value-added of sector n re-exported by a regional member (pure forward); *ii*) import content of inputs sourced directly from a regional member $t \in K$ and exported by sector n to final markets (pure backward); *iii*) import content of inputs sourced directly from a regional member $t \in K$ and exported by sector n to partners that re-export them (two-sided).[13] Extra-regional value-chain participation is then computed as the difference between the total GVC participation and the intra-regional one. In the Online Technical Appendix we provide a detailed derivation of these terms.

3.3.3 Measures of Domestic and Traditional Trade Output

The framework developed to single out GVC-related output allows also to compute the share of output that never crosses a border, i.e. purely domestic, as the sum of the domestic inputs and value-added that are not exported at all, $\mathbf{Dom}_s^X = \widehat{\mathbf{V}_s \mathbf{L}_{ss} \mathbf{A}_{ss}} \mathbf{L}_{ss} \mathbf{Y}_{ss} + \widehat{\mathbf{V}_s} \mathbf{L}_{ss} \mathbf{Y}_{ss}$, as well as output related to traditional trade, i.e. crossing only one border before being absorbed by final demand, $\mathbf{Trad}_s^X = \mathbf{X}_s - \mathbf{Dom}_s^X - \mathbf{GVC}_s^X$. In this way, we have obtained a full decomposition of the output produced by a country, i.e. $\mathbf{X}_s = \mathbf{Trad}_s^X + \mathbf{Dom}_s^X + \mathbf{GVC}_s^X$.

3.3.4 Forwardness Index

Finally, to fully assess the extent and nature of involvement in GVCs, it's possible to compute a relative measure of participation that we will label as "Forwardness Index". This index ranges from -1 to $+1$, and takes a value equal to *zero* at the global level. It is calculated by first subtracting the measure of "Pure Backward Participation" from that of "Pure Forward Participation", and then dividing this difference by overall GVC participation. This measure, when applied to individual country-pair-industries and GVC-trade, can be written as follows:

$$\mathbf{P}_{sr} = (\mathbf{GVC}PureForw_{sr} - \mathbf{GVC}PureBack_{sr}) \oslash \mathbf{GVC}_{sr}. \tag{9}$$

where the vector $\mathbf{P}_{sr}$ measures the "forwardness" of country s exports to country r, for each sector n, and each of its elements is bounded between -1 and 1. Forwardness at the country level can be obtained simply by summing across sectors and bilateral partners both the numerator and the denominator.[14] In the same way, a natural measure of the type of participation in output of countries and sectors in GVC can be straightforwardly obtained as

$$\mathbf{P}_s^X = \left(\mathbf{GVC}PureForw_s^X - \mathbf{GVC}PureBack_s^X\right) \oslash \mathbf{GVC}_s^X. \tag{10}$$

[13] See the Online Technical Appendix for detailed formulas.
[14] See the Online Technical Appendix for more details.

At the global level, P is equal to zero both for trade and output, given pure backward and pure forward participation are equal at that level of aggregation, $\sum_s^G P_s = 0$. Thus, any index different from zero at any level of aggregation might be interpreted as a deviation from the world aggregate average.

The forwardness index offers a synthetic means of evaluating the primary mode though which a country or a sector engages in GVCs. Previously, a separate strand of the literature has developed specific indicators, such as "upstreamness", "downstreamness" and "positioning", to characterize more accurately the participation mode (Antràs and Chor, 2019 and Wang et al., 2017; see Mancini et al., 2024 for a comprehensive database of such measures based on the most popular Inter-Country Input-Output tables). It is reassuring to see that the forwardness index proposed above shows a strong positive correlation with those measures of positioning.[15]

Incorporating both the dimensions of the extent of GVC participation and the primary participation mode within a unified framework provides a coherent and easily comprehensible method for a thorough evaluation of a country's or a sector's engagement in GVCs. Additionally, the fact that the forwardness index is bounded between -1 and 1 and neutral at the world level streamlines assessments when moving from a global perspective to specific country-sector interactions. Collectively, the set of indicators we present constitutes a straightforward and comprehensive toolbox of GVC descriptive statistics, readily applicable for policy analysis.

4 Results: Analyzing the Data Through the New Measures

We applied the measures developed in Section 3 to all well-known ICIO datasets: EORA, the Asian Development Bank MRIOT, OECD TiVA, and WIOD. This allowed us to create the range of measures discussed above for 189 countries worldwide, and to offer a sectoral breakdown which ranges from 26 to 56 industries over the years 1990-2019, with both sectoral breakdown and exact time coverage depending on the raw data availability in the corresponding ICIO data source. Applying the new measures to these data helps us answer two types of questions. First, they help us understand the extent of participation, meaning what portion of countries and sectors trade and economic output is linked to GVCs. Second, they help us determine how countries and sectors participate, specifically whether they primarily supply inputs to GVCs or if they are downstream users of GVC-related products. In Section 5 we will further show that accurate and theory consistent answers to these questions help improving the understanding of the global and local economic implications of GVC participation.

Before turning to showing how the new measures help quantify the extent and modalities of GVC participation, we quantify the additional information content that is captured by measuring GVC involvement through the lens of both the exporting and producing sectors. Figure 2 and 3 show the distribution of the share of GVC trade on total trade (y-axis) and the share of GVC output on total output (x-axis) for manufacturing and services in the year 2015, using the information available in the EORA dataset. These graphs reveal that at the country-sector level, the participation in GVCs varies widely and they indicate that GVC output and GVC trade data provide different information on the country-sector's engagement in GVC

[15] See Figure A1 in the Appendix. A similar correlation is found between position and forwardness in GVC-trade, as reported in Figure A2.

activities. Moreover, Table 1 suggests that GVC output provides richer information than GVC trade, as measured by a higher coefficient of variation, which is between two and three times larger than the one for GVC trade across all major ICIO datasets. The greater variation in output-related measures compared to trade-related ones persists consistently across sectors, countries, and combinations of countries and sectors. In Section 4.1 and Section 4.2 below, we will delve into these two questions further, illustrating the extent of participation in GVCs at the global level and by different countries and industries, as well as the specific roles they play within GVCs.

Figure 2: Bivariate density plot of GVC Output and GVC trade in manufacturing, 2015

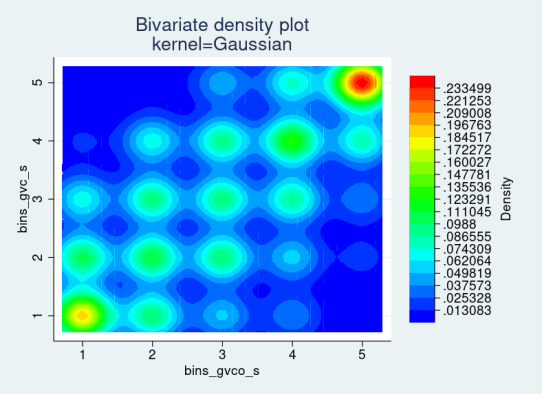
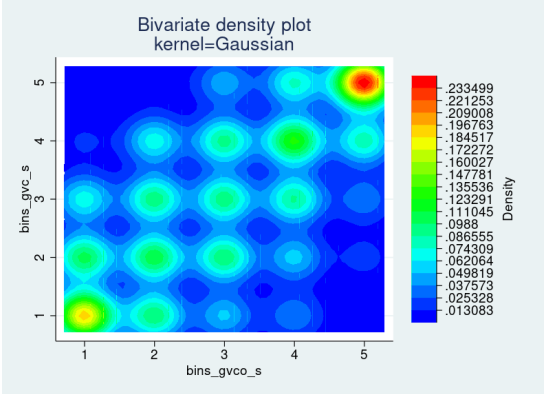


Figure 3: Bivariate density plot of GVC Output and GVC trade in services, 2015



Source: Own elaboration based on EORA

Table 1: GVC Output and GVC trade coefficients of variation across ICIO sources in 2015.

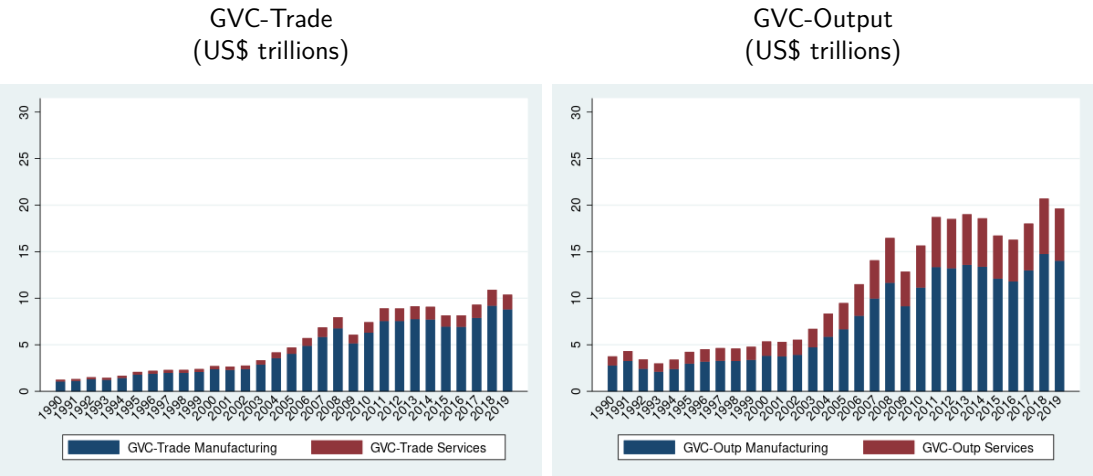
		Inter-Country Input Output Table			
	Coefficient of variation	**ADB-MRIO**	**EORA**	**OECD-TiVA**	**WIOD**
Sector	GVC-trade	0.24	0.23	0.34	0.26
	GVC-output	0.72	0.67	0.78	0.67
	Ratio	*2.99*	*2.93*	*2.33*	*2.63*
Country	GVC-trade	0.23	0.24	0.25	0.22
	GVC-output	0.84	0.70	0.95	0.91
	Ratio	*3.61*	*2.87*	*3.74*	*4.07*
Country-sector	GVC-trade	0.35	0.30	0.43	0.39
	GVC-output	1.38	1.09	1.45	1.52
	Ratio	*3.89*	*3.58*	*3.40*	*3.92*

4.1 What Part of a Country's Trade and Output are Involved in GVCs?

A broader perspective that encompasses both trade-related and output-related measures of GVC participation is important to answering the above-captioned question. In absolute terms, looking only at GVC trade understates the actual extent of GVCs by around 10 trillion USD, as GVC trade amounts to about 10 trillions USD while GVC output amounts to about 20 trillions USD. The severity of the underestimation obtained with standard measurement approaches that trace GVC engagement solely from the exporting sector perspective is well captured in Figure 4 which shows the level of participation from the viewpoint of the exporting sector compared to the producing sector. This difference matters greatly for some sectors. From the point of view of sectors, services participation in GVCs is modest in absolute terms when we

focus solely on the perspective of the exporting sector (about 1 trillion USD), but it appears five times larger when participation is measured from the viewpoint of GVC output (about 5 trillion USD). Even participation in manufacturing sectors appears significantly larger when taking the perspective of the producing sector compared to the exporting one (about 15 vs 9 trillion USD, respectively). One reason for such difference is that some sectors do not export much directly but exploit domestic chains to export indirectly. Measuring GVC participation from the viewpoint of the exporting sector erroneously attributes their contribution as belonging to exports of a downstream using sector.

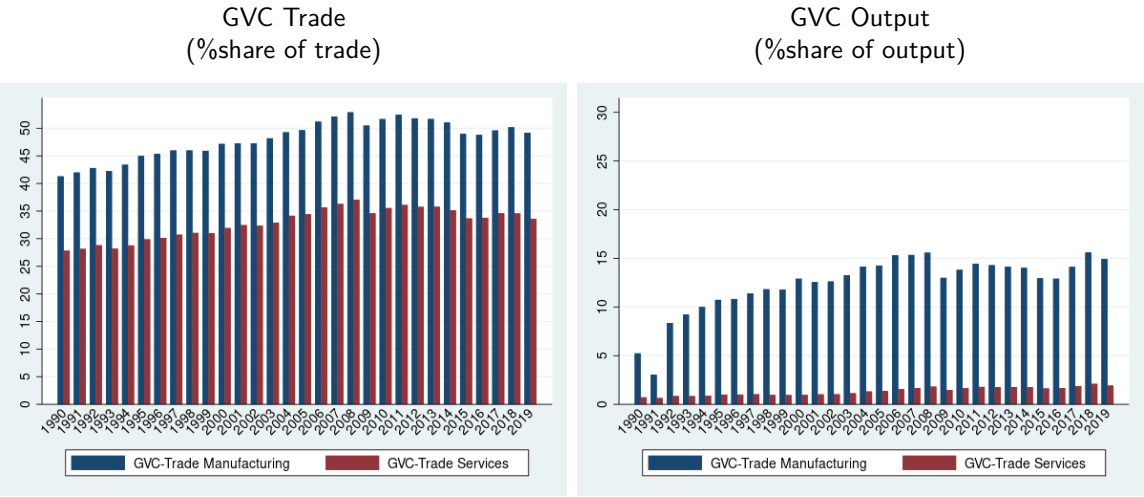
Figure 4: Exporter versus producer perspective in measuring GVC participation, *absolute* terms



Source: Own elaboration based on EORA and ADB MRIO

So far we have focused on absolute measures of GVC participation, in US$ terms. However, assessing GVC participation against both trade and output measures matters also for an accurate assessment of the relative measures of GVC participation, i.e. when they are expressed as a share of the total (trade and output, respectively). We can illustrate this point with some examples. First, it is noteworthy that half of manufacturing trade is related to GVCs, but only 15% of manufacturing output is GVC-related, as shown in Figure 5. Second, trade-related GVC participation in services – i.e. as a share of total trade in services – is apparently very high, posting similar figures to the one observed for manufacturing. Complementing trade-related GVC measures with output-related ones allows however to show that that the seemingly high share of services trade related to GVCs is driven by very low levels of total services exports, and is therefore not very informative. The additional information from GVC output measures appears in this case essential to an accurate understanding of the relative importance of GVCs in manufacturing and services. Third, GVC exposure of some countries whose export constitutes a small share of overall domestic output is also wrongly estimated by looking at GVC-related trade only. In this case, the assessment of their exposure to GVCs is overinflated, as in the case of GVC-trade in services. This for example was the case of China at the beginning of the process of trade liberalization. In the late 1980s and early 1990s Chinese exporting firms, mainly located in Special Economic Zones were highly involved in global value chain production, but the bulk of the economic activity was still generally domestically oriented. Computing relative GVC output participation on top of GVC trade participation would have indicated that the domestic economy was relatively insulated from foreign shocks despite its export sector being heavily reliant on GVCs.

Figure 5: Exporter versus producer perspective in measuring GVC participation, *relative* terms



Source: Own elaboration based on EORA and ADB MRIO

As a final point, the broader perspective based on both the exporting and producing perspective matters not only in absolute and relative term, but also for how we rank different countries' (and sectors') participation and exposure. At the country level, GVC trade and output are clearly correlated, but the country rank is different. Each dot in Figure 6 and Figure 7 is a country among the 30 countries worldwide with the highest real GDP. We highlight those countries whose rank moves by at least 25 positions when we compare GVC output to GVC trade participation. For example, in the left hand panel Germany is ranked 22nd in terms of GVC output participation but 53rd in terms of GVC trade participation, out of a total of 189 countries reported in the EORA dataset.

Figure 6: GVC Output Participation vs Trade Participation in Manufacturing, 2015

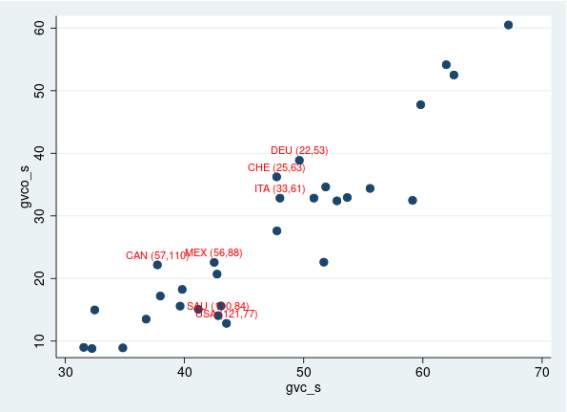
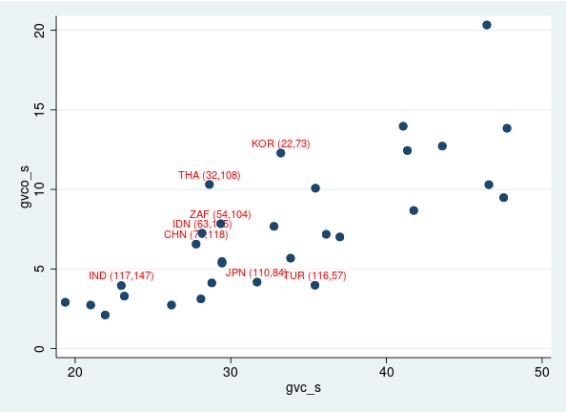


Figure 7: GVC Output Participation vs Trade Participation in Services, 2015



Source: Own elaboration based on EORA

4.2 How do Countries and Sectors Participate?

In GVC output, *Two-Sided* participation is the most relevant component, since it accounts for more than 60% of the total GVC participation (Figure 8). In GVC trade, however, the

two-sided participation is less significant (see Figure 9). This difference is explained by the fact that most exporting sectors and firms engage at the end or at the beginning of the chains. Instead, most producing sectors (GVC output) are characterized by two-sided exposure, i.e. they engage in import to export or sourcing to sell activities.

Figure 8: GVC Output Participation
(%share of total output)

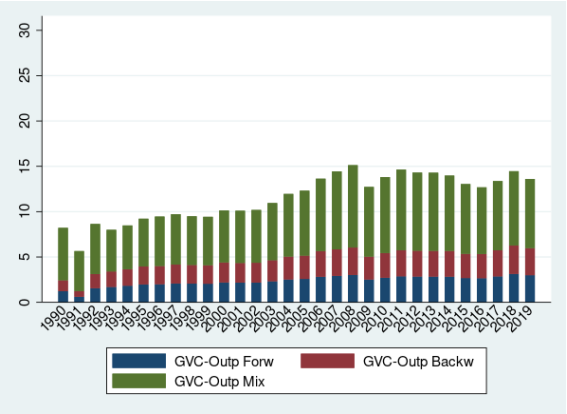
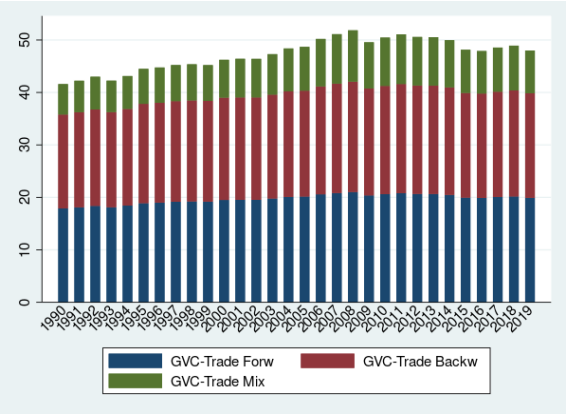


Figure 9: GVC Trade Participation
(%share of total trade)

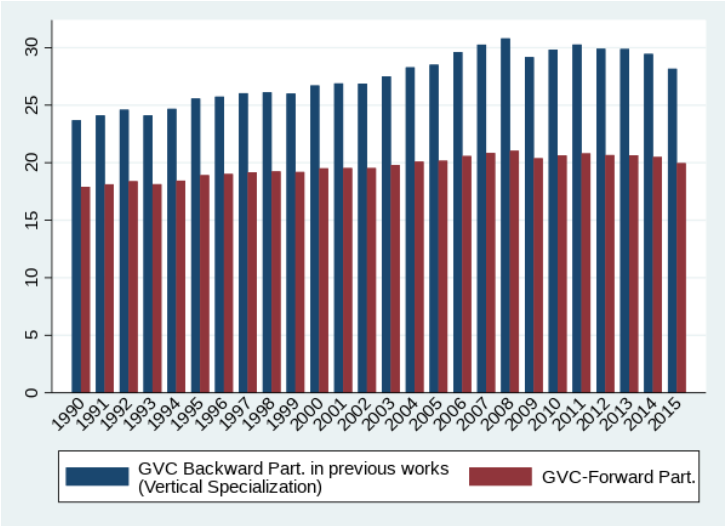


Source: Own elaboration based on EORA and ADB MRIO.

However, even if the intermediate or two-sided mode of participation is a relatively smaller share of overall participation from the exporting sector's perspective, ignoring it remains problematic: it risks inflating the significance of backward integration, which in turn can lead to misguided trade and industrial policy decisions. Our analysis, whore results are shown in Figure 10, proves this point. The standard bi-partite decomposition in backward and forward linkages leads backward linkages to appear systematically larger than forward ones, and it suggests the existence of an imbalance between the two at the global scale. Such a systematic discrepancy is unfunded theoretically and empirically puzzling. There are no economic theories supporting the dominance of one type of integration over the other, and empirically one would expect backward and forward linkages to even out at the global level, in the same way that world imports and exports balance out. From this evidence we conclude that the failure to clearly identify and track the intermediate (or two-sided) mode of participation leads to misrepresent GVC participation.

Capturing two-sided participation is important not only at the global level, but also at the country-sector level, as shown in Figure 11 and Figure 12, which report the distribution of different participation modes divided by total GVC participation. In addition, for almost 70% of country-sector pairs the intermediate mode of GVC output participation is the prevalent one, while two-sided participation accounts for more than two-thirds of total participation for about one-third of all country-sector pairs.

Figure 10: GVC Backward Participation as in previous works and Forward Participation at the global level (share of total trade)



Source: own elaboration based on EORA.

Figure 11: Distribution of GVC output participation modes over total GVC output, WIOD 2014.

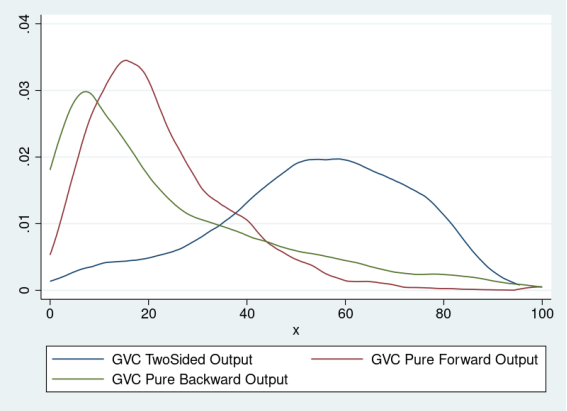
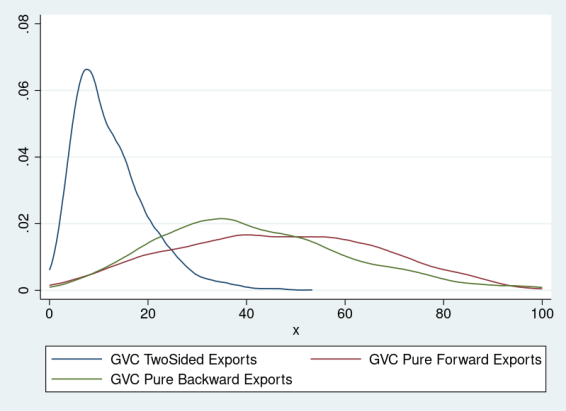


Figure 12: Distribution of GVC exports participation modes over total GVC exports, WIOD 2014.



Source: Own elaboration based on WIOD. The x-axis represents the share of the mode of GVC participation over total GVC participation, while the y-axis reports the density.

5 Why It Matters: Three Empirical Applications of the New Measures on the Economic Consequences of Trade and GVC Integration

This final part of the paper shows that the new measures of GVC participation help improve the characterization of the relationship between trade and economic growth and stability. The first exercise shows that these measures help predict the potential impact of trade shocks better than traditional measures of openness and GVC integration. The second and third exercises

show that despite increased exposure to foreign disruptions, GVC involvement correlates with greater output stability and higher income growth. We also find that two-sided participation and forward linkages drive the correlation between GVC participation and income growth, and also in the context of this economic relationship the new measures post greater information content than traditional measures.

5.1 Predicting Exposure

GVC participation measures are useful for inferring the potential consequences of trade shocks. We use a workhorse multi-country multi-sector model to simulate an increase in trade barriers. We show that the GVC measures developed in this paper exhibit a very high correlation with the impact of the trade shock. Such correlation is higher than the one obtained with standard measures of openness or vertical integration, a fact consistent with the assumption that the shock works through complex global supply networks.

Methodology

The Caliendo and Parro (2015) model is a multi-sector version of the traditional Eaton and Kortum (2002) Ricardian model of international trade, a cornerstone of international trade theory. The model includes several key features:

- Trade in both intermediates and finished goods, recognizing that, in modern global trade networks, countries trade very different kinds of products.
- A Cobb-Douglas production function that combines labor and intermediates. This function is a common way to illustrate the synergy between labor and intermediate goods in the production process.
- Sector-specific Fréchet productivity distributions. This means the model assumes different countries and sectors have different levels of productivity, influenced by the probability distribution known as Fréchet. Accordingly, countries tend to export goods in which they have a relative productivity advantage.
- Inter-country and inter-sectoral trade linkages, essential for understanding contemporary global trade patterns.

We resort to the Antràs and Chor (2019) version of the model, which relaxes the assumption that trade costs are only country-pair and selling-industry specific. A significant strength of the model is its compatibility with the Inter-Country Input-Output data, allowing for a robust theoretical and empirical interface on how different industries in various countries interact and trade with each other.[16] In other words, the model adeptly contextualizes tangible, real-world applications such as the expenditure patterns of the U.S. vehicle industry, and the share of it related to Mexican equipment imports.[17]

[16] Differently from Caliendo and Parro (2015), Antràs and Chor (2019) allow for different trade costs across intermediates and final goods. This simple extension enables the model to fully match all entries in an Inter-Country Input-Output table.

[17] See Antràs and Chor (2022) for a broad overview of this class of models.

More formally, the share of expenditure of country r in products coming from industry n of country s, used as inputs in sector m or consumed as final goods F, are defined as follows:

$$\pi_{sr}^{nm} = \frac{T_s^n \left(c_s^n \tau_{sr}^{nm}\right)^{-\theta^n}}{\sum_{k=1}^{S} T_k^r \left(c_k^n \tau_{kr}^{nm}\right)^{-\theta^n}} \quad \text{and} \quad \pi_{sr}^{nF} = \frac{T_s^n \left(c_s^n \tau_{sr}^{nF}\right)^{-\theta^n}}{\sum_{k=1}^{S} T_k^r \left(c_k^n \tau_{kr}^{nF}\right)^{-\theta^n}}, \tag{11}$$

where the parameter T_s^n is the scale parameter of the Fréchet productivity distribution, which denotes the technological state of country s in industry n. The term c_s^n represents the unit production cost faced by each industry n in every country s. Additionally, these equations factor in two types of trade costs: τ_{sr}^{nm}, which is the cost associated to shipping goods between sectors and countries; and τ_{sr}^{nF}, which denotes the trade cost of delivering the good to the final consumer in country r.

Trade costs include iceberg transport costs (v) and non-tariff barriers (b) in a multiplicative manner, i.e. $\tau_{sr}^{nu} = v_{sr}^{nu} \times b_{sr}^{nu}$, with $u = \{m, F\}$. In our simulation, we model the rise in trade costs as an increase in non-tariff barriers b.

Calibration of the model leverages the OECD's TiVA 2018 tables, ensuring data-driven precision. Sector-specific trade elasticities, derived from recent empirical studies (Fontagné et al., 2022 for goods and Egger et al., 2012 for services), provide further refinement. The model is solved using the 'hat algebra' approach, a standard in trade economics which ensures methodological rigor (Dekle et al., 2008).

Simulation Results and Analysis

The outcomes of our simulation exercises help evaluate how GVC participation measures correlate with the GDP losses induced by increased trade costs. The simulation involves a hypothetical 10% rise in non-tariff barriers, affecting both intermediates and final goods. This scenario is replicated for separate categories of goods, yielding consistent findings across different simulations.[18] There are three sets of noteworthy results:

- GDP losses and GVC participation: The simulation revealed a pronounced negative correlation between GVC-related output and the simulated decline in GDP. Specifically, as shown in Figure 13, countries that were heavily integrated into GVCs experienced a more significant drop in GDP following the increase in trade costs. This outcome underlines the susceptibility of countries more engaged in GVC activities to international trade disruptions.

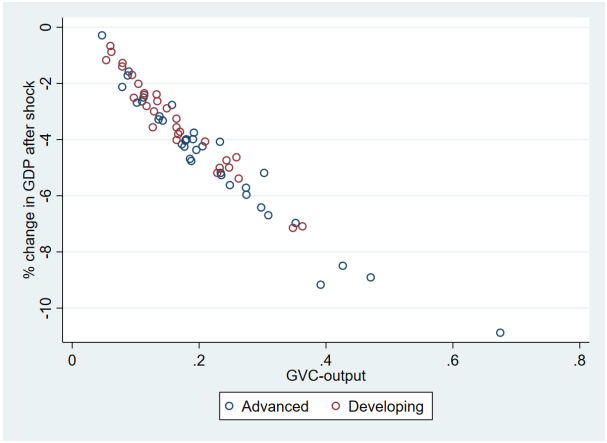
- Comparative Predictive Analysis: Further, we conducted a comparative predictive analysis using various metrics of GVC involvement. Our approach included a regression analysis where GVC proxies (X_i) were compared against the drop in GDP (ΔGDP_i) post-trade shock. The formula employed was $\Delta GDP_i = \alpha + \beta X_i + \varepsilon_i$, with i representing either sectors or countries. Notably, our tripartite measure of GVCs consistently demonstrated higher predictive accuracy compared to traditional measures such as trade openness and vertical specialization. This is evidenced by superior adjusted R^2 values in nearly all countries (Figure 14) and sectors (Figure A3, Appendix).[19]

[18] The results for the replication by category of goods are available upon request.

[19] Our tripartite decomposition performs better than our aggregate measures of GVCs, which in turn still out-performs standard measures. Results are similar for GVC-trade and available upon request.

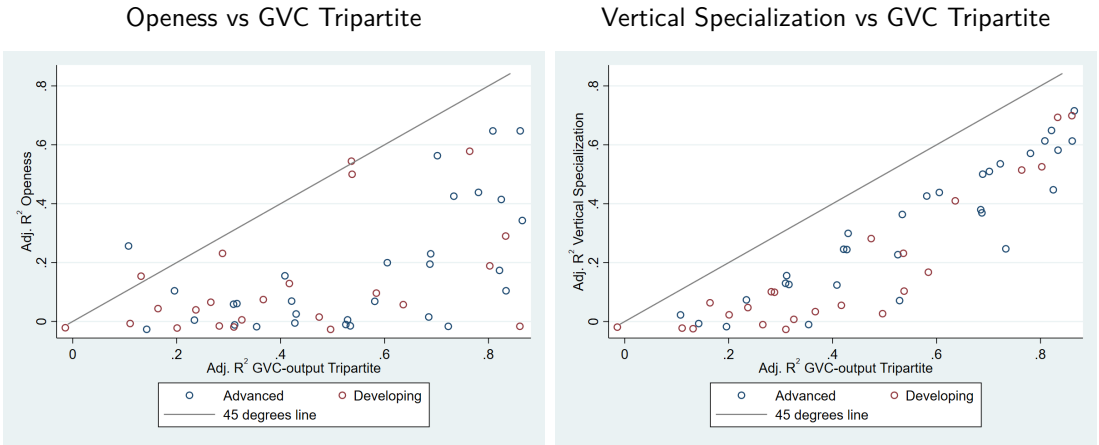
- GVC Participation and Resilience to Domestic Shocks: Lastly, our analysis extended to the relationship between domestic economic shocks and GVC participation. By simulating a 10% increase in domestic distortions affecting transactions across sectors *within* countries along the lines of Caliendo et al. (2022), we observed a negative association between the change in GDP triggered by these domestic shocks and the share of output which was purely domestic, i.e. not related to GVCs or trade, as depicted in Figure 15. This finding suggests that while involvement in GVCs increases exposure to international market fluctuations (Figure 13), it concurrently provides a buffer against domestic economic disruptions. This trade-off aligns with recent research in both macroeconomic (Caselli et al., 2020) and microeconomic (Kramarz et al., 2020) domains, and will be further explored below (section 5.2).

Figure 13: Correlation between simulated changes in GDP and GVC-output



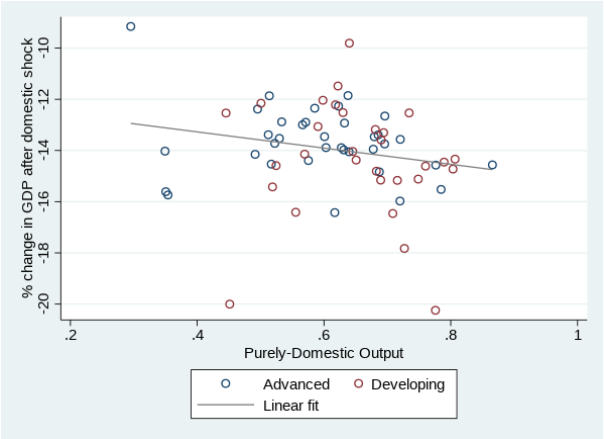
Source: Own elaboration based on OECD TiVA.

Figure 14: Predictive power of GVC participation, country-level regressions



Source: Own elaboration based on OECD TiVA. Note: The scatter plots report the adjusted R^2 of country-level regressions $\Delta GDP_s = \alpha + \beta X_s + \varepsilon_s$, where s are the sectors. Dots below the 45 degrees line represent datapoints for which the tripartite decomposition has superior explanatory power compared to more standard measures of trade openness and vertical specialization.

Figure 15: Correlation between simulated changes in GDP after a domestic shock and Purely Domestic Output



Source: Own elaboration based on OECD TiVA.

5.2 Quantifying the Mediating Role of GVC Involvement on Countries and Sectors' Output Responses to Demand Shocks

This section, continuing from our earlier results, focuses on the role of GVCs in mediating the impact of demand shocks on the domestic economy. We employ the proposed tripartite decomposition of GVC involvement, distinguishing between backward participation (input sourcing), forward participation (exposure to downstream demand shocks), and two-way participation (both input sourcing and exposure to downstream demand shocks).

The new metrics illustrate well the nuanced role of GVCs in providing economic stability. The results show that while GVC participation heightens exposure to certain external shocks, it simultaneously offers avenues for market diversification and risk mitigation. This insight is particularly relevant for countries with high domestic output volatility, a feature that characterizes many developing countries. This suggests that strategic integration into stable global markets through GVCs can stabilize the economies of such countries.

Methodology and Empirical Estimation Details

Our objective is to illustrate how different facets of GVC participation affect a country or sector's response to exogenous demand shocks. This involves examining the impact of these shocks on output variations in various country-sector pairs, taking into account the degree of their GVC involvement. The empirical analysis is intentionally based on already well established empirical frameworks, so to allow a better evaluation of the significance of the GVC participation measures. It comprises three steps:

- Estimating Exogenous Demand Innovations. We estimate demand innovations using global Input-Output (I-O) tables through a fixed effects model, along the lines of Alfaro et al. (2021) and Kramarz et al. (2020).
- Aggregating Direct and Indirect Shocks. We aggregate demand innovations through a shift-share instrument approach, extending the framework in Ferrari (2023) to differentiate between direct demand shocks (related to sales of final products) and indirect

demand shocks (related to sales of intermediate products). Our hypothesis is that the latter should be exclusively associated with GVC involvement, particularly forward or two-way participation.

- Integrating GVC Metrics into Empirical Models. We assess the impact of GVC participation on the stability of output to these shocks. The model integrates direct and indirect demand shocks with GVC participation metrics, allowing us to analyze how production modalities mediate output stability.

We estimate the exogenous demand innovation, or demand shocks, through a fixed effects model:

$$\Delta y^r_{ij,t} = \eta_{j,t} + \gamma^r_{i,t} + \nu^r_{ij,t} \qquad i \neq j. \tag{12}$$

Here, $\Delta y^r_{ij,t}$ indicate the change in final sales from country i to country j in sector r, expressed in percentage terms. Meanwhile, $\eta_{j,t}$ are the country-time demand innovations we want to recover. The model also accounts for exporting country-sector-time effects ($\gamma^r_{i,t}$).[20]

We construct direct and indirect demand shocks using the shift-share approach and Input-Output data, focusing on differentiating between shocks associated exclusively with GVCs and those that are not. Specifically, we assume that *indirect demand shocks* are associated with GVCs (through its forward and two-sided participation components). By contrast, *direct demand shocks* are associated with all components of demand: domestic, traditional trade, and GVC-related. Formally, using the shift-share approach:

- The direct *foreign* demand shock can be constructed as:

$$DirectForeignDemandShock^r_{i,t} = \sum_{j}^{G} \phi^r_{ij,t-1}\eta_{j,t}. \tag{13}$$

where $\phi^r_{ij,t}$ is the share of foreign market j in the final sales of country s in sector r.[21] Instead, the (direct) *domestic* demand shock for country j is simply the demand innovation, i.e. $DomesticDemandShock^r_{j,t} = \eta_{j,t}$. In our baseline analysis, we differentiate between domestic and foreign direct demand shocks. Subsequently, we combine these shocks into an aggregate index to simplify graphical representations.

- The indirect demand shock ($IndirectDemandShock^r_{i,t}$) can be constructed by aggregating final demand innovations ($\eta_{j,t}$) with a set of weights that capture the importance of downstream markets—i.e. distinct from those of direct shipment— for exports of intermediate products.[22]

[20] Results throughout the paper are robust to the inclusion of different sets of fixed effects in the estimation of demand innovations. The estimation is carried out by excluding country i from the sample when computing the jt demand innovation that might affect it, to reduce concerns of endogeneity.

[21] $\phi^r_{ij,t}$ is equal to $y^r_{ij} / \sum^G_j y^r_{ij}$; note that $\phi^r_{ii,t} = 0$.

[22] Specifically, $IndirectDemShock^r_{i,t}$ is computed as $\sum^G_j \psi^r_{ij,t-1}\eta_{j,t}$, where ψ^r_{ij} measures the exposure country j final demand for sales of intermediates exported by country i in sector r. This is calculated as $\psi^r_{ij,t} = \left(\sum^G_k \sum^N_s b^{rs}_{ik} y^s_{kj} - l^{rs}_{ii} y^s_{ij}\right) / \left(\sum^G_j \sum^G_k \sum^N_s b^{rs}_{ik} y^s_{kj} - l^{rs}_{ii} y^s_{ij}\right)$, where b^{rs}_{ik} and $l^{rs}_{ii} y^s_{ij}$ are the elements of the global and local Leontief inverse matrix respectively (see the Online Technical Appendix).

- Despite the focus of this empirical application is on the demand side, we also control for supply-side shocks in the analysis. We compute those by using almost the same procedure described above.[23]

Finally, we construct the regression model for estimating the change in output:

$$\begin{aligned}\Delta x^r_{i,t} = \alpha &+ \beta_1 DomesticDemandShock^r_{i,t} + \beta_2 DirectForeignDemandShock^r_{i,t} + \\ &+ \beta_3 IndirectDemandShock^r_{i,t} + \\ &+ \beta_5 \mathbf{GVC} PureForw^r_{i,t-1} + \beta_6 \mathbf{GVC} TwoSided^r_{i,t-1} + \\ &+ \mathbf{GVC} PureForw^r_{i,t-1} \times IndirectDemandShock^r_{i,t} + \\ &+ \mathbf{GVC} TwoSided^r_{i,t-1} \times IndirectDemandShock^r_{i,t} + \\ &+ \text{supply controls} + \ldots + \delta_t + \gamma^r_i + \epsilon^r_{i,t}. \end{aligned} \tag{14}$$

This model integrates various shocks and GVC participation metrics to assess their collective impact on output stability. $\Delta x^r_{i,t}$ is the change in gross output for a given country-sector observation. Since the model focuses in particular on the demand side, we interact our proxy of indirect demand shocks with measures of forward and two-sided participation, facilitating an assessment of how serving as a provider of inputs can potentially expose the output to fluctuations in downstream demand. The model features additional controls including domestic demand shocks, upstream supply shocks, time, country and sector fixed effects.

Results

The main results from our analysis are illustrated in Table 2 and related figures (Figure 16, 17, and 18). The key insights are as follows:

- GVC Participation and Shock Exposure: We find that sectors with higher GVC participation, especially in forward and two-sided roles, exhibit increased vulnerability to downstream demand shocks.
- Trade-off in GVC Participation: GVC involvement enhances sensitivity to GVC-related shocks but decreases sensitivity to domestic and traditional trade shocks. The latter tend to be of greater entity for most countries in the world and particularly for developing ones.
- Market Diversification through GVCs: Our analysis suggests that sectors and countries with higher GVC participation tend to have a more diversified market portfolio, indicating reduced risk exposure.
- Regional vs. Global Value Chains: Engagement in regional value chains offers less diversification potential compared to global value chains, highlighting the importance of global integration for risk mitigation and the limits of regionalization as an alternative strategy to integration on a global scale.

[23] The key assumption employed to identify supply shocks is that variations in sales of intermediate inputs of a certain sector across all producers and country-sector of usage are related to some supply perturbation specific to that sector. Additional details on the derivation of supply-side shocks can be found in Appendix C.

Table 2: WIOD GVC-Output

	(1) Δ Out	(2) Δ Out	(3) Δ Out	(4) Δ Out	(5) Δ Out
Domestic Demand shock	0.338***	0.338***	0.281***	0.281***	
	(0.007)	(0.007)	(0.008)	(0.008)	
Foreign Direct Demand shock	0.055***	0.035**	0.031*	0.026	
	(0.018)	(0.017)	(0.017)	(0.018)	
Direct Demand shock					-0.006
					(0.068)
Indirect Demand shock	0.083*	0.120***	0.095**	0.146***	0.119***
	(0.044)	(0.043)	(0.044)	(0.047)	(0.041)
GVC Pure Forward$_{t-1}$	0.082***	0.074**	0.097***	0.433***	0.423***
	(0.029)	(0.035)	(0.033)	(0.091)	(0.090)
GVC Two-Sided$_{t-1}$	0.018*	0.033**	0.066***	0.132***	0.151***
	(0.011)	(0.015)	(0.016)	(0.040)	(0.039)
Indirect Demand shock × GVC Pure Forw$_{t-1}$	0.634**	0.641**	0.741***	0.694**	1.254***
	(0.275)	(0.277)	(0.277)	(0.295)	(0.292)
Indirect Demand shock × GVC Two-Sided$_{t-1}$	0.611**	0.641***	0.626***	0.486*	0.634**
	(0.239)	(0.238)	(0.236)	(0.257)	(0.282)
Direct Demand shock × Non-GVC Output$_{t-1}$					0.374***
					(0.077)
Supply controls	Yes	Yes	Yes	Yes	Yes
Country-sector FE	No	No		Yes	Yes
Country FE	No	No	Yes		
Sector FE	No	Yes	Yes		
Year FE	Yes	Yes	Yes	Yes	Yes
R2	0.457	0.466	0.488	0.525	0.524
N	30,966	30,966	30,966	30,964	30,964

Standard errors in parentheses. Results based on WIOD data.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A more detailed analysis of the results illustrate these and additional aspects about the relation between GVC participation and output stability. To start with, both domestic and foreign-originating shocks are associated with greater output volatility, as demonstrated by the positive sign of coefficients for the corresponding variables in Table 2.[24] The mediating role of different types of Global Value Chain (GVC) participation is observed through interaction terms. These show positive and significant coefficients, indicating that greater engagement in forward and two- sided GVC participation is correlated with greater output vulnerability to downstream (indirect) demand shocks. Additionally, two-sided participation is shown to matter as much as forward participation. These observations hold true across various tests, including using different GVC metrics (i.e. based both on output and trade), data sources, and sample periods (see Appendix's Table A2 and A3). The positive correlation of two-sided exposure and demand shocks is a novel result in the literature, which has thus far focused on the relationship between forward linkages and demand shocks.

However, despite GVC involvement enhances sensitivity to GVC-related shocks, it also has an important mitigating role. Consistent with the simulations results in Section 5.1 on the trade-off between exposure to domestic disruptions and GVC participation, the empirical analysis in column (5) of Table 2 confirms that GVC involvement decreases sensitivity to direct demand shocks, which include domestic and traditional trade shocks. The positive and statistically significant coefficient for the interaction term with the component of output *not related* to GVC participation is proof of this point.

Given the trade-off, the next natural question is whether it is possible to quantify the overall impact of the different shocks to which output is exposed. This depends on a combination of three factors, which are country-sector specific: the estimated regression coefficients reported in Table 2; the extent of GVC participation; and the type of GVC linkages. To offer an accessible summary of the collective impact of these different factors, we discuss the additional results with the help of visual representations. Figure 16 provides three illustrative examples of different countries' and sectors' overall output sensitivity to indirect (or GVC-related) and direct demand (i.e. domestic and traditional trade) shocks. The examples provided represent three distinct types of GVC participation: China's production of motor vehicles presents a high share of non-GVC output, as its production serves mainly the domestic market; the Brazilian mining sector on the other hand is strongly integrated through forward linkages; lastly, China's electronics presents one of the highest levels of two-sided participation.[25] These illustrative example highlight interesting features of how the combination of forces indicated above concurs to determine the overall impact.

- Despite the differences in the dominant mode of GVC participation, output volatility in all three country-sector examples is predominantly influenced by direct (non-GVC) demand shocks, as indicated by the size of the red bars in Figure 16, higher than the blue bars in all three cases.
- The exposure to direct (non-GVC) demand shocks appears smaller in countries and sectors that are more deeply involved in GVC-related activities, that is the red bars are

[24] These observations hold true across various specifications, including using different combinations of country, sector and time effects. Table A1 in the Appendix reports all the coefficients of the regressors included in the model.

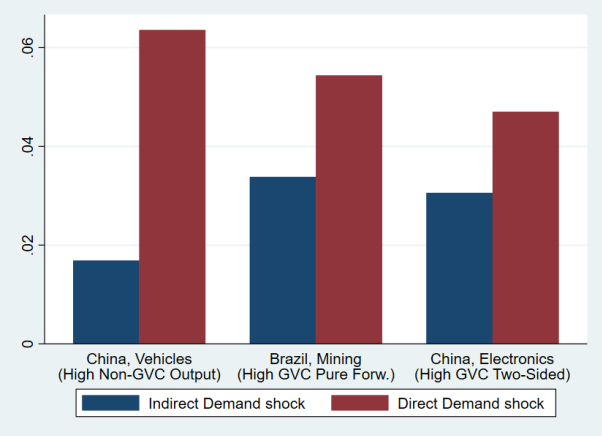
[25] The three sector-country combinations reported in Figure 16 have been selected because they represent the largest data points against two criteria: i) they belong to emerging or developing countries, and ii) they rank in the top decile of the distribution for the corresponding GVC indicator (i.e. non-GVC output, forward GVC output, two-way GVC output.)

smaller for country-sector pairs more involved in forward and two-sided GVC activities, such as Brazil mining and China electronics.

- Indirect demand shocks can similarly impact sectors engaged in pure-forward participation, exemplified by Brazilian mining, and those occupying a more intermediate position in the value chains, like China's electronics. This nuanced aspect is frequently overlooked by conventional classifications. By incorporating the two-sided component into the backward index (i.e., users of inputs), these latter link the resulting aggregate solely to upstream supply shocks.

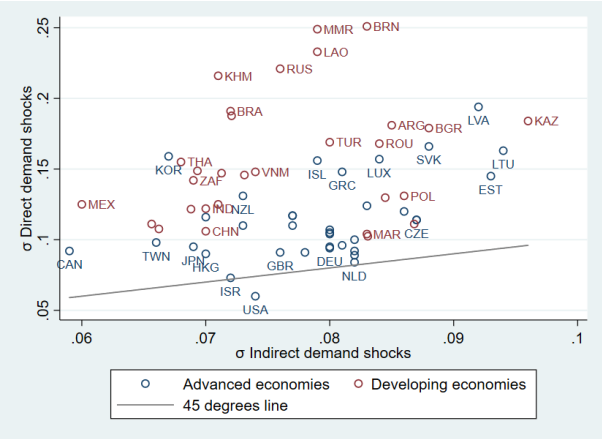
The trade-off between direct and indirect demand exposure is connected to the relationship between GVC-related shocks and market diversification. This is apparent by considering some of the factors that can influence this trade-off.

Figure 16: Impact of 1 SD of GVC and non-GVC demand shocks



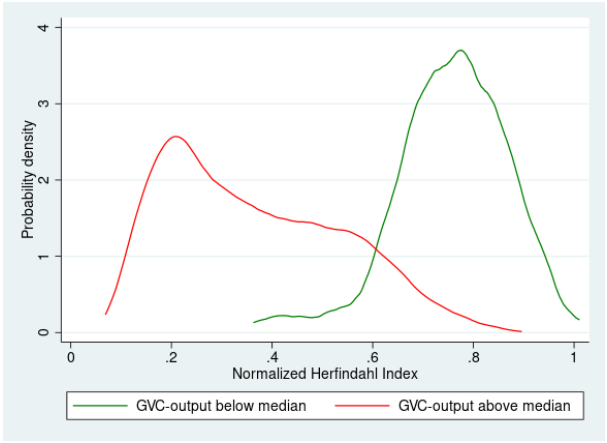
The factors influencing how GVC participation affects overall output variability are many. An important one, however, is the relative volatility of direct versus indirect shocks. The scatter-plot of Figure 17 shows that the standard deviation of indirect, or GVC-related, demand shocks is lower than that of direct demand shocks for all the countries in the sample but the United States. This pattern is especially pronounced in emerging and developing economies (the red dots in the picture), and is possibly associated with the fact that these countries tend to face higher domestic output volatility and lower market diversification. We conclude from this evidence that the trade-off in exposure between direct and indirect demand is likely to have important implications for the relationship between GVC-related shocks and market diversification.

Figure 17: Standard deviation of GVC and non-GVC shocks, by country



Additional statistics confirm the above hypothesis on the positive role of GVCs as a channel for diversifying exposure to foreign demand shocks. We find that sectors with higher GVC participation post a lower market concentration of final demand. Such finding is consistent with the possibility that they feature a more diversified portfolio and reduced risk exposure. This hypothesis is corroborated by Figure 18, which compares and contrasts the Herfindahl-Hirschman Index (HHI) distribution of sectors posting varying degrees of GVC participation. It shows that sectors with a GVC-output above the median have a substantially lower HHI distribution, and hence a more diversified portfolio.

Figure 18: HHI distribution of markets of final destination



Herfindahl-Hirschman Index (HHI) of final market concentration are computed based on the the weights of countries' on final absorption for each country-sector pair. In particular, the red line describes the HHI concentration for manufacturing in country-sector pairs with GVC participation above the median, and the green line represents the same indicator for country-sector pairs with GVC participation below the median.

A final statistical test we performed concerns the likely risk profile of regional value chains and of traditional forms of trade compared to the two extremes represented by GVCs (global engagement) and domestic production (fully local engagement). Our study suggests that participation in regional value chains and specialization traditional trade both offer an intermediate profile of risk exposure compared to the extremes. Again, the nexus with diversification is likely to drive the result. Regional value chains, linking countries with similar business cycles,

offer less diversification potential, while truly global value chains provide more opportunities for risk mitigation through market diversification. Similarly, specialization in traditional trade also offer less scope for diversifying demand shocks.

In summary, our findings emphasize the importance of GVCs as a tool of diversification and as mitigating factor of risks associated with domestic and external economic shocks. This is a particularly important insight for the nexus between trade and development, as it suggests that countries with high domestic output volatility can potentially stabilize their economies by integrating into more stable markets through GVCs.

5.3 GVC integration and Growth

The third and final application of the new GVC metrics consists in investigating the relationship between Global Value Chain (GVC) integration and economic growth, specifically GDP per capita growth. Our focus here is on the primary correlations with average growth (the first moment), complementing the analysis on the correlation with its variance (the second moment) which was presented previously, in Section 5.2.

The key question of the exercise is therefore if GVC participation is positively associated to (mean) economic growth, and if its explanatory power is statistically significant, even after controlling for traditional growth drivers and other, more standard, measures of trade openness and vertical integration.

Estimation Approach

To respond to this question, we propose a growth model based on Solow (1956), and employ a dynamic panel model setting, akin to standard growth models, to estimate both short-term and long-term effects of GVC integration, based on Caselli et al. (1996), Imbens (2002), and Bond et al. (2001). This setting also allows to address problems of omitted-variable bias and dynamic panel bias. The specification is as follows:

$$y_{it} = \rho y_{it-1} + x'_{it-1}\beta + \gamma_t + a_i + \varepsilon_{it} \tag{15}$$

where, y_{it} is the GDP per capita or output per worker; x'_{it-1} is a vector of the determinants of growth; γ_t and a_i are time and country fixed effects, respectively; and ε_{it} is the error term.

In our baseline specification we include, as standard determinants of economic growth, gross capital formation (savings) as a share of GDP, following the classic Solow model. In line with the methodological discussion in Section 3 and the results in Section 4, we introduce as measures of GVC participation the indicators for pure-backward, pure-forward, and two-sided GVC output as shares of total output. In both cases, we add controls for openness, using the share of output related to traditional trade. We acknowledge but do not address the endogeneity issue of GVCs in this specification, since our goal is to establish correlation, not causation. For this reason in all specifications the determinants of growth and GVC participation variables are treated as exogenous.

The dynamic (auto-regressive) specification allows to control for a highly persistent GDP per capita. Utilizing a standard five-year, non-overlapping period specification, as per Caselli et al. (1996), Bond and Windmeijer (2000), and Bond et al. (2001) helps in mitigating the

influence of business cycle fluctuations. We address issues of dynamic panel bias and persistence in the series by implementing the Blundell and Bond (1998) system-GMM technique.[26] Other important estimation choices include the following. First, we impose an assumption of exogeneity, whereby growth determinants are treated as exogenous and not instrumented with internal instruments within the framework of the system-GMM, due to initial condition problems and weak instruments issues (Kraay, 2015). Second, we adopt a two-step estimation process with small sample corrections, including Windmeijer (2005) finite-sample adjustment for the two-step covariance matrix, and we test the validity of the estimation extensively, using all the standard System-GMM tests, including AR1, AR2, and Hansen-J tests, confirming therby the reliability of our approach.

To reflect GVC participation by low income countries and to maximize the number of years covered, we use the EORA database for the period 1990-2015, matched with information from the World Bank World Development Indicators database.[27] Our final sample is made of 83 economies.

Estimation Results and Discussion

The main results are reported in Table 3, 4, and 5. The key insights are as follows:

- GVCs versus traditional trade as drivers of growth: We provide insights into the trade-growth nexus, which is extensively studied by the trade and growth economic literature (see Grossman and Helpman, 2015), by leveraging our output decomposition. This innovation allows us to separate GVC productions from productions linked to traditional trade. The analysis confirms that openness is associated with economic growth and suggests that GVC participation might be more relevant for growth than engaging in traditional trade. Output related to both traditional trade and GVCs –i.e., a broad proxy for openness– is positively correlated with growth (Table 3, column 1), and this correlation seems to be driven by GVCs rather than traditional trade (Table 3, columns 2 to 4).

- Growth and the mode of GVC participation: All modes of GVC participation seem to be positively correlated with growth (Table 4, columns 1 to 3), with the highest coefficient found for Two-sided GVC participation. When included concurrently in the regression analysis, each mode maintains a positive coefficient with statistical significance, apart from Pure Forward Participation (column 4).[28] Very similar results are obtained by replacing output-related GVC measures with their trade-related counterparts.[29]

[26] Introducing the dynamic component induces severe endogeneity in equation (15), known as dynamic panel bias in the literature since the lagged variable violates strict exogeneity and correlates with the idiosyncratic error. The methodology by Blundell and Bond (1998) is preferred to the alternative Arellano and Bond (1991) GMM estimates, as the latter provide weak instruments for high levels of persistence and relatively short time series, as in the case of our data. Hauk and Wacziarg (2009) shows that Arellano Bond GMM estimates of the Solow growth model are subject to the weak instruments problem.

[27] We winsorize the tails of the GDP income growth distribution at 1% and 99% to reduce the effect of possible spurious outliers while avoiding the loss of information. We drop from the sample countries with negative value-added, and exclude from the sample commodity exporters.

[28] Standard tests of Sys-GMM estimations are successfully passed and their results are reported in the last three rows of the table.

[29] See Table A4. With GVC-trade, the standard errors are larger when all the indicators are plugged into the same regressions (see Column 5 of Table A4).

- Growth and information content of different GVC integration indicators: Our analysis reveals that our bespoke indicators of GVC participation offer additional and distinct insights from more standard GVC participation metrics. As detailed in Table 5, we incorporate two standard proxies of GVC integration in the regression, namely the share of intermediates trade over total trade and vertical specialization (columns 1 and 2, respectively). Both metrics exhibit a positive correlation with growth, though the precision of the estimation for the former is comparatively lower. Subsequentl, we integrate our unique GVC participation measure (displayed in columns 3 and 4). Here, the GVC-output coefficient remains positive and statistically significant, with minimal variation in its size compared to the baseline estimate reported in Table 3, column 4. By contrast, the statistical significance of standard proxies drops to zero.

In summary, this third exercise reveals that participation in Global Value Chains (GVCs) is more crucial for economic growth than traditional trade. While both contribute positively to growth, the impact of GVCs is more significant. Different modes of GVC participation are beneficial. The new GVC participation indicators offer deeper insights compared to standard metrics, and these bespoke indicators maintain a strong, positive correlation with growth even after controlling for broader forms of international integration.

Table 3: Economic Growth and GVC vs Traditionsl trade: Sys-GMM results

	(1) GDP per cap	(2) GDP per cap	(3) GDP per cap	(4) GDP per cap
GDP per cap$_{t-5}$	0.921*** (0.020)	0.922*** (0.020)	0.921*** (0.020)	0.915*** (0.023)
GVC&Trad.Trade Output$_{t-5}$	0.086*** (0.030)			
Traditional-Trade Output$_{t-5}$		0.060 (0.037)		-0.098 (0.067)
GVC$_{t-5}$			0.070*** (0.018)	0.115*** (0.039)
Gross Saving rate$_{t-5}$	0.002 (0.001)	0.003** (0.001)	0.002 (0.001)	0.002 (0.001)
Observations	321	321	321	321
No. of instruments	18	18	18	19
AR1 (p-value)	0.000	0.000	0.000	0.000
AR2 (p-value)	0.232	0.153	0.244	0.178
Hansen-J (p-value)	0.486	0.474	0.516	0.669

Standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.010

Table 4: Economic Growth and GVC-related Output: Sys-GMM results results

	(1) GDP per cap	(2) GDP per cap	(3) GDP per cap	(4) GDP per cap
GDP per cap$_{t-5}$	0.916***	0.905***	0.914***	0.912***
	(0.021)	(0.028)	(0.022)	(0.023)
GVC Pure Backw$_{t-5}$	0.081**			0.052**
	(0.032)			(0.025)
GVC Pure Forw$_{t-5}$		0.052*		0.020
		(0.026)		(0.019)
GVC Two-Sided$_{t-5}$			0.097**	0.044*
			(0.038)	(0.026)
Traditional-Trade Output$_{t-5}$	-0.010	-0.028	-0.093	-0.086
	(0.054)	(0.058)	(0.076)	(0.066)
Gross Saving rate$_{t-5}$	0.002*	0.002*	0.002*	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	321	321	321	321
No. of instruments	19	19	19	21
AR1 (p-value)	0.000	0.000	0.000	0.000
AR2 (p-value)	0.194	0.123	0.180	0.178
Hansen-J (p-value)	0.547	0.654	0.639	0.647

Standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.010

Table 5: Economic Growth and GVC proxies: Sys-GMM results

	(1) GDP per cap	(2) GDP per cap	(3) GDP per cap	(4) GDP per cap
GDP per cap$_{t-5}$	0.929***	0.916***	0.920***	0.916***
	(0.017)	(0.021)	(0.016)	(0.022)
Trade in Interm$_{t-5}$	0.053		-0.003	
	(0.034)		(0.046)	
Vertical Specialization$_{t-5}$		0.099***		0.043
		(0.036)		(0.029)
GVC$_{t-5}$			0.101***	0.086**
			(0.029)	(0.037)
Gross Saving rate$_{t-5}$	0.002	0.003*	0.001	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Traditional-Trade Output$_{t-5}$	0.043	0.011	-0.084	-0.079
	(0.047)	(0.047)	(0.066)	(0.066)
Observations	259	321	259	321
No. of instruments	19	19	20	20
AR1 (p-value)	0.003	0.000	0.004	0.000
AR2 (p-value)	0.392	0.210	0.634	0.197
Hansen-J (p-value)	0.222	0.350	0.107	0.532

Standard errors in parentheses

* pj0.10, ** pj0.05, *** pj0.010

6 Conclusion

The emergence of Global Value Chains (GVCs) has reshaped international trade, offering opportunities and challenges for economic growth and policy-making. We focus on developing precise measures of GVC participation, integrating a tripartite decomposition approach and extending its application beyond trade to include production data. Other studies have quantified specific aspects of GVC participation, but with limitations in terms of scope and accuracy. Our methodology builds upon and refines existing frameworks, offering a more comprehensive, intuitive, theory-consistent, and statistically accurate assessment of GVC participation, which we also show to matter for improving our understanding of the trade-growth nexus.

Specifically, we present an accounting framework for a tripartite decomposition of GVC-related trade, which we also apply to output. The framework categorizes participation into pure forward, pure backward, and two-sided modes, and it allows to compare and contrast domestic production and international engagement in trade and output, further distinguishing the latter by modality of engagement. The proposed methodology makes it easier to establish the complexities, nuances and trade-offs of GVC dynamics, and how these contribute to shaping global and local economic outcomes.

We find that two-sided participation plays a significant and distinct role, that previous work failed to capture. For example, we find that it constitutes a transmission channel for demand shocks to intermediates. Additionally, our approach demonstrates that relying solely on trade data leads to both underestimation and overestimation problems. It underestimates the extent of GVCs by half, and especially in industries like services and upstream manufacturing; and it overestimates the exposure to foreign shocks for countries whose exports are highly concentrated, but represent a small share of the domestic economy. This latter characterization is often found in early phases of trade-led growth, in particular for large developing countries.

Finally we show that our findings have significant implications for understanding the economic consequences of trade and GVC integration. We show three examples of why they matter for the trade-development nexus. We show that the new metrics are effective predictors of the impact of trade disruption. We show that while they increase exposure to imported shocks, they at the same time offer overall greater output stability. They do so by shielding output from more local shocks, against which almost all countries in the world are more exposed. Finally, they appear to drive the positive correlation of trade with income growth.

In conclusion, the contributions of the paper underscore the importance of comprehensive and clear GVC measurement for informed policy decisions and economic development strategies. By proposing a unified framework, we provide a coherent and accessible methodology for evaluating and cross-benchmarking GVC engagement at both country and sector levels. The indicators we introduce, now available on the World Bank's WITS Platform offer a robust and extensive toolbox of GVC descriptive statistics, redily available for policy analysis. These measures provide an accurate and nuanced understanding of GVC participation, which is essential for navigating the complexities of modern global trade.

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A GVC Database on the World Integrated Trade Solutions

The broad set of measures discussed in the paper is available on the World Integrated Trade Solutions (WITS) platform: the dataset is available here and the data visualizations here.

Data sources

Inter-Country Input-Output data has been provisioned from multiple data sources and are constantly updated. These are the sources featured in the December 2022 version of the WITS GVC Database.

- EORA26 (1990-2015) 199.82 version (**eora**). Lenzen, M., Moran, D., Kanemoto, K., Geschke, A. 2013. 'Building Eora: A Global Multi-regional Input-Output Database at High Country and Sector Resolution.' *Economic Systems Research*, 25:1, 20-49. Please remember that the Eora MRIO is free for academic (university or grant-funded) work at degree-granting institutions. All other uses require a data license before the results are shared.
- WIOD 2016 version (2000-2014) (**wiodn**) and WIOD 2013 version (1995-2011) (**wiodo**). Timmer, M. P., E. Dietzenbacher, B. Los, R. Stehrer and G.J. de Vries, 2015. 'An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production.' *Review of International Economics*. 23: 575-605.
- WIOD Long-Run 1.1 version (1965-2000). Woltjer, P., Gouma, R. and Timmer, M. P. (2021), 'Long-run World Input-Output Database: Version 1.1 Sources and Methods', GGDC Research Memorandum 190.
- OECD TiVA 2022 version (2005-2020) (**tiva**). OECD, Trade in Value Added database, 2018, oe.cd/tiva
- ADB MRIO 2022 version (2000;2007-2021) (**adb**). Asian Development Bank MRIOT Database, mrio.adbx.online

The **GVC Trade dataset** contains measures related to international trade. The unit of observation is the exporting country-importing country-exporting sector-year. The **GVC Output dataset** contains measures related to gross output. The unit of observation is country-producing sector-year. All data are in millions of US dollars.

Variables description

GVC Trade dataset

GVC-related trade measures the value of goods and services exported by a sector or a country that crosses more than one border. The difference between gross trade and GVC-related trade is defined as **Traditional trade**, i.e. the value of goods and services that crosses just one border. The **Traditional trade** can also be divided into **Traditional trade in intermediate**

goods and **Traditional trade in final goods**. **GVC-related trade** presents two desirable features:

- once expressed as a share of gross trade, it is bounded between 0 and 1;
- it is additive at any level of aggregation/disaggregation of trade flows; thus, data can be summed at any level – total country exports/world exports/world sector exports/country groups and so on – in order to obtain the proper GVC participation measures at the desired level of aggregation

GVC-related trade is always traced in the exporting sector. The overall **GVC-related trade** encompasses three different types of GVC linkages.

- **Pure forward GVC related-trade**: value-added in goods and services entirely generated within the domestic chains – without any border crossing – exported by the sector and re-exported further by the partner. The exporting sector is engaged in GVC activities at the origin of the chain.
- **Two-sided GVC related-trade**: imported inputs bought by the exporting sector directly from abroad or indirectly through domestic chains, exported by the sector and further re-exported by the partner. The exporting sector is located in a central position of the chain.
- **Pure backward GVC related-trade**: imported inputs bought by the sector directly from abroad or indirectly through domestic chains, exported by the sector to the final market, as intermediates or final goods. The exporting sector is engaged in GVC activities close to the end of the chain.

A natural measure of the **Type of participation in GVC-related trade (forwardness)** at any level of aggregation can be straightforwardly obtained as the difference between pure forward and pure backward participation, divided by the overall GVC related-trade. This measure is bounded between -1 and 1 and it is equal to zero at the global level.

GVC Output dataset

GVC-related output is the output of a country or sector that directly or indirectly crosses more than one border. It provides a more general assessment of the amount of productions of each sector that is related to GVCs, since it takes into account the entire supply chain the sector participates to, regardless of its direct involvement in export activities.

The **GVC-related output** shares the same properties of GVC related-trade:

- once expressed as the share of output, it is bounded between 0 and 1;
- it is additive at any level of aggregation/disaggregation.

Within the total output of a country or sector, the amount that never crosses a single border, neither directly or indirectly, is labeled **Purely domestic output**. Instead, the output that directly or indirectly crosses just one border is labeled **Output related to traditional trade**, i.e. value-added produced by the sector and sold abroad to the final market, directly by the producing sector or indirectly trough domestic chains. The overall **GVC-related output** encompasses three different types of GVC linkages.

- **Pure forward GVC related-output**: value-added produced by the sector and sold directly abroad by the sector or indirectly trough domestic chains; then, re-exported by the partner country. In other terms, the GVC-output is traced in the sector where the value-added originates, the very first link of a chain. **Pure forward GVC related-output** might also be labeled as **GVC related-value-added**.

- **Two-sided GVC related-output**: domestic inputs bought by the sector within domestic chains and sold directly abroad by the sector or indirectly trough domestic chains, and re-exported by the partner; imported inputs bought directly from abroad by the sector or indirectly trough domestic chains, and sold directly abroad as inputs or indirectly trough domestic chains. In other terms, the GVC-output here is traced in the sector that simultaneously buys and sells intermediate inputs, in a central position of the chain.

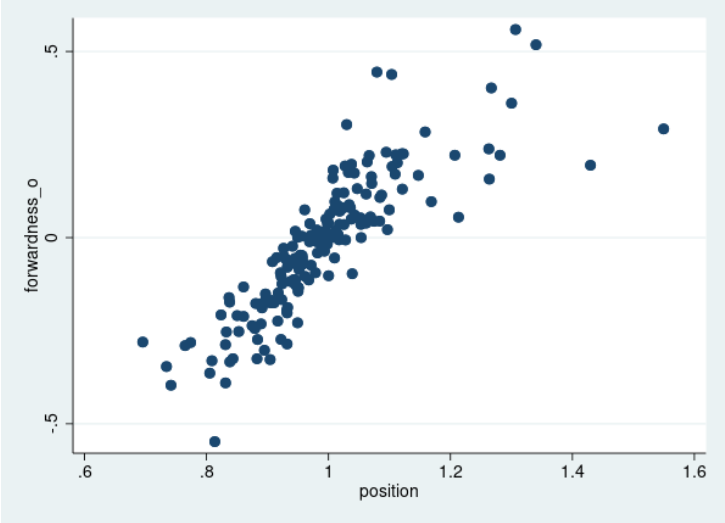
- **Pure backward GVC related-output**: imported inputs bought by the sector directly from abroad or indirectly through domestic chains, and embedded in final goods and services production sold to domestic consumers – if inputs crossed more than 1 border before – or to foreign consumers – if inputs crossed only 1 border. In other terms, GVC-output is traced in the sector that completes the final goods or services, the very last link of a chain. **Pure backward GVC related-output** might also be labeled as **GVC related-final goods and services**.

A natural measure of the **Type of participation in GVC-related output (forwardness)** at any level of aggregation can be straightforwardly obtained as the difference between pure forward and pure backward participation, divided by the overall **GVC related-output**. This measure is bounded between -1 and 1 and it is equal to zero at the global level.

Readers interested in computing their own measures of global value chain trade by origin and destination using also user-provided input output tables are referred to the `icio` module in Stata by Belotti et al. (2021).

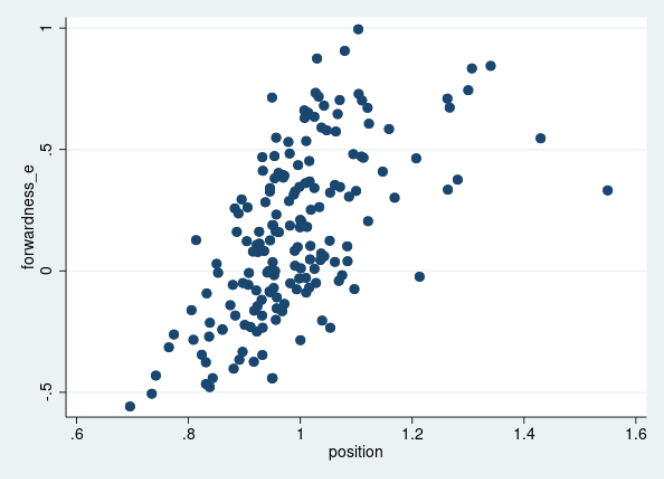
B Additional Evidence

Figure A1: Forwardness in output versus position



Source: own elaboration based on EORA. Position is computed as the ratio of upstreamness and downstreamness.

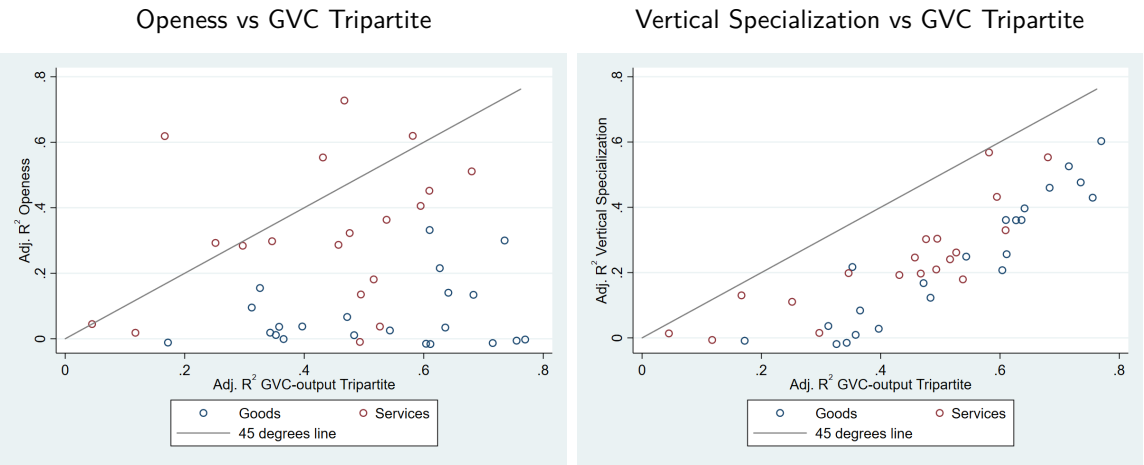
Figure A2: Forwardness in exports versus position



Position is computed as the ratio of upstreamness and downstreamness.

Source: own elaboration based on EORA. Position is computed as the ratio of upstreamness and downstreamness.

Figure A3: Predictive power of GVC participation, sector-level regressions



Source: Own elaboration based on OECD TiVA. The scatter plots report the adjusted R^2 of sector-level regressions $\Delta GDP_g = \alpha + \beta X_g + \varepsilon_g$, where g are the countries.

Table A1: WIOD GVC-Output

	(1) Δ Out	(2) Δ Out	(3) Δ Out	(4) Δ Out	(5) Δ Out
Domestic Demand shock	0.338***	0.338***	0.281***	0.281***	
	(0.007)	(0.007)	(0.008)	(0.008)	
Foreign Direct Demand shock	0.055***	0.035**	0.031*	0.026	
	(0.018)	(0.017)	(0.017)	(0.018)	
Direct Demand shock					-0.006
					(0.068)
Indirect Demand shock	0.083*	0.120***	0.095**	0.146***	0.119***
	(0.044)	(0.043)	(0.044)	(0.047)	(0.041)
Indirect Supply shock	0.258***	0.210***	0.232***	0.212***	0.190***
	(0.049)	(0.048)	(0.048)	(0.048)	(0.046)
Sectoral Supply shock	0.108***	0.097***	0.095***	0.093***	0.089***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
GVC Pure Forward$_{t-1}$	0.082***	0.074**	0.097***	0.433***	0.423***
	(0.029)	(0.035)	(0.033)	(0.091)	(0.090)
GVC Two-Sided$_{t-1}$	0.018*	0.033**	0.066***	0.132***	0.151***
	(0.011)	(0.015)	(0.016)	(0.040)	(0.039)
GVC Pure Back$_{t-1}$	-0.034*	0.024	0.050**	0.094	0.096
	(0.019)	(0.027)	(0.026)	(0.069)	(0.069)
Indirect Demand shock × GVC Pure Forw$_{t-1}$	0.634**	0.641**	0.741***	0.694**	1.254***
	(0.275)	(0.277)	(0.277)	(0.295)	(0.292)
Indirect Demand shock × GVC Two-Sided$_{t-1}$	0.611**	0.641***	0.626***	0.486*	0.634**
	(0.239)	(0.238)	(0.236)	(0.257)	(0.282)
Indirect Supply shock ×GVC Two-Sided$_{t-1}$	0.274*	0.269	0.280*	0.439**	0.690***
	(0.165)	(0.166)	(0.168)	(0.185)	(0.193)
Indirect Supply shock × GVC Pure Back$_{t-1}$	0.317***	0.328***	0.349***	0.387***	0.854***
	(0.107)	(0.108)	(0.109)	(0.107)	(0.122)
Direct Demand shock × Non-GVC Output$_{t-1}$					0.374***
					(0.077)
Country-sector FE	No	No		Yes	Yes
Country FE	No	No	Yes		
Sector FE	No	Yes	Yes		
Year FE	Yes	Yes	Yes	Yes	Yes
R2	0.457	0.466	0.488	0.525	0.524
N	30,966	30,966	30,966	30,964	30,964

Standard errors in parentheses. Results based on WIOD data.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2: WIOD GVC-Trade

	(1) Δ Out	(2) Δ Out	(3) Δ Out	(4) Δ Out
Foreign Direct Demand shock	0.052***	0.034*	0.029*	0.024
	(0.018)	(0.018)	(0.017)	(0.018)
Indirect Demand shock	0.071	0.110**	0.075*	0.123***
	(0.046)	(0.044)	(0.045)	(0.048)
Indirect Supply shock	0.220***	0.170***	0.195***	0.162***
	(0.050)	(0.049)	(0.050)	(0.049)
Domestic Demand shock	0.336***	0.334***	0.278***	0.276***
	(0.007)	(0.007)	(0.008)	(0.008)
Sectoral supply shock	0.106***	0.095***	0.093***	0.093***
	(0.007)	(0.007)	(0.007)	(0.007)
GVC Pure Forward$_{t-1}$	0.000	-0.026*	-0.018	-0.108***
	(0.013)	(0.015)	(0.014)	(0.030)
GVC Two-Sided$_{t-1}$	0.118***	0.138***	0.137***	0.486***
	(0.031)	(0.042)	(0.042)	(0.094)
GVC Pure Back$_{t-1}$	-0.027*	-0.006	0.030	-0.030
	(0.015)	(0.020)	(0.020)	(0.051)
Ind. Demand s. × GVC Pure Forw$_{t-1}$	0.178*	0.180*	0.219**	0.201**
	(0.103)	(0.101)	(0.102)	(0.102)
Ind. Demand s. × GVC Two-Sided$_{t-1}$	1.457***	1.489***	1.562***	1.135**
	(0.473)	(0.467)	(0.462)	(0.488)
Ind. Supply s. × GVC Two-Sided$_{t-1}$	0.551	0.589	0.512	1.075***
	(0.372)	(0.367)	(0.365)	(0.394)
Ind. Supply s. × GVC Pure Back$_{t-1}$	0.265***	0.254***	0.258***	0.272***
	(0.089)	(0.088)	(0.089)	(0.088)
Country-sector FE	No	No		Yes
Country FE	No	No	Yes	
Sector FE	No	Yes	Yes	
Year FE	Yes	Yes	Yes	Yes
R2	0.457	0.466	0.487	0.524
N	30,966	30,966	30,966	30,964

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Other datasets

	(1) Wiod P const	(2) Wiod P const	(3) Wiod Long Run	(4) Wiod Long Run
Foreign Direct Demand shock	0.059***	0.029*	0.025***	0.021**
	(0.018)	(0.018)	(0.009)	(0.009)
Indirect Demand shock	0.074*	-0.040	0.058***	0.035**
	(0.043)	(0.046)	(0.013)	(0.014)
Indirect Supply shock	0.167***	0.051	-0.009	-0.020
	(0.049)	(0.047)	(0.018)	(0.019)
Domestic Demand shock	0.084***	0.084***	0.180***	0.180***
	(0.007)	(0.007)	(0.009)	(0.009)
Sectoral supply shock	0.064***	0.065***	0.006**	0.009***
	(0.007)	(0.007)	(0.003)	(0.003)
GVC Pure Forward$_{t-1}$		0.485***		0.680***
		(0.085)		(0.207)
GVC Two-Sided$_{t-1}$		0.007		0.051
		(0.038)		(0.061)
GVC Pure Back$_{t-1}$		-0.011		0.290***
		(0.065)		(0.072)
Ind. Demand s. $\times$ GVC Pure Forw$_{t-1}$		0.397		0.810**
		(0.525)		(0.399)
Ind. Demand s. $\times$ GVC Two-Sided$_{t-1}$		0.739**		0.175**
		(0.299)		(0.080)
Ind. Supply s. $\times$ GVC Two-Sided$_{t-1}$		0.351*		0.187*
		(0.203)		(0.099)
Ind. Supply s. $\times$ GVC Pure Back$_{t-1}$		1.442***		0.325**
		(0.201)		(0.129)
Country-sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R2	0.235	0.251	0.429	0.433
N	31,181	30,964	19,736	19,640

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A4: Economic Growth and GVC-related Exports: Sys-GMM baseline results

	(1) GDP per cap	(2) GDP per cap	(3) GDP per cap	(4) GDP per cap	(5) GDP per cap
GDP per cap$_{t-5}$	0.923***	0.916***	0.920***	0.918***	0.918***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
GVC-Exp$_{t-5}$	0.178***				
	(0.050)				
GVC-Exp Pure Backw$_{t-5}$		0.090**			0.113
		(0.035)			(0.097)
GVC-Exp Pure Forw$_{t-5}$			0.062		0.103
			(0.041)		(0.084)
GVC-Exp Two-Sided$_{t-5}$				0.074***	0.007
				(0.023)	(0.064)
Traditional-Trade Output$_{t-5}$	0.045	0.009	0.080*	0.044	0.031
	(0.031)	(0.049)	(0.043)	(0.037)	(0.035)
Gross Saving rate$_{t-5}$	0.001	0.003**	0.003*	0.002	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	321	321	321	321	321
No. of instruments	19	19	19	19	21
AR1 (p-value)	0.000	0.000	0.000	0.000	0.000
AR2 (p-value)	0.293	0.183	0.171	0.290	0.273
Hansen-J (p-value)	0.536	0.316	0.479	0.453	0.300

Standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.010

C Supply side shocks

In order to construct indirect supply side shocks, we first isolate innovations that are common to a given sector of production worldwide, assuming that —once controlled for idiosyncratic factors— these variations are essentially supply-driven. Supply side innovations are singled out by estimating the θ_t^s parameters in the following fixed-effects model:

$$\Delta va_{ij,t}^{sr} = \theta_t^s + \gamma_{j,t}^r + \epsilon_{ij,t}^r \qquad s \neq r. \tag{C.1}$$

where $va_{ij,t}^{sr} = v_{i,t}^s z_{ij,t}^{sr}$ is the value-added content of the inputs sold by country-sector (i,s) to the country-sector (j,r). Only sales to other sectors are considered (i.e. $s \neq r$), in order to reduce endogeneity concerns .

Then, as for the demand side, we construct a proxy for country-sector specific input supply shocks ($inputSupplyShock_{i,t}^r$) by using a shift-share approach. Shocks originated in the upstream phases of the production are computed as:

$$inputSupplyShock_{i,t}^r = \sum_s^N \omega_{i,t-1}^{sr} \theta_t^s. \tag{C.2}$$

where $\omega_{i,t-1}^{sr}$ is the weight of the sector of origin s in the inputs used for the production of industry r in country i. It can be computed as:

$$\omega_{i,t}^{sr} = \frac{\sum_{j \neq i}^G w_{ji,t}^{sr}}{\sum_j^G \sum_s^N w_{ji,t}^{sr}}. \tag{C.3}$$

where $w_{ji,t-1}^{sr}$ s the weight of the sector of origin s in the inputs used for the production of industry r in country i that can be derived from I-O tables $GN \times GN$ matrix $\widehat{\mathbf{V}}\mathbf{B}\widehat{\mathbf{X}}$ (see Appendix 1 above and Baldwin et al., 2022).