Global trade in services, jobs, and incomes

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DOI:
10.33612/diss.104863895

Publication date:
2019

Chapter 2

Indicators on global value chains: A guide for empirical work

ABSTRACT

Traditionally, the main source of data used to measure countries' participation in international production networks or global value chains (GVCs) has been conventional international trade statistics. However, international fragmentation of production has weakened the analytic interpretability of these data as intermediate goods but also services cross borders many times on the way to their final destination. This is often referred to as the double (or multiple)-counting problem of international trade statistics.

This, in turn, has led to the development of a new branch of trade statistics, referred to as Trade in Value-Added (TiVA) providing new insights on GVCs, and corresponding databases, notably the OECD-WTO TiVA database, which provide a measure of international interdependencies through the construction of global input-output tables that show how producers in one country provide goods and/or services to producers and consumers in others. But with the field still relatively new, many users are struggling to fully understand how these new indicators should be used and indeed how they have been constructed.

This document is designed to address those difficulties, providing, where appropriate guidance on "dos" and "don'ts". It also reviews many other typical GVC indicators derived outside of input-output frameworks; recognising that gross measures of trade, and indicators derived from them, remain important and relevant for policy making.

This chapter is based on Ahmad et al. (2017). I added endnotes at the end of this chapter to correct typos in the OECD Working Paper version (reproduced here) and to provide additional clarification or context.

2.1 Introduction

The increasing fragmentation of production processes into activities scattered across different countries has challenged economists and statisticians to find ways to measure the extent of these developments and their potential implications. This phenomenon is intrinsically related to a surge in international trade in intermediate products, which dominate world trade flows, characterised in large part, and indeed further complicated, by the increasing role played by multinational enterprises (MNEs) (whether through intra-affiliate transactions or indeed through the control of supply chains). Increasingly, countries and firms specialise in particular stages of production according to their comparative and competitive advantages, and are linked in vertical supply chains through trade in intermediate products. This trend has been facilitated by technological progress, which has reduced transportation and communication costs, together with significant declines in trade barriers.

Traditionally, the main source of data used to measure countries' participation in international production networks or global value chains (GVCs) has been conventional international trade statistics, which, in the case of goods, offer the advantage of timely availability for a large number of countries, with a high level of disaggregation (in terms of products and trading partners), and with a high degree of international comparability.

As shown below, these data can be used to generate a suite of indicators that reveal the diversity of a country's direct export and import partners, as well as the products in which it trades. However, international fragmentation of production has weakened the analytic interpretability of these data and, in particular, analyses that attempt to show the benefits of trade to an economy (be that in terms of value added or jobs), as well as the true nature of interconnectedness across economies. This is often referred to as the double (or multiple)-counting problem of international trade statistics.

Perhaps the classic example of the impact of the phenomenon concerns processing trade, where firms, typically at the end of value chains, import parts for final assembly. Conventional gross trade data would indicate that the country has a comparative advantage in the production of the final good, despite the fact that it may have added relatively little value to the actual good through low-skilled part tasks. Thus, the comparative advantage should more accurately be described in this case as low-skilled assembly labour, rather than high-tech goods production.

Some countries maintain a special set of customs statistics related to processing trade[1] that can provide insights (and account for) any related 'double-counting'. However, for most countries these data are not available. Moreover, often processing trade statistics only reflect the tip of the iceberg, as they only consider trade associated with a special type of sub-contracting or outsourcing arrangement, and do not cover all other activities (the majority) related to the geographic fragmentation of production.[2] Indeed very little of the goods exported today, with the possible exception of mineral and agricultural products (and even here imported know-how services play a role), are produced exclusively within any one country.

To tackle head-on the double-counting problem that affects conventional trade data, whilst also better revealing the true nature of international and interindustry interdependencies, statisticians have recently begun to develop indicators using global supply and use tables (SUTs) and input-output tables (IOTs), which link national SUTs or IOTs and bilateral trade data (e.g., OECD-WTO, 2013[3]). Perhaps the best known initiative in this area is the Trade in Value Added (TiVA) database, which reflects a concerted effort by the Organisation for Economic Co-operation and Development (OECD) and the World Trade Organisation (WTO) to mainstream the development of (and improvements to) the necessary data within official national statistical information systems.[4] Indeed, at the 2015 United Nations Statistics Commission meeting the official statistics community endorsed the recommendations of the Friends of the Chair Group on International Trade and Economic Globalisation, including, in particular, the following:

> *Mainstreaming the development of recurrent global supply and use tables and input-output tables and building on work undertaken by OECD, in order to expand the coverage of the OECD-WTO database on trade in value added.*

Rising to this challenge the international statistics community has stepped-up co-operation, with the OECD in particular coordinating the development of a network of international agencies (and countries), each playing their role as developers of regional IOTs (for the regions where they have expertise and formal networks of national statisticians) that can be brought

[1] This refers to the trade of export processing zones (EPZs), which offer firms special customs arrangements (like tariff exemptions or reductions) on condition that imported intermediates are re-exported after assembly activities are completed. Examples of these data sets are the US Offshore Assembly Programme (OAP) and the European Union Processing Trade statistics, used in several empirical studies on international fragmentation of production (e.g., Feenstra et al., 2000; Swenson, 2005; Egger and Egger, 2005; Baldone et al., 2007).

[2] Processing trade statistics capture the cases where intermediate products are imported to be processed internally and then re-exported, as well as those where intermediates are exported to be processed abroad and then re-imported.

[3] www.oecd.org/sti/ind/49894138.pdf.

[4] Annex A provides an overview of other initiatives in this area.

together and integrated within a global IOT. The United Nations' Economic Commission for Latin America and the Caribbean (UN-ECLAC) is actively working with the OECD to explore the feasibility of mainstreaming the activity within the Latin American region, which partly reflects the catalyst for this paper.

In that sense, this document is designed to accelerate that process and maximise its feasibility by describing, in a comprehensive and integrated manner, a set of core indicators that are typically used to trace and analyse production fragmentation across countries; highlighting in addition their limitations (in particular, with regards to the changes introduced in the latest version of international accounting standards, the 2008 System of National Accounts). In this sense it is important to note that the document does not set out to be exhaustive in its coverage. Many other indicators exist, including many that have recently been developed as a result of new innovations in TiVA type analysis. But these are not typically in widespread use and, with respect to the newer indicators, they remain, to some extent, works-in-progress.

The note is also motivated by growing calls from users for a better understanding of the 'dos and don'ts' of the suite of indicators generated by these new statistical tools, which can be fostered by describing their structure, applications and limitations.

The following section sets the scene by describing indicators based on traditional international trade data. Section 2.3 introduces the input-output framework, used to create trade in value added estimates. Finally, Section 2.4 concludes.

2.2 Indicators based on international trade statistics

2.2.1 Trade data

Merchandise trade data are arguably one of the richest sources of data available in the economic statistics information system. They provide product-level information (with the Harmonised System (HS) coding covering around 5 000 goods), with almost complete country coverage and the identification of partner relationships. As such, despite some comparability issues relating to the trade regime used in the country (special versus general trade), recorded country of import and recorded country of export, asymmetries,[5] and treatment of confidential data, merchandise trade data provide one of the most important sources of information to derive GVC indictors.

[5] Although the OECD has developed a balanced merchandise trade dataset, see www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=STD/CSSP/WPTGS%282016)18 &docLanguage=En.

Trade in services data, collected according to the Extended Balance of Payments System (EBOPS), are also an important source of information. However, the quality of these data is significantly inferior to that on merchandise trade. For example, the level of product detail available rarely extends beyond dozens for most countries, and very few countries provide bilateral data.[6]

In addition, many countries have recently begun to develop new datasets that link the firms identified in customs records with the same firm recorded in statistical business registers (Trade by Enterprise Characteristics (TEC) database), to develop new insights on firms engaged in international trade.[7]

Because of the comparability issues regarding trade in services and the relative novelty and limited country coverage of TEC data, the more abundant and detailed merchandise trade data have typically formed the key focus of most traditional and conventional indicators on GVCs. In large part, this reflects the ability of merchandise trade data to differentiate between products on the basis of their likely end-use (for example, whether the goods are intermediate, consumption or capital in nature).

GVCs are seen as synonymous with international fragmentation of production. The ability to identify trade in intermediate products, as distinct from trade in final goods, can provide important insights into how countries integrate into GVCs, and indeed where they position themselves in those chains.

Notwithstanding the data on intermediate goods available in national SUTs and IOTs[8] (described in more detail below), the most commonly used definition of intermediate goods in merchandise trade is based on the United Nations' Broad Economic Categories (BEC) classification,[9] which provides a simple tool to link trade data to the three basic System of National Accounts' (SNA) classes: intermediate goods, capital goods and consumption goods.[10]

[6] The OECD and WTO have developed a balanced view of trade in services with missing estimates generated using a gravity model, https://one.oecd.org/document/STD/CSSP/WPTGS%282017)4/en/pdf.

[7] https://one.oecd.org/document/STD/CSSP/WPTGS%282017)5/en/.

[8] For example, Hummels et al. (2001) use national IOTs to show that vertical specialisation (i.e., the use of imported inputs in producing goods that are exported) has increased over time, and explained 30% of the growth in exports of 14 OECD and emerging market countries between 1970 and 1990.

[9] The original BEC classification, issued in 1971, was defined in terms of the Standard International Trade Classification (SITC) revision 1. Since then, it has been updated three times: 1) in 1976 in terms of the SITC revision 2; 2) in 1986 in terms of the SITC revision 3; and 3) in 2002, based on the more detailed goods description provided by the 2002 edition of the Harmonized Commodity Description and Coding System (United Nations, 2003). This fourth version, set up with reference to the third revision of the SITC, can be found at http://unstats.un.org/unsd/cr/registry/regdnld.asp?Lg=1. The fifth revision was endorsed by the UN Statistical Commission at its 47th session in 2016.

[10] The SNA intermediate goods class corresponds to the BEC code numbers 111 (food and beverages mainly for industry, primary), 121 (food and beverages mainly for industry, processed), 21 (industrial supplies not elsewhere specified, primary), 22 (industrial supplies not elsewhere specified, processed), 31 (primary fuels and

Several studies investigate international production fragmentation using the BEC classification as a starting point (for references see Sturgeon and Memedovic, 2010). However, the BEC classification is far from perfect and has been criticised for its subjective allocation of products, which is based on expert judgment concerning descriptive characteristics, particularly with regards to the fact that some goods may be used both as intermediates and final products (for example flour, which is classified as intermediate but can also be a consumption good if bought by households), and which may not align with the equivalent allocations used in national SUTs. In addition, up until the 4th Revision, the BEC classification was not available for trade in services. This has been addressed in the latest (5th) revision but the high level of aggregation in services trade data (as well as its novelty and limited availability in many countries) has restricted its application.

This has led many to refine the BEC classification in their own analyses. Sturgeon and Memedovic (2010), for example, use industry-specific manufactured intermediate goods (MIG) classifications in order to isolate 'true' (differentiated, customised, product-specific) intermediates from generic intermediates. The OECD, as part of its work in producing TiVA, has also developed a refinement to the BEC system that introduces categories of mixed use (Bilateral Trade Database by Industry and End-Use Category, BTDIxE).[11]

2.2.2 Trade data-based GVC indicators

The most commonly used GVC indicators based on international trade statistics are presented below. They are shown in a way that is not contingent on any actual definition used to define intermediate trade (i.e., BEC or alternatives).

Share of intermediate goods in exports and imports

The most basic version of this indicator measures the share of a country's exports of intermediate goods in its total goods' exports, which provides broad insights into the relative position of a country within GVCs (i.e., more or less upstream in the production of intermediate goods compared to final demand goods):

$$\mathrm{XISH_c} = \frac{\mathrm{EXGRI_c}}{\mathrm{EXGR_c}} \tag{2.1}$$

lubricants), 322 (processed fuels and lubricants), 42 (parts and accessories of capital goods, excluding transport equipment), and 53 (parts and accessories of transport equipment).

[11] www.oecd.org/trade/bilateraltradeingoodsbyindustryandend-usecategory.htm.

where $\text{EXGRI}_c = \sum_{q \in int} \text{EXGR}_c(q)$ are country *c*'s exports of intermediate goods; $\text{EXGR}_c = \sum_q \text{EXGR}_c(q)$ are country *c*'s total goods exports; *q*=1, 2,…, Q is the product index; and $q \in$ int is the subset of products corresponding to intermediate goods.

A variation of this indicator quantifies the share of imports of intermediate goods in total goods imports, which is particularly useful for countries participating in the downstream stages of supply chains (i.e., the assembly of finished goods from imported components):

$$\text{MISH}_c = \frac{\text{IMGRI}_c}{\text{IMGR}_c} \tag{2.2}$$

where $\text{IMGRI}_c = \sum_{q \in int} \text{IMGR}_c(q)$ country *c*'s imports of intermediate goods; and $\text{IMGR}_c = \sum_q \text{IMGR}_c(q)$ are country *c*'s total goods imports.

This indicator can also be used to provide insights into the integration of countries in bilateral and regional production networks, by calculating equivalent shares on a bilateral or regional basis.

Share of intermediate goods in total trade

This indicator shows the share of intermediates in total goods trade, including both exports and imports:

$$\text{TISH}_c = \frac{\text{EXGRI}_c + \text{IMGRI}_c}{\text{EXGR}_c + \text{IMGR}_c} \tag{2.3}$$

It can also be computed considering bilateral or regional trade flows.

Although TISH provides a complementary view of a country's participation in GVCs to the two separate indicators described above, this is not a comprehensive view. For example, a country with high levels of imports and exports relative to its gross domestic product (GDP) may have a similar TISH ratio to a country with a low ratio of trade to GDP.

Relative importance of trade in intermediates

Dullien (2010) proposes a variant of the previous indicator, which attempts to address some of the inadequacies mentioned above. The indicator, referred to here as the "relative importance of trade in intermediates" (RITI), is defined as the ratio of intermediate goods trade to a country's GDP:

$$\mathrm{RITI_c} = \frac{\mathrm{EXGRI_c} + \mathrm{IMGRI_c}}{\mathrm{GDP_c}} \tag{2.4}$$

By relating intermediates trade to GDP, instead of to total trade, this indicator provides insights into the relative importance of a country's participation in international production networks to the economy. However, both the share of intermediates in total trade (TISH) and the RITI index have the shortcoming that a country that imports a large volume of intermediate goods and re-exports those goods as intermediates without adding much domestic value could exhibit high values of both indicators. Additionally, like TISH, the RITI index cannot provide information on a country's position in value chains. Finally, although the indicator provides a better measure of the relative importance of trade to the economy, comparisons across countries should be conducted with care as larger economies will typically have lower ratios, in part reflecting the larger relative importance of domestic consumption, but also the relative potential of internal domestic supply chains to provide intermediates.

Ratio of intermediate imports to exports

This indicator, also called coverage ratio, relates a country's imports of intermediates to its intermediate exports, and can be used as a broad measure of a country's position in GVCs:

$$\mathrm{CRI_c} = \frac{\mathrm{IMGRI_c}}{\mathrm{EXGRI_c}} \tag{2.5}$$

Countries located at the beginning of the production chain (upstream) tend to import fewer intermediates and export more, resulting in a relatively low value of CRI. In contrast, countries that specialise in assembly and are located at the other end of the supply chain (downstream) tend to import more intermediate goods and export relatively less, resulting in a comparatively high value of CRI. However, some care is needed in interpretation as the indicator is not able to address scale (i.e., differences in economic size), nor is it necessarily able to provide for robust and meaningful international comparisons. For example, a country that imports most intermediates for producing final goods destined for domestic markets, and that has relatively limited intermediate exports will have a significantly higher ratio than an equivalent country with higher intermediate imports and exports.

Grubel-Lloyd index

Intra-industry trade indices in intermediates serve as a proxy of a country's insertion in GVCs, as well as to identify bilateral production linkages between countries and regions. A high level of intra-industry trade in intermediates (i.e., two-way exchange of intermediate goods within the same industry) is interpreted as indicating greater production links between participating countries, which would reflect international fragmentation.[12]

The most widely used intra-industry trade measure is the Grubel-Lloyd (GL) index. This index relates the net exports of a group of products *q* (usually defined within a standard industrial classification) with total trade (i.e., the sum of exports and imports) of the same products. At the bilateral level, the GL index in intermediates can be computed as:

$$\mathrm{GL_{c,p}} = 1 - \frac{\sum_{q\in int}\left|\mathrm{EXGR_{c,p}(q)} - \mathrm{IMGR_{c,p}(q)}\right|}{\sum_{q\in int}\left(\mathrm{EXGR_{c,p}(q)} + \mathrm{IMGR_{c,p}(q)}\right)} \tag{2.6}$$

where $\mathrm{EXGR_{c,p}(q)}$ are country *c*'s exports of intermediate products *q* to country *p*; and $\mathrm{IMGR_{c,p}(q)}$ are country *c*'s imports of intermediate products *q* from country *p*.

GL can be calculated for a country's world-wide trade as:

$$\mathrm{GL_c} = \sum_{p}\left[\left(\frac{\sum_{q\in int}\left(\mathrm{EXGR_{c,p}(q)} + \mathrm{IMGR_{c,p}(q)}\right)}{\sum_{q\in int}\left(\mathrm{EXGR_{c}(q)} + \mathrm{IMGR_{c}(q)}\right)}\right)\left(1 - \frac{\sum_{q\in int}\left|\mathrm{EXGR_{c,p}(q)} - \mathrm{IMGR_{c,p}(q)}\right|}{\sum_{q\in int}\left(\mathrm{EXGR_{c,p}(q)} + \mathrm{IMGR_{c,p}(q)}\right)}\right)\right] \tag{2.7}$$ [13]

where $\mathrm{EXGR_c(q)} = \sum_p \mathrm{EXGR_{c,p}(q)}$ are country *c*'s total exports of intermediate products *q*; and $\mathrm{IMGR_c(q)} = \sum_p \mathrm{IMGR_{c,p}(q)}$ are country *c*'s total imports of intermediate products *q*.

The index takes values between zero and one: values close to zero indicate a low level of intra-industry trade, whereas values approaching one indicate a high level of intra-industry trade.[14]

One shortcoming of the GL index is that it is highly sensitive to the level of aggregation of the trade data used (De Backer and Yamano, 2012). Another drawback of this indicator is its static nature, in the sense that it refers to the pattern of trade in one year. When the structure of

[12] It should be noted that, when intra-industry trade indices are computed including both intermediate and final goods, a high index value could not only indicate international fragmentation of production but also horizontal and vertical product differentiation for final goods (De Backer and Yamano, 2012).

[13] The index can also be calculated for a selected group of trade partners, as the weighted average of bilateral indexes.

[14] In the absence of intra-industry trade the index would be equal to zero (indicating pure inter-industry trade), while in the absence of inter-industry trade it would be equal to one (indicating pure intra-industry trade).

changes in trade patterns is important, marginal or "quasi-dynamic" intra-industry trade measures should be used (Brülhart, 2002).[15]

Revealed comparative advantages and product sophistication

The Revealed Comparative Advantage (RCA) index measures the intensity with which a country exports a product (or group of products). When applied to trade in intermediates, it can be computed as:

$$\mathrm{RCA_c(q)} = \frac{\mathrm{EXGR_c(q)}/\sum_{\mathrm{q\in int}}\mathrm{EXGR_c(q)}}{\sum_{\mathrm{c}}\mathrm{EXGR_c(q)}/\sum_{\mathrm{c}}\sum_{\mathrm{q\in int}}\mathrm{EXGR_c(q)}} = \frac{\mathrm{EXGR_c(q)}/\sum_{\mathrm{c}}\mathrm{EXGR_c(q)}}{\sum_{\mathrm{q\in int}}\mathrm{EXGR_c(q)}/\sum_{\mathrm{c}}\sum_{\mathrm{q\in int}}\mathrm{EXGR_c(q)}} \quad (2.8)$$

where $\mathrm{EXGR_c(q)}$ are country *c*'s exports of intermediate product(s) *q*.

First proposed by Balassa (1965), this index measures whether a product's share in a country's export basket is larger or smaller than the product's share in world trade (or, alternatively, whether a country's share in a product's world market is larger or smaller than the country's share in total world trade). Thus, a value larger (smaller) than one indicates that the country has a revealed comparative advantage (disadvantage) in the product(s).

Based on the RCA index, Hausmann et al. (2007) define a measure of product sophistication:

$$\mathrm{PRODY(q)} = \frac{1}{\sum_{\mathrm{c}}\mathrm{RCA_c(q)}}\sum_{\mathrm{c}}\mathrm{RCA_c(q)\,GDPPC_c} \quad (2.9)$$

where $\mathrm{GDPPC_c}$ is the GDP per capita of country *c*.

PRODY can be used to rank traded goods in terms of their implied productivity. Thus, the sophistication of a country's productive structure can be estimated as the weighted average PRODY of the products the country exports (where the weights are the shares of the products in the country's export basket).

The use of PRODY has been criticised due to the endogeneity of its definition (i.e., "rich countries export rich country products"). Hidalgo (2009) addresses this issue by proposing an alternative measure (referred to as $\widetilde{\mathrm{PRODY}}$), based on network analysis concepts:

[15] "Quasi-dynamic" measures of intra-industry trade consider trade flows in two different time periods, for example, by comparing two GL indices. This approach would be appropriate for a comparative static analysis, but it does not allow conclusions on the structure of the change in trade flows. See Brülhart (2002) for alternative "quasi-dynamic" and marginal intra-industry trade measures.

$$\widetilde{\mathrm{PRODY}}(q) \approx \frac{1}{k_q} \sum_c \widetilde{\mathrm{RCA}}_c(q)\, k_c \tag{2.10}$$

where $\widetilde{\mathrm{RCA}}_c(q) = 1$ if $\mathrm{RCA}_c(q) \geq \mathrm{RCA}^*$ (with RCA^* a threshold RCA level); $k_c = \sum_q \widetilde{\mathrm{RCA}}_c(q)$ represents the diversification of country *c* (given by the number of connections that the country has in the RCA network; i.e., the number of products with RCA); and $k_q = \sum_c \widetilde{\mathrm{RCA}}_c(q)$ is the ubiquity of product *q* in the network (given by the number of countries that export the product with RCA).

This alternative indicator is the basis of the so-called *method of reflections*, which allows estimating the complexity of countries' productive structures and the sophistication of products (Hidalgo, 2009; Hidalgo and Hausmann, 2009). The main downside of both measures is that they are derived using gross measures of trade. So, for example, a country engaged in assembly activities at the end of a high-tech value chain will appear to have a relative comparative advantage in the manufacture of high-tech goods, whereas the truth would more accurately reflect a comparative advantage in cheap labour.

2.2.3 Limitations of trade data

Indicators based on gross trade data have been widely used to evaluate the integration of countries into international production networks. This is facilitated by the fact that trade data are easily available and comparable across countries. However, and regardless of the definition of intermediate goods considered, conventional trade statistics have one key shortcoming that limits their suitability for the analysis of geographical production fragmentation. This chiefly reflects their inability to show the value added contributed by countries (firms) within each stage of the production process. Indeed, trade data on their own cannot reveal from which industries the value was added (i.e., products were exported) nor from which industries the products were imported. The inability of gross trade data to provide these perspectives is perhaps best characterised by the low shares of services trade in conventional statistics, relative to their contribution to overall economic activity, which reflects in large part the fact that the contribution of upstream services to goods exports is not accounted for in gross trade data.

A comprehensive and more accurate measurement of international production fragmentation, that tackles these shortcomings, requires combining trade data with data on the input-output structure of trading nations. This is the approach underlying the GVC indicators presented below.

2.3 Indicators based on input-output tables

2.3.1 Trade in value added

The emergence of GVCs as a dominant feature of world production poses challenges for empirical analysis of international trade. Since conventional trade statistics are affected by double-counting problems, their use may give a misleading perspective of the contribution of trade to economic growth and income (OECD-WTO, 2013).

Gross export data would only reflect actual benefits to the exporting economy's GDP[16], if the entire production process took place within that single country, which reflects an archaic view of production given the rise of international fragmentation. To the extent that exported goods usually require foreign inputs (either directly or indirectly[17]), the gross value of exports differs from the domestic value added contained in those exports. In fact, as shown below, gross export flows can be decomposed into domestic value-added components and imported components (foreign value added). While exports' contribution to economic well-being (in terms of income or employment) depends positively on their domestic value-added content, an increase in gross export flows may not necessarily imply a significant benefit to the exporting economy.

Additionally, the increasing complexity of international production networks is making it more difficult to identify the origin of goods. On the one hand, the value added incorporated in a final product may come from several countries, apart from the country of origin ascribed by customs records (Escaith, 2014b). For example, domestic value added exported by a country A to a country B may be indirectly exported to third countries by being embodied in country B's exports. Since customs records only reflect goods' last country of origin, value added could even end up being exported to a country with which no direct bilateral trade exists. Likewise, domestic value added may return to the exporting economy embodied in imported products. In addition, because they only have a product dimension, conventional gross trade statistics cannot on their own reveal the industries (and so production process used) of the economy where value added originates.

For the above reasons, there is an increasing recognition that analyses based on gross trade data can result in inaccurate assessments of the impact of international trade, which could lead

[16] The OECD is also leading international efforts to look through the pure trade and production, or GDP perspective, by developing accounting frameworks that also capture international flows related to value-added generated by foreign direct investment (a Gross National Income (GNI) perspective) (see Ahmad, 2015).
[17] Imported intermediates are used directly in the production of exported goods, and/or exported goods require intermediate inputs from domestic suppliers who, in turn, require foreign intermediates to produce those inputs.

to misguided political decisions. In contrast, the measurement of trade in value-added terms provides a better estimation of the contribution of trade to economic growth and job creation, as it aims to identify the domestic value (contribution) that each country adds to goods and services exports. In addition, bilateral trade imbalances measured in value-added terms may be very different from those implied by gross trade data (although total trade balances are the same[18]), since the latter exaggerate deficits with final goods producers (surpluses of exporters of final products).

In order to assess the actual contribution of each participating country and industry, the gross value of exports should be decomposed into value-added contributions from domestic and foreign industries. This can be done using international (intercountry or multiregional) IOTs, which combine national accounts and bilateral trade statistics linking production processes within and across countries. By capturing both direct and indirect linkages and exchanges between countries and industries, international IOTs are able to account for fragmentation of production, avoiding the double-counting problems that affect conventional trade data. Another key advantage of IOTs is that they classify products according to their use (as an input into another industry's production or as final demand).

2.3.2 Input-output analysis

In input-output analysis, the relationship between supply and demand of an economy *c* with K industries can be expressed in the following way[19]:

$$\mathbf{y}_c = \mathbf{Z}_c^D \boldsymbol{\iota} + \mathbf{f}_c \tag{2.11}$$

where $\mathbf{y}_c$ is a K×1 vector of the output of country *c* by source industry; $\mathbf{Z}_c^D$ is a K×K matrix of domestic intermediate demand for the products of country *c* (with $z_c^D(i,j)$ being the value of domestic products from industry *i* used as intermediates by industry *j*); $\boldsymbol{\iota}$ is a K×1 vector of ones; and $\mathbf{f}_c$ is a K×1 final demand vector for the products of country *c* by source industry (which includes both domestic final demand and gross exports).

Thus,

[18] Measuring trade in value-added terms does not change the overall trade balance of a country; it redistributes the surpluses and deficits across partner countries.

[19] An input-output model is constructed from observed data (expressed in monetary terms) for a particular economic area (usually a country) and a particular time period (usually a year). As it is customary in this literature, we use upper-case bold letters for matrices and lower-case bold letters for vectors. For simplicity, the time index is omitted here.

$$\begin{bmatrix} y_c(1) \\ \vdots \\ y_c(K) \end{bmatrix} = \begin{bmatrix} z_c^D(1,1) & \dots & z_c^D(1,K) \\ \vdots & \ddots & \vdots \\ z_c^D(K,1) & \cdots & z_c^D(K,K) \end{bmatrix} \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} + \begin{bmatrix} f_c(1) \\ \vdots \\ f_c(K) \end{bmatrix} \tag{2.12}$$

Each industry's intermediate demand of domestically produced products can be expressed in terms of technical coefficients, so that equation (2.11) translates into:

$$\mathbf{y}_c = \mathbf{A}_c^D \mathbf{y}_c + \mathbf{f}_c \tag{2.13}$$

where $\mathbf{A}_c^D$ is the K×K matrix of direct domestic input coefficients (or technical coefficients) of country *c*. Each coefficient $a_c^D(i,j)$ indicates the value of products from domestic industry *i* used by industry *j* as intermediate inputs to produce one (monetary) unit of output (i.e., $a_c^D(i,j) = z_c^D(i,j)/y_c(j)$).

Equation (2.13) represents the fundamental input-output identity introduced by Leontief (1936). The model can be rewritten as:

$$(\mathbf{I} - \mathbf{A}_c^D)\mathbf{y}_c = \mathbf{f}_c \tag{2.14}$$

where **I** is a K×K identity matrix.

Therefore:

$$\mathbf{y}_c = (\mathbf{I} - \mathbf{A}_c^D)^{-1}\mathbf{f}_c = \mathbf{B}_c\mathbf{f}_c \tag{2.15}$$

where $(\mathbf{I} - \mathbf{A}_c^D)^{-1}$ or $\mathbf{B}_c$ is the multiplier matrix, known as the Leontief inverse (or total requirements matrix). This matrix indicates how much output from each domestic industry is directly and indirectly required in country *c* to produce a given vector of final demand. For example, to satisfy one unit of final demand (i.e., to produce one unit of output) industry *j* requires $a_c^D(i,j)$ units from domestic industry *i*; in turn, to produce those $a_c^D(i,j)$ units industry *i* will require inputs from other domestic industries, generating in turn additional input requirements of those industries. Thus, the Leontief inverse captures all direct and indirect flows of domestic intermediate products involved in the production of one unit of each industry's output.

It is also possible to construct a $\mathbf{A}_c^M$ matrix of direct imported input coefficients of country *c*. Each coefficient $a_c^M(i,j)$ shows the foreign inputs from industry *i* required by domestic industry *j* to produce one unit of output (i.e., $a_c^M(i,j) = z_c^M(i,j)/y_c(j)$, where $z_c^M(i,j)$ is the value of imported products from industry *i* used as intermediates by industry *j*). As shown in subsection 2.3.4, matrices $\mathbf{A}_c^D$ (from which $\mathbf{B}_c$ is obtained) and $\mathbf{A}_c^M$ are the key components of most GVC indicators based on IOT information, which can be computed using national (i.e., single country) tables. Other indicators require the use of an international IOT.[20]

Following Johnson and Noguera (2012), in an international input-output framework with N countries equation (2.13) can be expressed as:

$$\mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{f} \tag{2.16}$$

with:

$$\mathbf{y} = \begin{bmatrix} \mathbf{y}_1 \\ \vdots \\ \mathbf{y}_N \end{bmatrix}, \quad \mathbf{A} = \begin{bmatrix} \mathbf{A}_{1,1} & \cdots & \mathbf{A}_{1,N} \\ \vdots & \ddots & \vdots \\ \mathbf{A}_{N,1} & \cdots & \mathbf{A}_{N,N} \end{bmatrix}, \quad \text{and} \quad \mathbf{f} = \begin{bmatrix} \sum_p \mathbf{f}_{1,p} \\ \vdots \\ \sum_p \mathbf{f}_{N,p} \end{bmatrix} \tag{2.17}$$

where each $\mathbf{y}_c$ is a K×1 vector of the output of country *c* by source industry (with $y_c(i)$ being the value of output in industry *i* of country *c*); each $\mathbf{A}_{c,p}$ is a K×K technical coefficient matrix with elements $a_{c,p}(i,j) = z_{c,p}(i,j)/y_p(j)$ (where $z_{c,p}(i,j)$ is the value of products from industry *i* in source country *c* used as intermediates by industry *j* in destination country *p*); and each $\mathbf{f}_{c,p}$ is a K×1 vector of final demand in country *p* of products from country *c* by source industry.[21]

Again,

$$\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{B}\mathbf{f} \tag{2.18}$$

where **I** is a (K×N)×(K×N) identity matrix.

Matrix **A** (referred to here as global technical coefficient matrix) summarises the entire structure of within-country, cross-country, and cross-industry intermediate products linkages. Consequently, the global Leontief inverse **B** (or global total requirements matrix) indicates how much output from each country and industry is required to produce a given vector of world final demand **f**.

[20] Matrices $\mathbf{A}_c^D$ and $\mathbf{A}_c^M$ can also be obtained from an international IOT.

[21] Thus, for each industry *i* in country *c* gross output is given by: $y_c(i) = \sum_p \sum_j z_{c,p}(i,j) + \sum_p f_{c,p}(i)$.

2.3.3 TiVA database

Although input-output analysis has a very long tradition, initiated by Wassily Leontief in 1936, its use has seen a resurgence in recent years. International (inter-country, world, global, multiregional or multi-country) IOTs provide a powerful tool for studying the interdependent structure that increasingly characterises production processes worldwide. They are an extension of the basic IOT framework in which the use of both intermediate and final imported products is broken down by origin country, showing in which foreign industry they were produced.

The construction of international IOTs requires harmonising and consolidating national IOTs (or SUTs) and bilateral trade data across countries, which usually needs significant transformation of data originally validated in national statistical systems. In recent years in particular, there have been a number of initiatives to develop such tables (see Annex A). The OECD Inter-Country Input-Output (ICIO) database that underpins the OECD-WTO TiVA database, is one of the best known of these initiatives, and the only one aiming to develop an internationally recognised 'official' international IOT within a coordinated network of national and international statistics agencies; a position reinforced at the 2015 meeting of the UN Statistical Commission.[22]

TiVA provides a publicly available dataset that includes a number of indicators of trade in value-added terms, as well as the underlying inter-country IOTs.[23] It currently covers 63 economies (all 34 OECD countries and 29 non-member countries, including Brazil, China, India, Indonesia, Russia, and South Africa), with a breakdown into 34 industries and availability for the years 1995 to 2011. The latest release of the database was in March 2017, which included estimates up to 2014 produced using nowcasting techniques. The initiative plans to continue releasing more detailed data in terms of country coverage and industry disaggregation, as momentum develops, and has seen extensions into a number of other policy relevant areas including on jobs and the environment[24], with additional extensions expanding industry granularity to provide insights on the role of SMEs and MNEs in GVCs[25]. Indicators currently included in the TiVA database, amongst many others include a decomposition of gross exports and the services content of gross exports by domestic and foreign origin, and the domestic value

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[22] http://unstats.un.org/unsd/statcom/doc15/2015-12-TradeStats-E.pdf.

[23] TiVA indicators can be accessed online at: http://www.oecd.org/industry/ind/measuringtradeinvalue-addedanoecd-wtojointinitiative.htm. The underlying inter-country IOTs are available for downloading at: http://www.oecd.org/sti/ind/input-outputtablesedition2015accesstodata.htm.

[24] http://oe.cd/io-emp and http://oe.cd/io-co2.

[25] www.oecd.org/std/its/enterprises-in-global-value-chains.htm and www.oecd.org/trade/OECD-WBGg20-gvc-report-2015.pdf.

added embodied in foreign final demand. In addition, the dataset includes information on bilateral trade balances based on flows of value added embodied in domestic final demand (which take into account the domestic or foreign origin of value added), and the intermediate imports embodied in exports.

The data was derived from the OECD's database of national IOTs and SUTs, which were integrated and harmonised into a global system using additional statistical sources, such as the Bilateral Trade in Goods by Industry and End-use (BTDIxE), International Trade in Services (TIS) and the Structural Analysis (STAN) industry databases. The main advantage, compared to other initiatives, is the statistical network within which this database was constructed, capitalising on the OECD's networks of official statistics agencies and its official Committees and Working Parties, omitting countries and industries that lacked sufficiently reliable data. This position is being further strengthened through the development of partnerships and closer collaboration with other regional initiatives (including Eurostat's FIGARO[26] and APEC-TIVA) and with UN regional agencies (including ECLAC). However, in recognition that some assumptions are required, meaning that Trade in Value Added is only estimated and not measured per se, the OECD refers to the indicators as estimates. Note however that the same limitations and assumptions in this instance also apply to other initiatives.

2.3.4 Input-output table based GVC indicators

The shortcomings of international trade statistics, in light of the increasing role played by international production networks in the world economy, have led to a greater use of input-output data to examine geographical production fragmentation and value added in trade. As a result, a number of indicators based on IOTs have been developed. This section presents a review of the main indicators, some of which may be computed from national IOTs (i.e., they do not require the use of an international IOT).

Ratio of imported inputs to domestic inputs

This indicator compares the values of imported and domestic intermediates used in production by country *c*. It can be computed on the basis of both national and international IOTs as:

$$\mathrm{RMD_c} = \frac{\boldsymbol{\iota}\mathbf{A}_\mathrm{c}^\mathrm{M}\mathbf{y}_\mathrm{c}}{\boldsymbol{\iota}\mathbf{A}_\mathrm{c}^\mathrm{D}\mathbf{y}_\mathrm{c}} \tag{2.19}$$

[26] Full International and Global Accounts for Research in Input-Output Analysis.

where ι is a 1×K vector of ones; $\mathbf{A}_c^M$ is a K×K matrix of direct imported input coefficients of country c; $\mathbf{A}_c^D$ is a K×K matrix of direct domestic input coefficients of country c; and y_c is a K×1 vector of the output of country c by source industry.[27] The indicator could also be computed at the sectoral level, as the ratio of imported inputs to domestic inputs used by each industry (see the equation in the Annex).

A value of RMD above (below) one indicates that imported (domestic) intermediates have a larger share in the country/industry's total inputs. Additionally, an increase (decrease) in the indicator over time would point to growing (decreasing) importance of international sourcing; however, care is needed in interpretation as movements over time may reflect differences in relative price variations, amongst other things. Moreover, the indicator only provides a limited perspective on countries' integration in GVCs, since it does not differentiate between imported inputs ultimately used to produce goods and services for domestic consumption and exports.

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Vertical specialisation

Vertical specialisation is defined as the use of foreign intermediates in producing exported products. According to Hummels et al. (2001), vertical specialisation occurs when: a) a good is produced in two or more sequential stages, b) two or more countries add value during the production of the good, and c) at least one country uses imported inputs in its stage of the production process, and some of the resulting output is exported. Therefore, while all imported intermediates are consistent with (a) and (b), only those that become embodied in exported goods are consistent with the third condition.

Four vertical specialisation indicators are presented below.

[27] From an international IOT, $\mathbf{A}_c^M$ can be obtained as: $\mathbf{A}_c^M = \sum_{p \neq c} \mathbf{A}_{p,c}$.

Direct import content of exports

The most basic indicator of vertical specialisation, referred to here as VSD, was initially suggested by Hummels et al. (2001):

$$\mathrm{VSD_c} = \frac{\boldsymbol{\iota}\mathbf{A}_\mathrm{c}^\mathrm{M}\mathbf{e}_\mathrm{c}}{\boldsymbol{\iota}\mathbf{e}_\mathrm{c}} \tag{2.20}$$

where $\mathbf{A}_\mathrm{c}^\mathrm{M}$ is the K×K direct import coefficient matrix of country *c*; $\mathbf{e}_\mathrm{c}$ is a K×1 vector of gross exports of country *c* by source industry; and ι is a 1×K vector of ones.

This indicator can be computed using both national and international IOTs. It provides an estimate of the direct import content of exports[28], and so is limited in the sense that it cannot reveal the importance of indirect imports (i.e., those used by upstream domestic suppliers to any given exporting industry). Amongst other things, this also means that the value of the indicator, at least for the total economy, will vary, potentially significantly, depending on the degree of aggregation (i.e., the value of K). Indeed, the greater the degree of disaggregation the lower the value of VSD.[i]

VSD can also be computed considering bilateral exports in the following way:

$$\mathrm{VSD_{c,p}} = \frac{\boldsymbol{\iota}\mathbf{A}_\mathrm{c}^\mathrm{M}\mathbf{e}_\mathrm{c,p}}{\boldsymbol{\iota}\mathbf{e}_\mathrm{c,p}} \tag{2.21}$$

where $\mathbf{e}_\mathrm{c,p}$ is a K×1 vector of gross exports from country *c* to country (or group of countries) *p* by source industry. Thus, imported inputs directly embodied in a country's exports can be decomposed by destination country or region. In addition, an international IOT provides the means to decompose VSD on the basis of the import's country of origin.

Total (direct and indirect) import content of exports

The production of exports requires the direct use of both domestic and foreign intermediates. In turn, inputs sourced from domestic suppliers may require the use of imported intermediates, as well as inputs produced by other domestic industries which, in turn, use foreign intermediates in their production process, and so on. As discussed above, ignoring these indirect import requirements leads to an underestimation of the foreign content of exports and, therefore, the importance of imports for production.

[28] In addition, imported inputs do not necessarily embody only foreign inputs (i.e., they may also embody inputs supplied by the importing country through an upstream exporting activity).

Following this logic, a second indicator of vertical specialisation – referred to as VS (Hummels et al., 2001) – incorporates both direct and indirect imported inputs embodied in a country's exports:

$$\mathrm{VS_c} = \frac{\boldsymbol{\iota}\mathbf{A}_c^M(\mathbf{I}-\mathbf{A}_c^D)^{-1}\mathbf{e}_c}{\boldsymbol{\iota}\mathbf{e}_c} = \frac{\boldsymbol{\iota}\mathbf{A}_c^M\mathbf{B}_c\mathbf{e}_c}{\boldsymbol{\iota}\mathbf{e}_c} \tag{2.22}$$

where $\mathbf{A}_c^M$ and $\mathbf{A}_c^D$ correspond, respectively, to the K×K direct import and domestic input coefficient matrices of country *c*; **I** is a K×K identity matrix; $\mathbf{B}_c$ is the K×K Leontief inverse of country *c*; $\mathbf{e}_c$ is the K×1 vector of gross exports of country *c* by source industry; and ι denotes a 1×K vector of ones.

Additionally, VS can be computed on a bilateral basis as:

$$\mathrm{VS_{c,p}} = \frac{\boldsymbol{\iota}\mathbf{A}_c^M(\mathbf{I}-\mathbf{A}_c^D)^{-1}\mathbf{e}_{c,p}}{\boldsymbol{\iota}\mathbf{e}_{c,p}} = \frac{\boldsymbol{\iota}\mathbf{A}_c^M\mathbf{B}_c\mathbf{e}_{c,p}}{\boldsymbol{\iota}\mathbf{e}_{c,p}} \tag{2.23}$$

where $\mathbf{e}_{c,p}$ is a K×1 vector of gross exports from country *c* to country (or group of countries) *p* by source industry.

Also, from VS and VSD the indirect foreign content of exports (as a share of total gross exports) can be computed as:

$$\mathrm{VSI_c} = \frac{\boldsymbol{\iota}\mathbf{A}_c^M\left(\mathbf{I}-\mathbf{A}_c^D\right)^{-1}\mathbf{e}_c - \boldsymbol{\iota}\mathbf{A}_c^M\mathbf{e}_c}{\boldsymbol{\iota}\mathbf{e}_c} = \frac{\boldsymbol{\iota}\mathbf{A}_c^M\left[\left(\mathbf{I}-\mathbf{A}_c^D\right)^{-1}-\mathbf{I}\right]\mathbf{e}_c}{\boldsymbol{\iota}\mathbf{e}_c} = \frac{\boldsymbol{\iota}\mathbf{A}_c^M(\mathbf{B}_c-\mathbf{I})\mathbf{e}_c}{\boldsymbol{\iota}\mathbf{e}_c} \tag{2.24}$$

A proxy of the domestic value added embodied in exports could be computed as the difference between gross exports and total (direct and indirect) foreign inputs contained in those exports:

$$\widetilde{\mathrm{DVAX}}_c = \boldsymbol{\iota}\mathbf{e}_c - \boldsymbol{\iota}\mathbf{A}_c^M(\mathbf{I}-\mathbf{A}_c^D)^{-1}\mathbf{e}_c = \boldsymbol{\iota}[\mathbf{I}-\mathbf{A}_c^M(\mathbf{I}-\mathbf{A}_c^D)^{-1}]\mathbf{e}_c = \boldsymbol{\iota}(\mathbf{I}-\mathbf{A}_c^M\mathbf{B}_c)\mathbf{e}_c \tag{2.25}$$

It should be noticed that VS provides only a first order approximation to the foreign value-added content of exports. It is not able to account for any domestic value added that may be embodied in imported inputs, reflecting, for example two-way trade in intermediates (i.e., when a country's exported products are used as inputs by other countries to produce goods that are shipped back home). That being said, the evidence suggests that for many countries, at least at the total economy level, estimates of VS (as well as VSI and $\widetilde{\mathrm{DVAX}}$) computed using national IOTs are very close to the equivalent estimates one would derive using an international IOT.

However, the relationship begins to breakdown when estimates are derived by partner and industry.

In addition, international IOTs can provide more detailed insights on the position of countries in international production chains, which cannot be done with a national IOT alone. A relatively higher value of VS for intermediates indicates a stronger integration in the upstream production of parts and components (for the production of other goods), while a higher value of VS for final goods reflects a greater importance of downstream assembly activities.

Exports embodied in other countries' exports

A third vertical specialisation indicator, called VS2, portrays an alternative perspective of a country's participation in GVCs by capturing the exports embodied in other countries' exports. While VSD and VS look at vertical specialisation from the viewpoint of an exporting country demanding intermediates from abroad, VS2 measures vertical specialisation from the viewpoint of an exporting country supplying intermediate inputs abroad (Yi, 2003):[29]

$$\mathrm{VS2}_c = \frac{\sum_{p \neq c} \boldsymbol{\iota}\, \mathbf{A}_{c,p}\left(\mathbf{I} - \mathbf{A}_{p,p}\right)^{-1} \mathbf{e}_p}{\boldsymbol{\iota}\mathbf{e}_c} = \frac{\sum_{p \neq c} \boldsymbol{\iota}\mathbf{A}_{c,p}\mathbf{B}_{p,p}\mathbf{e}_p}{\boldsymbol{\iota}\mathbf{e}_c} \qquad (2.26)$$

where $\mathbf{A}_{c,p}$ is a K×K matrix of input coefficients of country *p* for the products imported from country *c* (with each coefficient $a_{c,p}(i,j)$ showing the inputs from industry *i* in country *c* required in country *p* by industry *j* to produce one unit of output); $\mathbf{A}_{p,p}$ is the K×K matrix of direct domestic technical coefficients of country *p*; **I** is a K×K identity matrix; $\mathbf{B}_{p,p}$ is the K×K Leontief inverse matrix of country *p* (given by the block matrix drawn from the global Leontief inverse); $\mathbf{e}_p$ is a K×1 vector of the exports of country *p* by source industry; $\mathbf{e}_c$ is a K×1 vector of the exports of country *c* by source industry; and $\boldsymbol{\iota}$ is a 1×K vector of ones.

Thus, VS2 indicates how much of a country's exports are used as intermediate inputs in the production of other countries' exports. Naturally, countries that participate heavily in the first stages of the production chain (such as the extraction of natural resources), and those specialised in the production of intermediates (e.g., parts and components), will tend to have higher ratios.

[29] As pointed out in UNCTAD (2013), "although the degree to which exports are used by other countries for further export generation may appear less relevant for policymakers as it does not change the domestic value-added contribution of trade, the participation rate is a useful indicator for the extent to which a country's exports are integrated in international production networks and it is thus helpful in exploring the trade-investment nexus".

Together, VS2 and VS give a more complete picture of countries' involvement in GVCs, both upstream (i.e., as a producer of intermediates to be included in other countries' exports) and downstream (i.e., as a demander of imported intermediates to include in one's own exports) (Hummels et al., 2001). Of note here is that VS measures, as defined above, are based on national IOTs and, so, do not adjust for any domestic value added that may be included in imports.

As in the case of the other two indicators of vertical specialisation presented above, VS2 can be computed considering bilateral or regional exports (by not summing over partner countries *p* or by summing over a subset of these countries, respectively).[30ii]

Vertical specialization-based trade

Amador and Cabral (2009) propose a relative measure of vertical specialisation-based trade (i.e., the use of imported inputs in producing goods that are exported) that combines information from IOTs and international trade data. International trade data is used in the identification and quantification of vertical specialisation activities, while input-output information is used to identify which products are intermediate goods employed in the production of other products.[31]

An international product specialisation index, based on Balassa (1965), is computed for both exports and imports in order to identify the relevant vertical specialisation activities. In terms of the notation previously used, the index for exports can be expressed as:

$$B^{*}_{EXGR_{c,i}} = \frac{\frac{EXGR_{c,i}}{EXGR_{c}}}{\bar{\mu}_{EXGR_{i}}} = \frac{\frac{EXGR_{c,i}}{EXGR_{c}}}{\frac{1}{N}\sum_{c=1}^{N}\frac{EXGR_{c,i}}{EXGR_{c}}} \tag{2.27}$$

[30] Also, the import content of exports could be computed in levels (i.e., the value of imported inputs embodied in exports), instead of being expressed as a share of gross exports like in equations (2.18) to (2.22) and (2.24). In addition, it could be disaggregated by exporting industry (either considering bilateral or total country's exports).

[31] Amador and Cabral (2009) use information from the 1997 IOT of the United States to identify the intermediate products used in the production of each good, assuming that the main characteristics of the production chain do not change over time and from one country to another. Although the authors recognise that this can be a strong assumption, they argue that "the inputs used in the production of each good probably depend more on technology than on cross-country differences", while "the fact that US produces most existing goods ensures abroad production coverage".

where $\mathrm{EXGR}_{c,i}$ are country *c*'s exports of products from industry *i*; EXGR_c are country *c*'s total exports; and $\overline{\mu}_{\mathrm{EXGR}_i} = \frac{1}{N}\sum_{c=1}^{N}\frac{\mathrm{EXGR}_{c,i}}{\mathrm{EXGR}_c}$ is the unweighted average export share of industry *i* across N countries.[32]

Similarly, the index for imports can be written as:

$$B^{*}_{\mathrm{IMGR}_{c,j}} = \frac{\frac{\mathrm{IMGR}_{c,j}}{\mathrm{IMGR}_c}}{\overline{\mu}_{\mathrm{IMGR}_j}} = \frac{\frac{\mathrm{IMGR}_{c,j}}{\mathrm{IMGR}_c}}{\frac{1}{N}\sum_{c=1}^{N}\frac{\mathrm{IMGR}_{c,j}}{\mathrm{IMGR}_c}} \tag{2.28}$$

where $\mathrm{IMGR}_{c,j}$ are country *c*'s imports of products from industry *j*; IMGR_c are country *c*'s total imports; and $\overline{\mu}_{\mathrm{IMGR}_j} = \frac{1}{N}\sum_{c=1}^{N}\frac{\mathrm{IMGR}_{c,j}}{\mathrm{IMGR}_c}$ is the unweighted average import share of industry *j* across countries.[33]

The basic intuition behind this vertical specialisation measure is that if a country shows simultaneously a high export share of a good and a high import share of a related intermediate product, relative to the world averages, then international vertical linkages are likely to play a role. The definition of high export and import shares depends on the distribution of B^{*}_{EXGR} and B^{*}_{IMGR}, respectively. In every period *t*, if $B^{*}_{\mathrm{EXGR}_{c,i}} > B^{*\mathrm{PRC}}_{\mathrm{EXGR}_i}$ and $B^{*}_{\mathrm{IMGR}_{c,j}} > B^{*\mathrm{PRC}}_{\mathrm{IMGR}_j}$, then product *j* is identified as associated with vertical specialisation activities in country *c*; where *j* is an intermediate good used in the production of *i*, and $B^{*\mathrm{PRC}}_{\mathrm{EXGR}_i}$ and $B^{*\mathrm{PRC}}_{\mathrm{IMGR}_j}$ are the threshold percentiles of the cross-country distribution of $B^{*}_{\mathrm{EXGR}_{c,i}}$ and $B^{*}_{\mathrm{IMGR}_{c,j}}$, respectively.[34]

Once identified, vertical specialisation activities are quantified. In each country and for each product *j*, the value of intermediate imports that surpasses the value implied by the threshold percentile is considered as trade due to vertical specialisation activities in period *t*. This "excess" of intermediate imports is estimated by first determining, for each country in each period, the level of imports that would make $B^{*}_{\mathrm{IMGR}_{c,j}} = B^{*\mathrm{PRC}}_{\mathrm{IMGR}_j}$, which is given by the following expression:

[32] Alternatively, the index can be computed using average shares weighted by each country's participation in world exports: $\mu^{W}_{\mathrm{EXGR}_i} = \sum_{c=1}^{N}\frac{\mathrm{EXGR}_{c,i}}{\mathrm{EXGR}_c}\frac{\mathrm{EXGR}_c}{\sum_{c=1}^{N}\mathrm{EXGR}_c}$.

[33] Also in this case, weighted average shares could be considered.

[34] Since the detection of relevant vertical specialisation activities using this procedure depends heavily on the percentile that defines the threshold, and in order to abstract from intra-industry trade or country characteristics that would justify trade flows somewhat higher than the world average, Amador and Cabral (2009) consider five different high-order threshold percentiles (75, 80, 85, 90, and 95). The use of different threshold percentiles provides an interval for the dimension of estimated vertical specialisation activities.

$$\mathrm{IMGR}_{c,j}^{PRC} = \frac{\frac{B_{\mathrm{IMGR}_j}^{*PRC}}{N}\left(\sum_{p\neq c}^{N}\frac{\mathrm{IMGR}_{p,j}}{\mathrm{IMGR}_p}\right)\left(\sum_{k\neq j}^{S}\mathrm{IMGR}_{c,k}\right)}{1-\frac{B_{\mathrm{IMGR}_j}^{*PRC}}{N}\left(1+\sum_{p\neq c}^{N}\frac{\mathrm{IMGR}_{p,j}}{\mathrm{IMGR}_p}\right)} \tag{2.29}$$

[35]iii

Then, in each period *t* the relative measure of vertical specialisation activities for each country/product pair is computed as:

$$\mathrm{VSM}_{c,j}^{PRC} = \mathrm{IMGR}_{c,j} - \mathrm{IMGR}_{c,j}^{PRC} \tag{2.30}$$

Given its additive properties, in each period, $\mathrm{VSM}_{c,j}^{PRC}$ can be summed to provide a breakdown of vertical specialisation-related trade by country or by product over time. Also, the results can be grouped by geographical area or in accordance with any upper-level product classification.

To facilitate comparisons between countries or products and over time, the measure is computed as a percentage of total imports for each country/geographical area or for each product:

$$\mathrm{VSM}_{c}^{PRC} = \frac{\sum_j \mathrm{VSM}_{c,j}^{PRC}}{\sum_j \mathrm{IMGR}_{c,j}} \tag{2.31}$$

or

$$\mathrm{VSM}_{j}^{PRC} = \frac{\sum_c \mathrm{VSM}_{c,j}^{PRC}}{\sum_c \mathrm{IMGR}_{c,j}} \tag{2.32}$$

The relative nature of this measure is given by the fact that the yearly identification and quantification of vertical specialisation activities is based on the relative dimension of trade flows, which are compared with an international threshold that changes over time. As the

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[35] From equation (2.26): $B_{\mathrm{IMGR}_j}^{*PRC} = \frac{\frac{\mathrm{IMGR}_{c,j}^{PRC}}{\mathrm{IMGR}_c}}{\frac{1}{N}\left(\sum_{p\neq c}^{N}\frac{\mathrm{IMGR}_{p,j}}{\mathrm{IMGR}_p}\right)+\frac{1}{N}\left(\frac{\mathrm{IMGR}_{c,j}^{PRC}}{\mathrm{IMGR}_c}\right)}$. Thus:

$$B_{\mathrm{IMGR}_j}^{*PRC}\left[\frac{1}{N}\left(\sum_{p\neq c}^{N}\frac{\mathrm{IMGR}_{p,j}}{\mathrm{IMGR}_p}\right)+\frac{1}{N}\left(\frac{\mathrm{IMGR}_{c,j}^{PRC}}{\mathrm{IMGR}_c}\right)\right] = \frac{\mathrm{IMGR}_{c,j}^{PRC}}{\mathrm{IMGR}_c}$$

$$B_{\mathrm{IMGR}_j}^{*PRC}\left[\frac{1}{N}\left(\sum_{p\neq c}^{N}\frac{\mathrm{IMGR}_{p,j}}{\mathrm{IMGR}_p}\right)\right]\left(\mathrm{IMGR}_{c,j}^{PRC}+\sum_{k\neq j}^{S}\mathrm{IMGR}_{c,k}\right) = \mathrm{IMGR}_{c,j}^{PRC}\left(1-\frac{1}{N}B_{\mathrm{IMGR}_j}^{*PRC}\right)$$

$B_{\mathrm{IMGR}_j}^{*PRC}\left[\frac{1}{N}\left(\sum_{p\neq c}^{N}\frac{\mathrm{IMGR}_{p,j}}{\mathrm{IMGR}_p}\right)\right]\left(\sum_{k\neq j}^{S}\mathrm{IMGR}_{c,k}\right) = \mathrm{IMGR}_{c,j}^{PRC}\left[1-\frac{B_{\mathrm{IMGR}_j}^{*PRC}}{N}\left(1+\left(\sum_{p\neq c}^{N}\frac{\mathrm{IMGR}_{p,j}}{\mathrm{IMGR}_p}\right)\right)\right]$, from which $\mathrm{IMGR}_{c,j}^{PRC}$ is obtained.

authors point out, the measure should be taken as conservative because, in dynamic terms, it only captures the cases where the increase of vertical specialisation activities is strong enough to translate into a growth of intermediate imports above that implied by the international threshold. This would result in an underestimation of vertical specialisation activities in situations where the international threshold is increasing.

The main advantage of this indicator, over related measures of vertical specialisation like Hummels et al. (2001), is the ability to generate estimates over a longer time period (Baldwin and Lopez-Gonzalez, 2015). VS requires an IOT for every year, whereas VSM only requires a general view of a production function (based on insights from IOTs at a given point in time), which is assumed to be stable and generalisable to all countries. However, evidence from national IOTs points to significant differences in production functions for a given industry across countries, enlarged in recent years by fragmentation of production; thus, some care is necessarily needed in making comparisons across countries and time. As before, care is also needed in interpreting measures over time on account of differential price changes across products.

Trade in value added indicators[iv]

In many respects, measures that capture the value added embodied in a country's exports mirror those that capture exports' import content. So, for example, using only a national IOT, and leaving aside taxes and subsidies, the complement of (i.e., 1 minus) the share of imports in a country's exports equals the domestic value-added (in basic prices) share. However, as noted above, in a global context the issue is more complex as, in reality, imports often include domestic value added that was exported and then re-imported.

Indeed, it is at least in part to capture these flows (in addition to better understanding the nature of interconnectedness) that global IOTs have been developed. Koopman et al. (2014) elaborate these arguments further and point out that the measures of vertical specialisation developed by Hummels et al. (2001), using only national IOTs, are implicitly based on the assumption that the value of imports originates wholly from foreign sources, which does not hold in the presence of two-way trade in intermediate goods. They highlight this by decomposing the value of gross export flows into distinct components that differentiate between domestic value added and import content, further broken down into different items such as intermediate exports passing to third countries, intermediates and finished exports that are consumed as final demand in the importing country, and domestic value added that returns to the host embodied in imports. These breakdowns, or variants of them, form the basis of many of today's key measures of trade in value added, described in more detail below.

One issue worth re-emphasising, although it is of general relevance to many of the indicators presented above, concerns the impact of aggregation within an input-output framework (whether that framework is national or multiregional). The underlying assumption in indicators that use IOTs is that the firms allocated to a given industry each have the same import content relative to their output and the same export propensity relative to their output. However, where information at the firm level is available, it points to exporting firms having different import intensities and export propensities (in particular, it points to exporting firms typically having higher imports per unit of output than non-exporting firms). This means for example that, all other things being equal, measures of the import content of exports based on IOTs will generally be downward biased, and estimates of the domestic value content of exports will be upward biased. Work is however on-going to improve the quality of national SUTs, through the construction of what have become referred to as Extended SUTs, encouraging splits of industries into grouping that better capture heterogeneity in import-output and export-output ratios (through a focus on characteristics of firms that are more homogeneous with regards to GVC measurement).[36]

Domestic value-added content of exports

As intimated above, the domestic value-added embodied in a country's exports can be divided into three components: direct value-added, indirect value-added and re-imported value-added. Direct value-added reflects the direct contribution made by the industry producing the exported product, indirect value-added reflects the indirect contribution of domestic suppliers made through upstream transactions, and re-imported value-added reflects the domestic value-added that returned home embodied in intermediate imports used by the industry in question (see also Ahmad, 2015). While direct and indirect domestic value-added can be computed using national IOTs, the calculation of re-imported domestic value-added requires a multiregional IOT.

Total (direct and indirect) domestic value-added contained in country c's gross exports is given by:

$$\mathrm{DVAX_c} = \boldsymbol{\iota}\widehat{\mathbf{V}}_{\mathrm{c}}(\mathbf{I} - \mathbf{A}_{\mathbf{c}}^{\mathrm{D}})^{-1}\mathbf{e}_{\mathrm{c}} \qquad (2.33)$$

[36] www.oecd.org/sti/ind/tiva/eSUTs_TOR.pdf.

where $\widehat{\mathbf{V}}_c$ is a K×K diagonal matrix of value-added coefficients of country c by source industry[37]; $\mathbf{A}_c^D$ is the K×K matrix of direct domestic input coefficients of country c; $\mathbf{I}$ is a K×K identity matrix; $\mathbf{e}_c$ is a K×1 vector of gross exports of country c by source industry; and $\boldsymbol{\iota}$ is a 1×K vector of ones.

The direct domestic value-added content of gross exports is computed as:

$$\mathrm{DVAXD_c} = \boldsymbol{\iota}\widehat{\mathbf{V}}_c\mathbf{e}_c \tag{2.34}$$

[v]

Thus, the indirect domestic value-added embodied in a country's gross exports (originating from domestic intermediates) is given by:

$$\mathrm{DVAXI_c} = \mathrm{DVAX_c} - \mathrm{DVAXD_c} = \boldsymbol{\iota}\widehat{\mathbf{V}}_c[(\mathbf{I} - \mathbf{A}_c^D)^{-1} - \mathbf{I}]\mathbf{e}_c \tag{2.35}$$

The domestic value-added content of gross exports can be decomposed into a sum of value-added exported to different destination countries (which could also be grouped in regions), by replacing vector $\mathbf{e}$ in equations (2.33) to (2.35) with a K×N matrix of gross exports from each industry of origin to each destination country. It could also be disaggregated by exporting industry (by not multiplying by $\boldsymbol{\iota}$).[vi]

Additionally, the domestic value-added content of gross exports can be decomposed into that contained in direct exports that serve foreign intermediate demand and direct exports that satisfy foreign final demand[38]:

$$\mathrm{DVAX_c^{INT}} = \boldsymbol{\iota}\widehat{\mathbf{V}}_c(\mathbf{I} - \mathbf{A}_c^D)^{-1}\mathbf{e}_c^{INT} \tag{2.36}$$

$$\mathrm{DVAX_c^{F}} = \boldsymbol{\iota}\widehat{\mathbf{V}}_c(\mathbf{I} - \mathbf{A}_c^D)^{-1}\mathbf{e}_c^{F} \tag{2.37}$$

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[37] $\widehat{\mathbf{V}}_c = \begin{pmatrix} v_{c,1} & 0 & \cdots & 0 \\ 0 & v_{c,2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & v_{c,K} \end{pmatrix}$, where the ith element of the diagonal is the value-added share (i.e., the ratio of value-added to gross production) of industry i from country c. Each $v_{c,i}$ can be computed as $v_{c,i} = 1 - \sum_j a_c(j,i) = 1 - \sum_j \left(a_c^D(j,i) + a_c^M(j,i)\right)$(from national IOTs), or as $v_{c,i} = 1 - \sum_p \sum_j a_{p,c}(j,i)$(from an international IOT, where $a_{p,c}(j,i)$ is the value of inputs from industry j in source country p used by industry i in destination country c to produce one unit of output).

[38] The decomposition of gross exports by type of demand served requires the use of multiregional input-output data.

where $\mathbf{e}_c^{INT}$ is a K×1 vector of intermediate gross exports of country *c* by source industry; and $\mathbf{e}_c^{F}$ is a K×1 vector of final gross exports of country *c* by source industry. Both $DVAX_c^{INT}$ and $DVAX_c^{F}$ could be additionally decomposed by destination countries or regions, as well as by exporting industry.

The share of the domestic value-added content of exports in a country's total gross exports, called the VAX ratio in Johnson and Noguera (2012), provides a measure of the value-added generated throughout the economy for each monetary unit of exports[vii]:

$$DVAXSH_c = \frac{DVAX_c}{\boldsymbol{\iota}\mathbf{e}_c} \tag{2.38}$$

This indicator takes values between zero and one. The lower (higher) DVAXSH the higher (lower) the foreign content of exports and so the higher (lower) the importance of imports to exports. Beyond its direct application, it also provides insights on the degree of 'double-counting' in trade statistics.

The use of an international IOT allows the measurement of an additional component of a country's value-added exports, first formalized by Koopman et al. (2011): the domestic value-added embodied as intermediate inputs in third countries' exports. It also provides the basis to measure the re-imported domestic value-added contained in each country's gross exports.

A global value-added export matrix can be computed from multiregional input-output data as:

$$\mathbf{VAX} = \widehat{\mathbf{V}}\mathbf{BE} = \begin{pmatrix} \widehat{\mathbf{V}}_1 \sum_s \mathbf{B}_{1,1}\mathbf{e}_{1,s} & \cdots & \widehat{\mathbf{V}}_1 \sum_s \mathbf{B}_{1,p}\mathbf{e}_{p,s} & \cdots & \widehat{\mathbf{V}}_1 \sum_s \mathbf{B}_{1,N}\mathbf{e}_{N,s} \\ \vdots & & \vdots & \ddots & \vdots \\ \widehat{\mathbf{V}}_c \sum_s \mathbf{B}_{c,1}\mathbf{e}_{1,s} & \cdots & \widehat{\mathbf{V}}_c \sum_s \mathbf{B}_{c,p}\mathbf{e}_{p,s} & \cdots & \widehat{\mathbf{V}}_c \sum_s \mathbf{B}_{c,N}\mathbf{e}_{N,s} \\ \vdots & & \vdots & \ddots & \vdots \\ \widehat{\mathbf{V}}_N \sum_s \mathbf{B}_{N,1}\mathbf{e}_{1,s} & \cdots & \widehat{\mathbf{V}}_N \sum_s \mathbf{B}_{N,p}\mathbf{e}_{p,s} & \cdots & \widehat{\mathbf{V}}_N \sum_s \mathbf{B}_{N,N}\mathbf{e}_{N,s} \end{pmatrix} \tag{2.39}$$

where $\widehat{\mathbf{V}}$ is a (K×N)×(K×N) diagonal value-added coefficient matrix[39]; $\mathbf{B}$ is the (K×N)×(K×N) global Leontief inverse matrix (where each block $\mathbf{B}_{c,p}$ is a K×K matrix that gives the amount of sectoral gross output in producing country *c* required per unit of output by each industry in destination country *p*); and $\mathbf{E}$ is a (K×N)×N matrix of gross exports (where each $\mathbf{e}_{p,s}$ is a K×1 vector of gross exports of country *p* to country *s* by source industry).[viii]

The diagonal terms of matrix **VAX** measure the domestic value-added embodied in each country's gross exports (i.e., $\widehat{\mathbf{V}}_c \sum_s \mathbf{B}_{c,c}\mathbf{e}_{c,s}$ is a K×1 vector of domestic value-added contained in country *c*'s exports by source industry). Each country's indirect value-added exports (i.e., the domestic value-added embodied as intermediate inputs in third countries' gross exports) are given by the sum of off-diagonal elements along each row of matrix **VAX**[40]:

$$\mathrm{DVAX2}_c = \boldsymbol{\iota}\widehat{\mathbf{V}}_c \sum_{p\neq c}\sum_{s} \mathbf{B}_{c,p}\mathbf{e}_{p,s} \qquad (2.40)$$

[41][ix]

Finally, the re-imported domestic value-added content of gross exports can be computed for each country *c* as the difference between total value-added exports and its direct and indirect components[42]:

$$\mathrm{DVAXR}_c = \boldsymbol{\iota}\widehat{\mathbf{V}}_c \sum_{s} \mathbf{B}_{c,c}\mathbf{e}_{c,s} - \mathrm{DVAXD}_c - \mathrm{DVAXI}_c \qquad (2.41)$$

[x]

As noted above, these estimates are likely, in practice, to be upward biased.

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39 $\widehat{\mathbf{V}} = \begin{pmatrix} \widehat{\mathbf{V}}_1 & 0 & \cdots & 0 \\ 0 & \widehat{\mathbf{V}}_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \widehat{\mathbf{V}}_N \end{pmatrix}$, where each $\widehat{\mathbf{V}}_c$ is a K×K diagonal matrix of direct value-added coefficients of country *c* by source industry. The *i*th element of the diagonal of each $\widehat{\mathbf{V}}_c$ matrix is $v_{c,i} = 1 - \sum_p \sum_j a_{p,c}(j,i)$, where $a_{p,c}(j,i)$ is the value of inputs from industry *j* in source country *p* required by industry *i* in destination country *c* for one unit of output. Alternatively, $\widehat{\mathbf{V}} = \mathrm{diag}[(\mathbf{I}-\mathbf{A}')\boldsymbol{\iota}]$, where $\mathbf{A}'$ is the transpose of the (K×N)×(K×N) global technical coefficient matrix, $\mathbf{I}$ is a (K×N)×(K×N) identity matrix, and $\boldsymbol{\iota}$ is a (K×N)×1 vector of ones. Thus, the first set of K elements of the diagonal of $\widehat{\mathbf{V}}$ contains the value-added coefficients for country *c*=1, followed by the K value-added coefficients for country *c*=2, and so on.

40 The name given here to this indicator (DVAX2) was adopted following the criterion used for naming the measures of vertical specialisation presented before (i.e., VS and VS2).

41 The so-called reflected domestic value-added (i.e., the domestic value-added embodied in a country's intermediate exports used by the direct importer to produce goods shipped back to source) can be separated from indirect value-added exports in equation (2.38) (as $\boldsymbol{\iota}\widehat{\mathbf{V}}_c \sum_p \mathbf{B}_{c,p}\mathbf{e}_{p,c}$).

42 DVAX is equivalent to OECD-WTO's EXGR_DVA indicator, and DVAXSH is equivalent to OECD-WTO's EXGR_DVASH indicator. The OECD-WTO database also provides separate measures for the direct, indirect and re-imported components of the domestic value-added content of exports (called EXGR_DDC, EXGR_IDC and EXGR_RIM, respectively).

Foreign value-added content of exports

The foreign value-added content of exports, conceptually similar to Hummels et al. (2001) VS1 indicator, can be computed for each country *c* from a multiregional IOT as the sum of off-diagonal elements along each column of matrix **VAX**:

$$\mathrm{FVAX_c} = \sum_{p \neq c} \boldsymbol{\iota}\widehat{\mathbf{V}}_p \sum_{s} \mathbf{B}_{p,c}\mathbf{e}_{c,s} = \sum_{p \neq c} \boldsymbol{\iota}\widehat{\mathbf{V}}_p \mathbf{B}_{p,c}\mathbf{e}_c \quad (2.42)$$

where $\widehat{\mathbf{V}}_p$ is the K×K diagonal matrix of value-added coefficients of country *p*; $\mathbf{B}_{p,c}$ is the K×K block matrix drawn from the global Leontief inverse that gives the amount of gross output in producing country *p* required for one unit of country *c*'s output (by origin and destination industries); $\mathbf{e}_{c,s}$ is a K×1 vector of gross exports of country *c* to country *s* by source industry; $\mathbf{e}_c$ is a K×1 vector of country *c*'s total gross exports by source industry; and $\boldsymbol{\iota}$ is a 1×K vector of ones.

This indicator can also be computed by breaking up exports by industry of origin, destination country, and/or type of demand served (final or intermediate), as in the case of DVAX. In addition, it can be decomposed by country of origin (i.e., $\mathrm{FVAX_{p,c}}$ representing the value-added from country *p* embodied in country *c*'s exports), and indeed by source industry within each origin country.

The FVAX ratio for country *c* is given by[43]:

$$\mathrm{FVAXSH_c} = \frac{\mathrm{FVAX_c}}{\boldsymbol{\iota}\mathbf{e}_c} = 1 - \mathrm{DVAXSH_c} \quad (2.43)$$

xi

Equation (2.43) shows that the sum of domestic and foreign value-added contents of exports must account for all gross exports (i.e., value-added from all sources must sum to official trade flows), both at aggregate and sector level (where taxes and subsidies on production and taxes (and subsidies) on products incurred on intermediate consumption by industries in country *c* are included in measures of domestic value added).

GVC participation index

[43] FVAX is equivalent to OECD-WTO's EXGR_FVA indicator, and FVAXSH is equivalent to OECD-WTO's EXGR_FVASH indicator.

Koopman et al. (2011) propose an indicator, referred to as the GVC participation index, which aims to capture the nature of a country's involvement in vertically fragmented production processes. The index of country *c* is given by:

$$\mathrm{GVC\_participation_c} = \frac{\mathrm{DVAX2_c}}{\boldsymbol{\iota}\mathbf{e}_\mathrm{c}} + \frac{\mathrm{FVAX_c}}{\boldsymbol{\iota}\mathbf{e}_\mathrm{c}} \qquad (2.44)$$

where $\mathrm{DVAX2_c}$ is the value-added of country *c* embodied as intermediate inputs in other countries' gross exports (or indirect value-added exports); $\mathrm{FVAX_c}$ is the foreign value-added embodied in country *c*'s gross exports; $\mathbf{e}_c$ is a K×1 vector of country *c*'s total gross exports by source industry; and $\boldsymbol{\iota}$ is a 1×K vector of ones.

Often the index is used to compare countries' participation in GVCs relative to other countries and over time. Indeed, a common interpretation is that the higher the foreign value-added embodied in gross exports and the higher the domestic value-added contained in third countries' gross exports, the higher the country's participation in international production chains. This is however a mistake, as the indicator only provides a measure of the relative importance in a country's exports of upstream (backward linkages) and downstream (forward linkages) positions in international production networks (where the downstream component provides a narrow measure of upstream participation). For example, a country with exports amounting to a marginal share of GDP may have a participation index of one, while a country with a low participation index could have a very high share of exports to GDP –indeed it should be noted that, typically, the larger the economy the lower the index–. Thus, the indicator should instead be used to describe the nature of a country's participation in GVCs. For countries lying upstream in the value-chain (i.e., those who participate by providing inputs to other countries), the indirect value-added share in gross exports will generally be higher than the share of foreign value-added. In contrast, for countries lying downstream in the value-chain (i.e., those who use a large portion of imported intermediates to produce final goods for exports), the share of foreign value-added will be higher than that of indirect value-added exports.

Note, too, that the downstream component of the index strictly attempts to capture value added embodied in parts that are shipped through to a third country, to provide a narrow definition of GVC participation. As such, by design, it does not capture any domestic value added exported in intermediate inputs that are used by the importing country to produce goods for domestic final consumption. In other words, the indicator is likely to produce a lower estimate of GVC participation (as defined) for countries whose exports of intermediates are disproportionately directed to larger economies, where the capacity to further process the intermediates for selling on in their larger consumer market, is also larger, compared to smaller economies.

In addition, it should be noted that the measure is designed to capture the flows of value added as they pass through GVCs. In this sense, which is also a consideration for many other GVC indicators (including VS), it is important to note that the measure will be affected by the extent to which the parent firm, controlling a value chain with goods and services passing through affiliates, chooses to record flows related to management and control services, and in particular flows related to the use of intellectual property. In practice, especially because of the opportunities provided by fiscal optimisation, these can be recorded in official statistics as either primary income flows (and, so, not recorded as trade) or trade in services. In the latter case, participation indices will generally provide lower measures of participation, all other things being equal, for the countries where parent firms are located.

Value-added induced by final demand

The indicators that decompose gross export flows on the basis of the origin and destination of value-added presented above are not the only prism through which trade in value-added can be measured. A complementary approach is to look at where the value-added is consumed as final consumption at the end of the value chain.

Measures of trade in value-added based on this approach can be computed using multiregional input-output data, from which the global value-added production matrix is obtained as[44]:

$$\mathbf{VAF} = \widehat{\mathbf{V}}\mathbf{BF} = \begin{pmatrix} \widehat{\mathbf{V}}_1 \sum_s \mathbf{B}_{1,s}\mathbf{f}_{s,1} & \cdots & \widehat{\mathbf{V}}_1 \sum_s \mathbf{B}_{1,s}\mathbf{f}_{s,p} & \cdots & \widehat{\mathbf{V}}_1 \sum_s \mathbf{B}_{1,s}\mathbf{f}_{s,N} \\ \vdots & & \vdots & \ddots & \vdots \\ \widehat{\mathbf{V}}_c \sum_s \mathbf{B}_{c,s}\mathbf{f}_{s,1} & \cdots & \widehat{\mathbf{V}}_c \sum_s \mathbf{B}_{c,s}\mathbf{f}_{s,p} & \cdots & \widehat{\mathbf{V}}_c \sum_s \mathbf{B}_{c,s}\mathbf{f}_{s,N} \\ \vdots & & \vdots & \ddots & \vdots \\ \widehat{\mathbf{V}}_N \sum_s \mathbf{B}_{N,s}\mathbf{f}_{s,1} & \cdots & \widehat{\mathbf{V}}_N \sum_s \mathbf{B}_{N,s}\mathbf{f}_{s,p} & \cdots & \widehat{\mathbf{V}}_N \sum_s \mathbf{B}_{N,s}\mathbf{f}_{s,N} \end{pmatrix} \quad (2.45)$$

where $\widehat{\mathbf{V}}$ is the (K×N)×(K×N) diagonal value-added coefficient matrix; $\mathbf{B}$ is the (K×N)×(K×N) global Leontief inverse matrix (where each block $\mathbf{B}_{c,s}$ is a K×K matrix that

[44] Based on Koopman et al. (2014).

gives total requirements from country *c* for one unit of country *p*'s gross output, by origin and destination industries); and **F** is a (K×N)×N matrix of final demand (where each $\mathbf{f}_{s,p}$ is a K×1 vector of final products produced in country *s* and consumed in country *p*).

Thus, elements in the diagonal columns of the (K×N)×N matrix resulting from equation (2.45) (i.e., $\widehat{\mathbf{V}}_c \sum_s \mathbf{B}_{c,s}\mathbf{f}_{s,c}$) give each country's production of value-added absorbed at home (including the domestic value-added that returns home after being processed abroad: $\widehat{\mathbf{V}}_c \sum_{s\neq c} \mathbf{B}_{c,s}\mathbf{f}_{s,c}$). Exports of value-added that are finally consumed as final demand are given by the elements in the off-diagonal columns of matrix **VAF**.

From the final demand perspective, total domestic value-added induced in country *c* by foreign final demand (or total value-added exports) can therefore be computed as:

$$\mathrm{DVAF_c} = \boldsymbol{\iota}\widehat{\mathbf{V}}_c \sum_{p\neq c}\sum_{s} \mathbf{B}_{c,s}\mathbf{f}_{s,p} \tag{2.46}$$

where $\boldsymbol{\iota}$ is a 1×K vector of ones.[xii]

Following Koopman et al. (2014), DVAF can be decomposed according to where and how value-added exports are absorbed:

$$\mathrm{DVAF_c} = \boldsymbol{\iota}\widehat{\mathbf{V}}_c \sum_{p\neq c} \mathbf{B}_{c,c}\mathbf{f}_{c,p} + \boldsymbol{\iota}\widehat{\mathbf{V}}_c \sum_{p\neq c} \mathbf{B}_{c,p}\mathbf{f}_{p,p} + \boldsymbol{\iota}\widehat{\mathbf{V}}_c \sum_{p\neq c}\sum_{s\neq c,p} \mathbf{B}_{c,p}\mathbf{f}_{p,s} \tag{2.47}$$

The first term in equation (2.47) is the domestic value-added content of country *c*'s (direct) final exports; the second term denotes the domestic value-added embodied in country *c*'s intermediate exports used by the direct importing country to produce final products that are consumed domestically; and the third term is the domestic value-added in country *c*'s intermediate exports used by the direct importing country to produce final products for third countries.

Thus, the demand-side approach provides a measure of the value-added of one country directly and indirectly contained in other countries' final demand. By reflecting the domestic value embodied in each country's exports of intermediates that are further processed and sold to final consumers in other countries, DVAF shows how industries in one country are connected to consumers in other countries, even where no direct trade relationship exists (Ahmad, 2015).

Value-added exports can also be expressed as a share of gross exports:

$$\text{DVAFSH}_c = \frac{\text{DVAF}_c}{\boldsymbol{\iota}\mathbf{e}_c} \tag{2.48}$$

where $\mathbf{e}_c$ is a K×1 vector of country *c*'s gross exports by source industry.

In addition, it is possible to calculate the foreign value-added induced by each country's domestic final demand (i.e., the value-added used by one country to satisfy its final demand but created in other countries). For each country *c*, total foreign value-added embodied in domestic final demand (or total value-added imports) can be computed as:

$$\text{FVAF}_c = \boldsymbol{\iota}\sum_{p\neq c}\sum_{s}\widehat{\mathbf{V}}_p\mathbf{B}_{p,s}\mathbf{f}_{s,c} \tag{2.49}$$

Similarly to DVAF, FVAF can be decomposed according to where and how value-added imports originate:

$$\text{FVAF}_c = \boldsymbol{\iota}\sum_{p\neq c}\widehat{\mathbf{V}}_p\mathbf{B}_{p,c}\mathbf{f}_{c,c} + \boldsymbol{\iota}\sum_{p\neq c}\widehat{\mathbf{V}}_p\mathbf{B}_{p,p}\mathbf{f}_{p,c} + \boldsymbol{\iota}\sum_{p\neq c}\sum_{s\neq c,p}\widehat{\mathbf{V}}_p\mathbf{B}_{p,s}\mathbf{f}_{s,c} \tag{2.50}$$

Therefore, total value-added imports of country *c* include the foreign value-added embodied in country *c*'s intermediate imports used to produce final products that are consumed domestically (first term of equation (2.50)); the foreign value-added that comes directly from a partner country to satisfy country *c*'s final demand (second term of equation (2.50)); and the foreign value-added in country *c*'s final imports that has been indirectly transferred through other partner countries (last term of equation (2.50)). Thus, this indicator shows how industries abroad are connected to consumers at home, even where no direct trade relationship exists.

The difference between DVAF and FVAF gives the country's trade balance in value-added terms:

$$\text{TBVAF}_c = \text{DVAF}_c - \text{FVAF}_c \tag{2.51}$$

The domestic value-added induced by foreign final demand (or value-added exports) can be decomposed into the value-added generated by final demand in different countries (which could also be grouped into regions). It can also be disaggregated by exporting industry. Similarly, foreign value-added induced in each country by domestic final demand (or value-added imports) can be decomposed by origin country and/or source industry, showing where this value-added originates. Thus, countries' trade positions in value-added terms can be calculated at the bilateral level.[45]

Length of GVCs[xiii]

The length of GVCs is defined by the number of production stages involved. It is related to the "average propagation length", an indicator whose origins lie in traditional input-output analysis (Dietzenbacher and Romero, 2007). Based on the index of the number of production stages proposed by Fally (2012a, 2012b) for a single country IOT, in an international IOT framework an index providing an indication of the length of GVCs can be computed as:

$$\mathbf{n} = \boldsymbol{\iota}(\mathbf{I} - \mathbf{A})^{-1} = \boldsymbol{\iota}\mathbf{B} \tag{2.52}$$

where $\mathbf{n}$ is a 1×(N×K) vector with the indexes for all countries and industries; $\boldsymbol{\iota}$ is a 1×(N×K) vector of ones; and $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$ is the global Leontief inverse.

An index value of one indicates that there is only a single production stage in the final industry, and increasing values reflect additional inputs from the same industry or other industries. It can also be computed distinguishing between domestic and imported inputs, illustrating the relative importance of domestic and foreign stages of the value chain.

Some care is however needed in using the index. For a start, it is important to note that the index is not in and of itself, in practice, a measure of length. More accurately, the index is a measure of the average number of stages (plants) involved in the production chain, weighted by the value added at each stage, and this in turn presupposes that the production chain follows a sequential (snakes) rather than concurrent (spiders) process (Baldwin and Venables, 2013).

In addition, the index in theory requires establishment (or plant) level data, which is not typically available in a conventional IOT (which instead provides data on the basis of industries, i.e., aggregations of plants). This means that the results can be, in turn, sensitive to the level of industry aggregation used in IOTs, and indeed the nature of the statistical unit (e.g., many European economies create their tables using information on enterprises and not establishments), and indeed whether transactions within firms are consolidated or not – typically the smaller the statistical unit, and the lower the degree of consolidation, the higher the estimate of the stages of production. Nevertheless, despite these caveats, the indicator provides useful, albeit broad, insights on the length and evolution of the value chains.

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[45] OECD-WTO's demand-side indicators include the domestic value-added embodied in foreign final demand (FFD_DVA), the foreign value-added embodied in domestic final demand (DFD_FVA), as well as the bilateral trade balance in value-added terms (BALVAFD).

Distance to final demand[xiv]

Distance to final demand reflects countries' location in the value chain (upstream or downstream). Fally (2012a, 2012b) and Antràs et al. (2012) propose a measure of "upstreamness", based on the number of stages between the production of a good and final demand. Thus, starting from one industry in a given country, the index measures how many stages of production are left before the goods or services produced by this industry reach final demand.

In an international IOT framework, a measure of the distance to final demand can be computed as:

$$\mathbf{d} = \boldsymbol{\iota}(\mathbf{I} - \mathbf{G})^{-1} \tag{2.53}$$

where **d** is a 1×(N×K) vector with the indexes for all countries and industries; **ι** is a 1×(N×K) vector of ones; **I** is a (K×N)×(K×N) identity matrix; **G** is a (K×N)×(K×N) global matrix of output coefficients (or allocation coefficients); and $(\mathbf{I} - \mathbf{G})^{-1}$ is the so-called Ghosh inverse.[46] Note that the measure corresponds to the more traditionally known Ghosh-inverse forward-linkage measure.

A larger value of $d_c(i)$ implies that industry *i* in country *c* is more specialised in the production of inputs at the beginning of the value chain, relative to other industries with lower indexes. The same caveats presented above for length of GVCs are also relevant here.

2.3.5 Limitations of IOT based statistics

The use of multiregional IOTs has become a common approach for empirically evaluating countries' participation in GVCs. However, it is important to note that this data source poses some limitations. The construction of these tables is a data-intensive process and presents numerous challenges, creating a trade-off between country and time coverage and degree of reliability, because for certain countries the quality of the data is poor. In particular, the precise identification of the links between exports of one country and the purchasing industries or final demand consumers in the importing country is subject to numerous problems, due to data restrictions and inconsistencies across countries (Ahmad, 2015).

[46] Each coefficient of matrix **G** is given by $g_{c,p}(i,j) = z_{c,p}(i,j)/y_c(i)$, where $z_{c,p}(i,j)$ is the value of products from industry *i* in source country *c* used as intermediates by industry *j* in destination country *p*, and $y_c(i)$ is the value of industry *i*'s output in country *c*. Thus, these allocation coefficients represent the distribution of industry *i*'s output across domestic and foreign industries.

The allocation of trade flows by country and industry of origin and destination is based on a number of assumptions. The main one is the proportionality assumption, according to which the origin-country share of a given imported product consumed in a given country, and recorded in the import flow tables that often accompany national IOTs (which show imports by product, by industry or category of final demand), is the same for all industries in that country. Furthermore, for countries with no import flow tables available, the same share of intermediate imports in total intermediate consumption is assumed, for each product, for all purchasing industries.[47] This proportionality assumption may not reflect the actual origin when the quality of intermediate products required differs across industries and countries of origin specialise in particular qualities (Escaith, 2014b). The allocation of flows is even more challenging in the case of services, as the availability of data on bilateral trade in services is limited, especially for developing countries.

As noted above, another drawback of multiregional IOTs is their high degree of sectoral aggregation, which does not reflect the detailed level of specialisation that characterises the fragmentation of production processes across countries. This creates an aggregation bias, as different firms (and different underlying GVCs) are allocated to a single industry. It is assumed that all firms in that industry use the same production technique to produce the same products, which are sold to the same consumers and markets. However, in reality exporting firms may differ widely in their production techniques and use of foreign inputs from firms producing only for the domestic market (Escaith, 2014b). This will generally result in lower shares of foreign content than might be recorded if more detailed IOTs were available (Ahmad, 2015).

To account for firm heterogeneity, more detailed information is needed. As pointed out by Ahmad (2015), this does not necessarily demand increasing the number of industries but disaggregating industries available within current IOTs into characteristics required to better measure GVCs (for example, into groups of exporting firms and non-exporting firms). Micro-level measurement and analysis of GVCs would also allow controlling for firm heterogeneity, establishing the links between firms in the different countries and in different stages of the production process; however, further micro-data disclosure and sharing is required to allow for progress in this front (Amador and Cabral, 2014).

An important new challenge for trade in value added indicators based on IOTs concerns the recent changes introduced in the 2008 SNA. The two most relevant in this respect are the changes related with 'goods sent abroad for processing' and 'merchanting'. The 2008 SNA

[47] The standard assumption is to apply a fixed import proportion to all product's purchasers (industries and final consumers), equal to the ratio of imports to total domestic demand for that product.

recommends that imports and exports should be recorded on a strict change of ownership basis. That is, flows of goods between the country owning the goods and the country providing the processing services should not be recorded as imports and exports of goods. Instead, the fee paid to the processing unit should be recorded as an import of processing services by the country owning the goods and an export of processing services by the country providing it. The consequence of this for trade-in-value-added based indicators may be profound. For example, following the implementation of the 2008 SNA recommendations, countries with large processing activities, and therefore with a high import content of exports in current trade in value added estimates, will see significant falls in these ratios (as any intermediate import used in the processing activity whose ownership remains with the principal firm supplying the processor will no longer be recorded as intermediate consumption on official SUTs and IOTs). Other indicators, for example the backward component of the GVC participation index, will be similarly affected. For mechanting, complications will be introduced whenever purchases and subsequent sales by a merchanter cross over two periods, as in the first period an imputation for imports as a negative export will necessarily be made in the country where the merchanter is resident. To overcome these challenges, the OECD is working with partners to investigate the scope to re-impute flows for goods for processing, such that intermediate consumption of imports continues to be recorded (in other words, assuming that ownership has changed).

2.4 Some final considerations

The increasing fragmentation of production processes across countries has challenged economists and statisticians to find new ways to measure the extent of this phenomenon and its potential implications. The purpose of this paper is to present a review of the main indicators on GVCs currently in widespread use, and to serve as a guide for empirical work.

The indicators commonly used to analyse countries' participation in international production networks, based on either international trade data or IOTs, each have their strengths and weaknesses. Measures based on international trade data have the advantage of high coverage (in terms of countries and time periods) and low complexity of the required data, as well as an acceptable degree of comparability across countries. In addition, the detailed product-level information on trade in intermediate goods –relative to that of IOTs – allows for a more precise characterisation of countries' specialisation patterns. However, a shortcoming of trade data is that there is no link to production, and so to the industry of origin or indeed the industry actually using any intermediate in its production process. Additionally, the growing complexity of international production networks makes it increasingly difficult for conventional trade measures to capture the full linkages among countries (since customs records often only reflect a product's last country of origin, although efforts are being made to improve this through the compilation of additional data such as country of consignment). Another important drawback of trade data is that they are affected by double-counting issues, as the value of intermediate products is counted each time they (or the good in which they are subsequently embedded) cross a national border, which can artificially inflate the importance of trade. Also, available trade data only insufficiently account for trade in services, since they do not reflect the value originating in service-related activities that is embodied in traded goods.

Indicators based on input-output statistics improve upon measures based on conventional trade data in terms of the accuracy of the resulting quantification and characterisation of GVCs. By capturing both direct and indirect linkages and exchanges between countries and industries, multiregional IOTs allow for the measurement of the foreign content of exports and the value truly generated by each country (and industry). This avoids the double-counting problems inherent in trade statistics, fully tracking the original sources of the value-added embodied in gross trade flows. However, the accuracy of the measurement of production fragmentation is constrained by the high degree of sectoral aggregation in IOTs, which creates an aggregation bias and generally, at least following the 1993 SNA, results in lower shares of foreign content than might be recorded if more detailed tables were available. Accuracy is also affected by the proportionality assumption, on which the allocation of trade flows by country of origin and destination is based. Additionally, the limited availability of comparable input-output data (especially for developing countries) hampers the country and time coverage of indicators based on input-output statistics.

Notwithstanding that indicators based on multiregional IOTs represent a substantial methodological advance, considerable work still needs to be done in order to adequately map and measure countries' participation in GVCs. The existing databases allow macro-sectoral level analyses, but more detailed information is required to account for firm heterogeneity (for example, by splitting industries into groups of exporting firms and non-exporting firms). The use of firm-level data, a line of research that has emerged recently, can also improve the quality of the information provided by IOTs; however, further micro-data disclosure and sharing is required to allow for progress in this front. Also, the coverage of developing countries in international IOTs should be extended using official data, in order to adequately reflect the actual specificities of these countries (Escaith, 2014b).

Appendix Chapter 2

OECD Inter-country Input-Output (ICIO) database

The OECD ICIO underpins the OECD-WTO TiVA database. The latest version of the ICIO contains data for 63 economies and 34 industries (on an ISIC Rev 3 basis) following the 1993 SNA, and cover the years 1995-2011, with additional tables based on now-casting techniques available for the 2012-2014 period. Future releases in 2018 and beyond will be on a 2008 SNA basis, as countries increasingly implement the latest accounting standards. The efforts in this regard are expected to be bolstered as regional partners engaged in similar initiatives, such as Eurostat's FIGARO initiative, APEC-TiVA, ECLAC, TiVA and NAFTA-TiVA, gather momentum.

A. Other initiatives to create inter-country input-output tables

An early example of efforts to look at inter-country relationships is the Global Trade Analysis Project (GTAP), coordinated by the Center for Global Trade Analysis of Purdue University. Set up in the 1990s, primarily for economic modelling purposes, the GTAP database is a "cross-section of consistent data on consumption, production, and trade" for a particular reference year.[48] Although the sources of the database are national IOTs, GTAP is not an international IOT (as this concept is understood). One drawback of this database is that it does not provide separate data for trade in intermediate and final products, thus making it necessary to transform trade flows in order to construct inter-country IOTs from GTAP data (Tsigas et al., 2012). Also, since it is benchmarked only on trade statistics, sector level supply and demand data for individual countries may show large discrepancies with corresponding national accounts statistics. Another shortcoming of the GTAP database is that there is no consistency imposed between its different versions, which makes it difficult to perform comparisons over time.

The first true inter-country IOT is the Asian International Input-Output Table (AIIOT), produced by the Institute of Developing Economies-Japan External Trade Organization (IDE-JETRO) in collaboration with the national statistical offices and research institutes of the participating countries. AIIOT comprises 9 Asian economies (China, Indonesia, Japan, Malaysia, Philippines, Republic of Korea, Singapore, Taiwan, and Thailand) plus the Unites States, with five-year interval tables for the period 1985-2005. More recently, international IOT

[48] The last version available (version 9), released in May 2015, has three reference years (2004, 2007 and 2011), 140 regions (countries) and 57 sectors. For a description of this and previous versions see www.gtap.agecon.purdue.edu/databases/default.asp.

databases with a more 'global' scope have become available, including the Trade in Value-Added (TiVA) database and the two described next: the World Input-Output Database (WIOD), and Eora.[49]

a) World Input-Output Database

The WIOD is a publicly available multiregional input-output database developed by a consortium of European institutions to "analyze the effects of globalization on trade patterns, environmental pressures and socio-economic development" (Timmer, 2012).[50] The most recent version, released in 2016, covers 43 countries which account for more than 85% of world GDP (the 28 members of the European Union, Norway, Switzerland, and 13 major non-European economies), and estimates for the non-covered part of the world (presented as "Rest of the world"), with a timeframe spanning 15 years (from 2000 to 2014).[51] This is an update to the 2013 release of the database, which covered 40 countries with a slightly earlier timeframe (from 1995 to 2011).[52]

The first step in the construction of the database was building a time series of national SUTs. National SUTs (or IOTs) published by the National Statistical Institutes were taken as a starting point to construct harmonised and standardised SUTs with 56 industries that together cover the entire economy.[53] These harmonized SUTs were then benchmarked to National Accounts and used to estimate national tables for non-benchmark years (using the so-called SUT-RAS method, developed for this specific purpose). The second step consisted in linking national SUTs across countries through detailed bilateral international trade statistics, to

[49] Other multiregional input-output databases are the GTAP-MRIO (based on the GTAP database) and EXIOPOL (see Tukker and Dietzenbacher, 2013; Andrew and Peters, 2013; and Tukker et al., 2013). Unlike WIOD, Eora and TiVA, these two databases are not publicly available and have a greater emphasis on environmental issues.

[50] The WIOD project, funded by the European Commission, included the following institutions: University of Groningen, and CPB Netherlands Bureau for Economic Policy Analysis (The Netherlands); Institute for Prospective Technological Studies (Spain); The Vienna Institute for International Economic Studies, and Österreichisches Institut für Wirtschaftsforschung (Austria); Zentrum für Europäische Wirtschaftsforschung, and Hochschule Konstanz (Germany); The Conference Board Europe (Belgium); Institute of Communication and Computer Systems (Greece); Central Recherche SA, and the Organisation for Economic Cooperation and Development (OECD) (France). The full database is available free of charge at www.wiod.org, and a detailed description of its construction can be found in Dietzenbacher et al. (2013).

[51] The non-European countries covered are Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Republic of Korea, Russia, Taiwan, Turkey, and the United States. Estimations for "Rest of the World" are based on bilateral trade data and totals for industry output and final use categories from the UN National Accounts, assuming the average input structure of key emerging countries (Brazil, Russia, India, China, Indonesia, and Mexico).

[52] See Timmer et al. (2016) for more information on the updated WIOD and how it compares to the initial release.

[53] Products classification is based on the international Classification of Products by Activity (CPA), while industries classification is based on revision 4 of the International Standard Industrial Classification of all economic activities (ISIC Rev. 4) (or ISIC Rev. 3 in the 2013 release of the WIOD). The tables adhere to the 2008 version of the SNA (in the 2013 release of the WIOD, the 1993 version of the SNA is used).

construct international SUTs in which the use of products is broken down according to origin country.[54] Finally, international SUTs were transformed into symmetric World Input-Output Tables (WIOTs) of the format 56 industries by 56 industries.

The WIOD database consists of time series of: 1) national tables (national IOTs at current prices and national SUTs at current and previous year prices), and 2) world tables (international SUTs at current and previous year prices, WIOTs at current and previous year prices, and interregional IOTs for 6 regions (Euro-zone, Non-Euro European Union, NAFTA, China, East Asia, and BRIIAT[55])). Additionally, the database provides detailed socio-economic and environmental satellite accounts (capital stock, investment, wages and employment by skill type, energy use, emissions, land use, materials use and water use). The tables trace the flows of consumption, production and incomes within and across countries, and break down products according to their origin. Thus, WIOD can be used for both inter-temporal and cross-country comparisons.

b) Eora database

Eora is a publicly available multiregional input-output database that focuses on environment issues and has as primary aim the comprehensiveness of coverage, both in terms of countries and industries.[56] It covers 187 countries with a time frame spanning from 1990 to 2011, and includes 25-500 industries (depending on the country).

The database draws upon information from a variety of primary data sources: national IOTs, SUTs and national accounts data from countries' statistical offices; macroeconomic aggregates from the United Nations National Accounts Main Aggregates Database; and trade data from the United Nations Commodity Trade Statistics Database (COMTRADE) and the United Nations Service Trade Statistics Database. In order to create a continuous time series of balanced and consistent multiregional IOTs, combining the often conflicting data sources and dealing with missing data, interpolation and estimation techniques are used. Since the tables are balanced to match principally data from large economies, there are important deviations from

[54] Use tables were first split into domestic products and foreign products (based on a distinction by end-use categories derived from a refinement of BEC codes); in a second stage, the use of foreign products was split according to country of origin.
[55] BRIIAT comprises Brazil, Russia, India, Indonesia, Australia, and Turkey.
[56] The Eora project was developed by the University of Sydney and funded by the Australian Research Council. The full database can be downloaded for free at http://worldmrio.com, and a description of its construction can be found in Lenzen et al. (2013). The UNCTAD TiVA dataset, which provides statistics related to trade in value-added, was constructed using the Eora multiregional IOTs.

observed trade flows and GDP (Cattaneo et al., 2013).[57] Therefore, the database should be used with caution, especially if a high reliability and precision of the results on smallest countries (for which input-output data availability is often very limited) is important.[58]

A guiding principle of Eora is close adherence to the raw data, in the sense that changes to the structure of the original raw data are avoided as much as possible, for the sake of transparency. Thus, the database includes original SUTs, industry-by-industry or product-by-product IOTs, depending on the country, with data expressed in current national currencies. These different national tables are linked into one yearly compound multiregional IOT (constructed in current US dollars), where original national sectoral disaggregations are maintained. However, Eora also provides a time series of harmonised multiregional IOTs, based on a 25-industry classification. The monetary tables are complemented by satellite accounts covering 35 environmental and resource use indicators.

The main advantage of Eora over WIOD is its broader country coverage, which makes possible a more comprehensive analysis of developing countries' participation in GVCs. However, the inclusion of data-poor countries reduces the level of statistical rigor, raising concerns about the accuracy of such analysis.

c) EXIOPOL database

EXIOPOL is a detailed, transparent, harmonised, global Multi-Regional Environmentally Extended Input-Output Table that covers 43 countries with 129 industry sectors and products. It also, by design, includes data on 30 emitted substances and 80 resources by industry. The latest version covers data for 2007.

[57] The database provides information on the reliability of the raw data by means of standard deviation estimates, which reflect the extent to which each data point was interpolated or estimated, during the process of assembling the global multiregional IOTs, from constituent primary data sources. However, in many cases the standard deviations of raw data are based on assumptions, since very little information on the uncertainty of macroeconomic and input-output data is available.

[58] For 74 of the 187 countries covered in the database, specific IOTs or SUTs were obtained from various statistical agencies. For a small number of countries (including Australia, the United Kingdom and some Central Asian economies) tailor-made input-output data sets were used. In other cases, national IOTs were estimated from actual macroeconomic aggregates using a "template" 25-sector IOT, which is considered to describe a typical economic structure.

Endnotes *These endnotes correct typos in the OECD Working Paper version (post-publication) and provide additional clarification or context.*

[i] *(p. 27)* The statement is not true in all situations (Hummels et al., 2001). For example, suppose a sector produces two goods: one that relies heavily on imported intermediates and is heavily exported; the second good uses no imported inputs and is not exported. At the sectoral level, VSD is underestimated (hence a disaggregation increases VSD). Aggregation matters and can lead to either an underestimation or overestimation of VSD.

[ii] *(p. 30)* The footnote should refer to equations (2.20), (2.22), and (2.26).

[iii] *(p. 32)* The footnote should refer to equation (2.28), not to (2.26).

[iv] *(p. 33)* The OECD-WTO TiVA initiative considers Trade in Value Added to include indicators that measure value-added embodied in gross trade *and* indicators that measure value-added embodied in (foreign) final demand. The OECD does not make a distinction in terminology between those two sets of indicators. However, in the Groningen tradition, only the latter set of indicators refers to trade in value-added (along the lines of Johnson and Noguera, 2012) while the former would be considered indicators based on vertical specialization (along the lines of Hummels et al., 2001).

We use the broad OECD meaning of trade in value added, which includes all the above indicators, to be consistent with the terminology still used by the organization that published this document. Thus the sections "Domestic value-added content of exports" and "Foreign value-added content of exports" (based on VAX notation) refer to indicators related to value-added embodied in gross trade (i.e., using the vertical specialization approach); and the section "Value-added induced by final demand" (based on VAF notation) refers to indicators related to value-added embodied in final demand (i.e., using the value-added exports approach). Note that our references to VAX do not relate to the VAX-ratio measure by Johnson and Noguera (2012).

For further information and a list of OECD indicators, many of which are similarly defined as ours, see: OECD (2019).

[v] *(p. 35)* Equation (2.34) contains a typo: instead of $\mathrm{VAXD_c}$ it should be $\mathrm{DVAXD_c}$.

[vi] *(p. 35)* The sentence in parenthesis is incorrect. The correct way of disaggregating the domestic value-added content of gross exports is by post-multiplying by a K×K diagonal matrix $\hat{\mathbf{E}}_\mathrm{c}$, indicating all exports for each separate industry, i.e., $\boldsymbol{\iota}\hat{\mathbf{V}}_\mathrm{c}[(\mathbf{I}-\mathbf{A}_\mathrm{c}^\mathrm{D})^{-1}-\mathbf{I}]\hat{\mathbf{E}}_\mathrm{c}$.

[vii] *(p. 36)* Equation (2.38) is misattributed as Johnson and Noguera's (2012) proposed VAX ratio. This is incorrect because the VAX ratio indicates the exports of value-added induced by foreign final demand (i.e., value-added exports) for each monetary unit of exports, not $\mathrm{DVAX_c}$ (which we had defined as domestic value-added embodied in gross exports).

[viii] *(p. 37)* This sentence contains a typo relating to the definition of the Leontief inverse. The Leontief inverse refers to the (extra) amount of sectoral gross output in producing country *c* required per (extra) unit of final demand (not "per unit of output").

[ix] *(p. 37)* The footnote should refer to equation (2.40), not to (2.38).

[x] *(p. 37)* In equation (2.41), $\mathrm{DVAXD_c} - \mathrm{DVAXI_c}$ can be simplified as $\mathrm{DVAX_c}$.

[xi] *(p. 38)* Equation (2.43) is only true if $\mathrm{DVAX_c} = \boldsymbol{\iota}\widehat{\mathbf{V}}_{\mathrm{c}}\mathbf{B}_{\mathrm{c,c}}\mathbf{e}_{\mathbf{c}}$. The previous paragraphs correctly explain how to measure the domestic value-added in gross exports using multi-regional or global IOTs (based on block matrices derived from the global Leontief inverse). This is what was intended to be reflected in equation (2.43). However, equation (2.33) had defined $\mathrm{DVAX_c}$ based on a national IOT, which could cause confusion in its interpretation. The definition of $\mathrm{DVAX_c}$ in equation (2.33) would be incorrect if used in the context of equation (2.43).

[xii] *(p. 41)* Note that Johnson and Noguera's (2012) VAX-ratio indicator is obtained by dividing $\mathrm{DVAF_c}$ by gross exports of country *c*.

[xiii] *(p. 43)* Equation (2.52) on length of GVCs is based on an indicator in De Backer and Miroudot (2014) and Los (2017). This indicator is inspired by Fally's indicator on GVC length (based on a national IOT), which we adapted to an ICIO table. We emphasize that this is only an indicator of the length of the value chain, not an actual measure of GVC length (which requires plant-level information).

Los (2017) observes that there are two key differences between the type of indicator we present in equation (2.52) and the measure of average propagation lengths (APL) proposed by Dietzenbacher and Romero (2007). First, the sale of a product to final users is a transaction in the production process. An index value of one thus implies that all goods and services produced are directly purchased by final consumers (i.e., no intermediate inputs are used to produce a final good or service). Second, the indicator aggregates all upstream industries *i* when measuring the average number of transactions required before final users are the owners of a product delivered by industry *j*.

Hence, Los (2017) argues that the indicator is appropriately characterized as showing the importance of specialized activities in GVCs. This is based on a weighted average of the production length involved in the industries that provide inputs to the production process. If equation (2.52) is element-wise post-multiplied by a (K×N)×(K×N) matrix of zeroes in the diagonal blocks and ones elsewhere, the average number of international transactions (giving the physical degree of international fragmentation of production processes) is computed.

[xiv] *(p. 44)* Equation (2.53) is better characterized as showing the position of countries in the value chain and gives the average number of production stages for industry output to be absorbed in final demand. This is also based on an indicator in De Backer and Miroudot (2014) and Los (2017). The measure corresponds to the row sum of the Ghosh Inverse matrix. The row sum gives the strength of total forward linkages in the production process (Johnson, 2018). Note that there is a mistake in the equation in De Backer and Miroudot (2014), which is also reflected in equation (2.53). The Gosh inverse should be post-multiplied (instead of pre-multiplied) by a vector of ones. Thus, the correct equation for distance to final demand (see e.g., Los, 2017) is $\mathbf{d} = (\mathbf{I} - \mathbf{G})^{-1}\boldsymbol{\iota}$, where $\boldsymbol{\iota}$ is a column-vector of ones and $\mathbf{d}$ is also a column-vector.