Identifying hubs and spokes in global supply chains using redirected trade in value added

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Abstract

The increasing importance of global supply chains has prompted the use of analytical tools based on trade in value added – instead of traditional measures in gross value. We use this analytical framework to develop indicators that identify hubs and spokes in international supply chains. Using these indicators and the Global Trade Analysis Project (GTAP) databases we identify the importance of redirected value added trade and the hub and spoke relationships at the aggregate level and for specific highly integrated industries.

Keywords: Trade in value added, vertical specialization, global supply chains, global input-output tables, hubs and spokes
JEL Classification: F1, C67, D57

1 Introduction

Production of goods and services is becoming more complex because of increasing trade in intermediate inputs. This not only entails a growing number of traded intermediate inputs, but also that these intermediates are increasingly located at various countries. As a result, production is increasingly organized along global supply

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chains in which the tasks required to produce goods and services are performed at many locations all over the world.[1]

Traditional trade statistics reporting the sales value –which is closely related to the production value– do not measure spatial fragmentation well. This was no problem when production processes were integrated within a single country. However, this changed with the increasing importance of international supply chains over the last decades. First, it creates a "double counting" problem: the value of traded intermediates is counted at least twice in the trade statistics if these intermediates are used in exports. Second, it is more difficult to associate production with final consumption, since intermediate goods produced in one country can be processed in a second country before they are exported and finally consumed in a third one –and these supply chains can easily include more than three countries. Thus, traditional trade statistics no longer provide sufficient information on where exports of intermediate inputs are used and in which part of the production process the country's firms are actually most active. In addition, the increased importance of global supply chains motivates the study of how different countries and regions integrate (or not) into them and the role these countries play within particular global supply chains.

The recent literature on trade in value added has overcome some of these problems by bringing together two old topics in international economics. The first draws on the old literature on input-output (IO) accounting in interregional models. The second relies on the more recent literature that measures vertical specialization and trade in domestic value added. The IO tables provide an account of the use of imported intermediate inputs in domestic production (i.e., we can distinguish between foreign and domestic value added in the production of final goods), while detailed and consistent multilateral international trade transactions provide a full account of trade in domestic value added with all trading partners.

The main purpose of this paper is to move beyond recently constructed indicators of vertical specialization –that measure the importance of international inputs as a share of gross trade– and develop new analytical tools that can map out the economic relations that underlie global supply chains. We contribute to the literature by creating indicators that can consistently identify the hubs and spokes in these global chains by industry and country. Until now hubs and spokes in the trading system were more informally addressed in the literature on bilateral free trade agreements (Baldwin, 2007) and in network analysis (De Benedictis and Tajoli, 2011). Because these papers only cover bilateral trade at the macro level it is hard to identify global supply chains. By analysing the value added of trade at the sectoral level we are able to link global trade patterns with global supply chains such as the Dreamliner

[1] A famous and often quoted example is the Boeing 787 Dreamliner. It is presently produced by 43 firms in 135 locations all over the world. From Boeing's headquarters in Chicago 70 percent of all tasks are offshored: A way of producing an airplane that was infeasible before the 1990s. The value added embedded in the Dreamliner as a final product is thus generated by all these firms and in all these locations. Another example is the global production process of the iPod (see Dedrick et al, 2010).

and the iPod. For that purpose we define global supply hubs as those industry-country pairs that use a relatively large share of imported value added in producing output for final use abroad. Our indicators also identify global supply spokes, which are the regions that are important suppliers of the intermediate inputs to the hubs –the incoming spokes– or the final destinations that are important receivers of the value added that is redirected by the hubs– the outgoing spokes.[2] The key element in identifying both hubs and spokes is redirected value added, either as a share of outgoing intermediate value added exports or as a share of incoming intermediate value added imports. We emphasize in our analysis the "pass-through" via a specific industry-country pair of incoming foreign intermediate value added imports that are leaving the country again to their foreign final destination and we call this pass-through "redirected value added".

The first general measure of foreign inputs in global production chains was provided by Hummels et al (2001). In their seminal paper they proposed to use the foreign intermediate content of exports as a measure of vertical specialization (VS).[3] However, the data employed and the VS indicator proposed in Hummels et al (2001) were not suitable to capture the intricacies and complexities of extended international supply chains where intermediate inputs flow through multiple countries, sometimes several times. These drawbacks have been highlighted in several recent papers on trade in value-added: Daudin et al (2011), Johnson and Noguera (2012a,b), Koopman et al (2010) and Koopman et al (2013). In addition, these papers have also overcome the data and methodological shortcomings. On the empirical side the data limitations have been overcome by using the GTAP datasets, which combine input-output tables with integrated trade flows for the global economy for specific years that yields a consistent global input-output matrix (cf. Dimaranan, 2006; Narayanan and Walmsley, 2008; Narayanan et al, 2012). This database can track production processes within different countries and provide measures of the value added required for trade flows.[4] We follow the recent literature and use the GTAP database, but it is important to note that the methodology that we develop in this paper to identify hubs and spokes is independent of the database, and thus it can be applied to alternative databases.

On the theoretical side, recent papers have constructed a similar methodological framework that can account for trade in value-added in the presence of multi-country and multi-stage production processes.[5] The main results for most of these papers

[2]In a recent paper Baldwin and Lopez-Gonzalez (2013) also identify the hubs in the global trading system, but mainly at the country level and only with sectoral disaggregation for China.

[3]In particular, VS is the share of intermediate imports in gross exports. If we define DV as the share of domestic value-added in gross exports then: VS+DV=1. Therefore, a higher VS value is associated with higher amounts of imports in exports (i.e. more vertical specialization), and less domestic value added in exports.

[4]More recently, the WIOD (Timmer, 2012; Dietzenbacher et al, 2013) and the OECD-WTO databases are also used to analyse trade in value added. However, the GTAP has a much larger number of countries: more than one hundred in contrast to only 40 in WIOD.

[5]Cf. Trefler and Zhu (2010), Daudin et al (2011), Johnson and Noguera (2012a,b), Koopman et al (2010), Koopman et al (2013) and Foster-McGregor and Stehrer (2013).

are relatively similar. They find that the average foreign content of domestic exports is between 20 to 30% (the VS measure).[6] In addition, bilateral trade balances are substantially different when comparing trade in value-added and gross trade. For instance, the trade deficit of the USA with China is around 30% smaller when using trade in value-added. These analyzes have successfully dealt with the double-counting issue. However, from their analysis it is not straightforward to identify hub-and-spoke patterns in global supply chains.

The main contribution of our paper is our usage of a decomposition of trade in value-added to create indicators that identify the hubs and spokes in international supply chains. Previous papers considered value added trade from the perspective of the origin or final destination country, while we focus on the final producer country.[7] In particular, we develop a decomposition of trade in value added into absorption (i.e. value added used and consumed in the destination country), diversion (i.e. value added which is incorporated in further processing activities in other countries before it is re-exported to the destination country) and reflection (i.e. value added that is further processed in another country and sent back to the home country) in an exhaustive and clear manner.

As a way to illustrate our methodology we calculate our indicators from global input-output tables derived from the GTAP database. Using our indicators we can clearly identify the spokes and hubs in global supply chains. Our results are consistent with other partial findings in the literature and they follow common priors: global production networks are mainly located in North America, Europe and the Asia-Pacific region (China, East Asia and Southeast Asia). Within these regions, some sub-regions act like hubs in a regional network. For instance, the region other NAFTA (ONA) serves as a hub for the USA, and the region EU12 (the new EU member states) is a hub for EU15 (the old EU member states).[8] In addition, our estimations also allow an in-depth industry analysis of hub and spoke relationships, which are mainly found for manufacturing sectors, such as electronic equipment (ELE), other machinery and equipment (OME), motor vehicles (MVH), other transport equipment (OTN) and chemicals, rubber and plastics (CRP). In particular, electronic equipment is the best example of a globally integrated supply chain which has its production core in the Asia-Pacific region, while the USA and EU15 are important outgoing spokes for the hubs in Asia. In the sector other machinery and equipment, EU15 and the Asia-Pacific region (except China) are the global hubs, while EU12 and OWE (other Western Europe) are regional hubs to the EU15 and ONA is a regional hub to the USA. We also find that although China's

[6] Johnson and Noguera (2012a) construct a different indicator –their VAX-ratio– which is the ratio of domestic value-added exports to gross exports, which is on average 73% in 2004. Daudin et al (2011) emphasize rationalization and use their "Trade Intensity Bilateral Index" between regions, which is also based on value added exports.

[7] In this respect, our paper is closest to Johnson and Noguera (2012a), who also analyse trade in value added within a triangular trading scheme. However, their focus is on the final destination rather than the final producer and their methodology does not identify the industry-country pairs that are important in redirecting trade in value added.

[8] This pattern is also analyzed in the recent paper by Johnson and Noguera (2012b).

importance as a global hub has been increasing for ELE and CRP, it is not a hub for the sectors OME, MVH and OTN. The relative importance of ONA as a hub in the OTN and MVH sectors has been decreasing between 2001 and 2007. Finally, for services, agriculture, and the energy sectors we do not find substantial global supply chains as measured by the shares of redirected value added.

The paper is organized as follows. In Section 2 we start with the general concepts and relations of global input-output analysis. We then explain our decomposition method of bilateral trade in value added and define our indicators for detecting hubs and spokes in global supply chains. We present our results for trade in value added and our identification of hubs and spokes at the industry level in Section 3. We conclude in Section 4.

2 Methodological framework

We provide the background and details of the methodology used to identify the different components of value-added trade. To make the exposition easier, we start with some remarks on notation. With the exception of the sets M and N, upper-case letters denote matrices (e.g. Z). All lower-case symbols (not denoting indexes or set-elements) represent vectors or scalars. To represent diagonal matrices we use the hat sign as in $\hat{z}$, which denotes a matrix with z on its main diagonal and zeros elsewhere. Z' indicates the transpose of matrix Z. The unit or summation vector is denoted by ι, and ι_s is used as a selection vector (the s^{th} entry of ι_s being one and all other entries being zero). The unit matrix is denoted by I. Regions, which can be a single country or a set of countries, are indexed by the letters r, s, σ and ρ, which are part of the set $M = \{1, 2, \cdots, m\}$, while sectors are indexed by i, j and k, which belong to the set $N = \{1, 2, \cdots, n\}$. Region-related matrices are denoted by Z_{rs}, where r refers to the region of origin and s to the region of destination. Final destinations are always indicated with a superscript. For instance, Z_{rs}^{ρ} denotes the input from region r that region s needs to produce final output for region ρ. Sector-related entries of matrices or vectors are denoted between brackets as in $Z(i, j)$, where i is the sector of origin and j the destination sector. We use w as a subscript that defines a variable with a global total, obtained via summation of subscripted variables over the region set M. For example, $Z_{rw} = \sum_{s \in M} Z_{rs}$. Similarly, we use t for an entry of a variable that represents results for the total economy, obtained via summation over the sector set N. Thus, $z(t) = \sum_{i \in N} z(i)$.

2.1 Trading schemes in global input-output analysis

We make use of global input-output matrices that have the following structure:[9]

$$\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1m} & f_1^1 & f_1^2 & \dots & f_1^m & x_1 \\ S_{21} & S_{22} & \cdots & S_{2m} & f_2^1 & f_2^2 & \dots & f_2^m & x_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \iddots & \vdots & \vdots \\ S_{m1} & S_{m2} & \cdots & S_{mm} & f_m^1 & f_m^2 & \cdots & f_m^m & x_m \\ p_1' & p_2' & \cdots & p_m' & & & & & \\ x_1' & x_2' & \cdots & x_m' & & & & & \end{bmatrix} \tag{1}$$

where S_{rs} denotes the $n \times n$ sectoral matrix of intermediate deliveries from region r to region s, f_r^s is the n vector with final outputs produced in region r that are used in region s, x_r is the vector containing gross output values of region r, while p_s' is the sectoral row-vector of length n denoting the sum total of primary inputs used in production in region s which equals sectoral value added. Finally, x_s' is the row-vector with gross input values used in region s.

For each region r total gross outputs equal the sum of intermediate outputs and final outputs or:

$$x_r(i) = S_{rw}(i,t) + f_r^w(i) \tag{2}$$

Gross input values are obtained from total use of intermediate outputs and value added:

$$x_s(j) = S_{ws}(t,j) + p_s(j) \tag{3}$$

Summarizing (1) as:

$$\begin{bmatrix} S & F & x \\ p' & & \\ x' & & \end{bmatrix} \tag{4}$$

we define matrices of input coefficients A and v: $A_{rs}(i,j) = S_{rs}(i,j)/x_s(j)$ denotes the delivery from sector i in region r to sector j in region s per unit of gross input (of sector j in region s), and $v_s(j) = p_s(j)/x_s(j)$ represents the use of value added in sector j of region s per unit of gross input (of sector j in region s). From (2) and the definition of A we have:

$$x = S\iota + F\iota = Ax + f^w = (I - A)^{-1} f^w = Bf^w \tag{5}$$

which relates global final demands f^w to gross production. The elements of the global Leontief inverse $B_{rs}(i,j)$ represent the amount of gross output (of sector i in region r) that is directly and indirectly needed per unit of final output (of sector j in region s).

[9] In fact, the GTAP dataset also includes specific entries for international transportation services. More specifically, intermediate supplies and intermediate and final demands for international transportation services. To keep our exposition as simple as possible, our treatment of these details is moved to Appendix 5.2.

Let us denote the ρ^{th} column of F as $f^\rho = F\iota_\rho$, which represents the use of final output in region ρ. Multiplying the gross output requirements for f^ρ with values added per unit of gross input yields the corresponding value added requirements (Θ) of final demands in ρ:

$$\Theta(f^\rho) = \hat{v}B\hat{f}^\rho \tag{6}$$

At the global level value added exactly matches final demand. Hence, $v'B$ equals the unit vector.[10] Then, it is easily verified that the column sum of $\Theta(f^\rho)$ equals final output use in ρ:

$$\iota'\Theta(f^\rho) = v'B\hat{f}^\rho = f'^\rho \tag{7}$$

and that the row sum equals the value added required for this final output use:

$$\Theta(f^\rho)\iota = \hat{v}Bf^\rho = \hat{v}x(f^\rho) = p(f^\rho) \tag{8}$$

where we expressed both gross output x and value added p as a function of the final demand vector f^ρ. Recall that $\hat{v}$ is the diagonal matrix of v.

Not all values added in $\Theta(f^\rho)$ are traded internationally. There is one block in this matrix where part of domestic value added remains at home: $\hat{v}_\rho B_{\rho\rho}\hat{f}^\rho_\rho$, which represents domestic values added needed to produce domestic final output that is used at home. To obtain a matrix that contains only traded values we first need to subtract, within this block, the non-traded component $(\hat{v}_\rho \Delta^{-1}_{\rho\rho}\hat{f}^\rho_\rho)$[11] to obtain the trade-only block: $\hat{v}_\rho(B_{\rho\rho} - \Delta^{-1}_{\rho\rho})\hat{f}^\rho_\rho$, which represents value added exports from ρ that are needed abroad to produce the intermediate imports required for the production of f^ρ_ρ.

Thus, we arrive at the matrix Γ^ρ, which contains the cross-border bilateral value added requirements for final output use in region ρ:

$$\Gamma^\rho = \underbrace{\begin{bmatrix}
\hat{v}_1B_{11}\hat{f}^\rho_1 & \hat{v}_1B_{12}\hat{f}^\rho_2 & \cdots & \hat{v}_1B_{1r}\hat{f}^\rho_r & \cdots & \hat{v}_1B_{1\rho}\hat{f}^\rho_\rho & \cdots & \hat{v}_1B_{1m}\hat{f}^\rho_m \\
\hat{v}_2B_{21}\hat{f}^\rho_1 & \hat{v}_2B_{22}\hat{f}^\rho_2 & \cdots & \hat{v}_2B_{2r}\hat{f}^\rho_r & \cdots & \hat{v}_2B_{2\rho}\hat{f}^\rho_\rho & \cdots & \hat{v}_2B_{2m}\hat{f}^\rho_m \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \iddots & \vdots \\
\hat{v}_rB_{r1}\hat{f}^\rho_1 & \hat{v}_rB_{r2}\hat{f}^\rho_2 & \cdots & \hat{v}_rB_{rr}\hat{f}^\rho_r & \cdots & \hat{v}_rB_{r\rho}\hat{f}^\rho_\rho & \cdots & \hat{v}_rB_{rm}\hat{f}^\rho_m \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \iddots & \vdots \\
\hat{v}_\rho B_{\rho 1}\hat{f}^\rho_1 & \hat{v}_\rho B_{\rho 2}\hat{f}^\rho_2 & \cdots & \hat{v}_\rho B_{\rho r}\hat{f}^\rho_r & \cdots & \hat{v}_\rho(B_{\rho\rho} - \Delta^{-1}_{\rho\rho})\hat{f}^\rho_\rho & \cdots & \hat{v}_\rho B_{\rho m}\hat{f}^\rho_m \\
\vdots & \vdots & \iddots & \vdots & \iddots & \vdots & \ddots & \vdots \\
\hat{v}_mB_{m1}\hat{f}^\rho_1 & \hat{v}_mB_{m2}\hat{f}^\rho_2 & \cdots & \hat{v}_mB_{mr}\hat{f}^\rho_r & \cdots & \hat{v}_mB_{m\rho}\hat{f}^\rho_\rho & \cdots & \hat{v}_mB_{mm}\hat{f}^\rho_m
\end{bmatrix}}_{\begin{bmatrix} f'^\rho_1 & f'^\rho_2 & \cdots & f'^\rho_r & \cdots & f'^\rho_\rho - v'_\rho\Delta^{-1}_{\rho\rho}\hat{f}_\rho & \cdots & f'^\rho_m \end{bmatrix} \text{ Column sums}}
\overbrace{\begin{bmatrix} p_1(f^\rho) \\ p_2(f^\rho) \\ \vdots \\ p_r(f^\rho) \\ \vdots \\ p_\rho(f^\rho) - \hat{v}_\rho\Delta^{-1}_{\rho\rho}f^\rho \\ \\ p_m(f^\rho) \end{bmatrix}}^{\text{Row sums}} \tag{9}$$

The diagonal matrix elements denote domestic inputs and the off-diagonal ones indicate foreign inputs. Along the rows of Γ^ρ we find the value added exports from a specific country into final output production for ρ in the different countries

[10] The direct proof is by rewriting $v' = \iota'(I - A)$ and then evaluating $v'B = \iota'(I - A)B = \iota'$.

[11] $\Delta^{-1}_{\rho\rho}$ denotes the local Leontief inverse for country ρ, i.e. the Leontief inverse obtained from the national input-output table of ρ.

producing this output. Strictly, the matrix contains sector-specific entries, such that $\Gamma^{\rho}_{r\sigma}(i,j)$ represents the internationally traded value added from sector i in region r that is needed by final producer σ for final j-output use in ρ. More loosely, we describe the entries of this matrix as bilateral value added trade needed for final output use in ρ. For example, $\Gamma^{\rho}_{r\sigma}$ provides the value added generated in r that is used by the final producer σ to supply the final destination ρ.

2.2 Decomposing bilateral trade in value added

We show how we can distinguish different varieties of trade in value added by a simple inspection of the various entries of Γ^{ρ}. We attach four different interpretations to the export flows that are present in this matrix.

First, we consider the blocks on the main diagonal except the one that gives the domestic requirements for the production of f'^{ρ}_{ρ}:

$$\Gamma^{\rho}_{rr} = \hat{v}_r B_{rr} \hat{f}^{\rho}_{r} \quad \forall (r,\rho) \in M : r \neq \rho \tag{10}$$

These Γ^{ρ}_{rr} flows represent domestic value added from region r that is needed to produce final output exports in r for the foreign final destination ρ.

Second, turning to the column with the requirements for f'^{ρ}_{ρ}, we consider:

$$\Gamma^{\rho}_{r\rho} = \hat{v}_r (B_{r\rho} - \delta_{r\rho}\Delta^{-1}_{\rho\rho}) \hat{f}^{\rho}_{\rho} \quad \forall (r,\rho) \in M \tag{11}$$

where $\delta_{r\rho}$ is a toggle variable which is one if $r = \rho$ and zero otherwise. These $\Gamma^{\rho}_{r\rho}$ exports indicate value added generated in r for intermediates used by region ρ to produce final output consumed domestically.

Third, we consider the blocks:

$$\Gamma^{\rho}_{r\sigma} = \hat{v}_r B_{r\sigma} \hat{f}^{\rho}_{\sigma} \quad \forall (r,\sigma,\rho) \in M : r \neq \rho, r \neq \sigma, \sigma \neq \rho \tag{12}$$

These $\Gamma^{\rho}_{r\sigma}$ exports represent values added generated in r that are diverted by region σ via final output exports from σ to ρ.

Fourth, we inspect the blocks:

$$\Gamma^{\rho}_{\rho\sigma} = \hat{v}_{\rho} B_{\rho\sigma} \hat{f}^{\rho}_{\sigma} \quad \forall (\sigma,\rho) \in M : \sigma \neq \rho \tag{13}$$

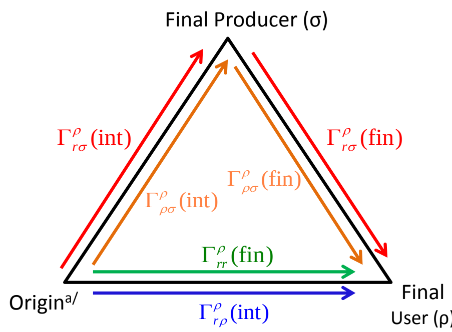
These $\Gamma^{\rho}_{\rho\sigma}$ exports indicate value added generated in ρ that is reflected by σ –through its final output exports– back again to ρ.

We conclude that four different types of value added exports can be distinguished. The value added requirements defined as $\Gamma^{\rho}_{rr}(r \neq \rho)$ are for direct final output exports. The requirements in $\Gamma^{\rho}_{r\rho}$ are for intermediates converted to final use in the final destination region, while $\Gamma^{\rho}_{r\sigma}(r \neq \rho, r \neq \sigma, \sigma \neq \rho)$ represents the requirements for intermediates diverted to third countries. Finally, $\Gamma^{\rho}_{\rho\sigma}(\sigma \neq \rho)$ are the value added requirements for intermediates that are reflected back to the original region. We use the term "redirected" value added trade to refer to the sum total of diverted and reflected trade in value added.

2.3 Triangular trading scheme and links with other indicators

We illustrate the information on these four categories of value added exports with Figure 1. Note that the final producer is importing –either directly or indirectly– intermediates from the origin: $\Gamma^{\rho}_{r\sigma}(int)$ and $\Gamma^{\rho}_{\rho\sigma}(int)$, while it exports final output: $\Gamma^{\rho}_{r\sigma}(fin)$ and $\Gamma^{\rho}_{\rho\sigma}(fin)$. Also, by definition the final destination region of reflected trade: $\Gamma^{\rho}_{\rho\sigma}(fin)$ is the same as the origin region.

Figure 1: Triangular trading scheme



Note a/: The region of origin can be a third region (r), the same as the final producer (σ) or the same as the final user (ρ).

Figure 1 shows that we analyse bilateral trade in value added from different perspectives. For instance, we can focus on trade in value added from a particular origin to a specific final destination by taking the sum of all flows that pass through the final producers (Γ^{ρ}_{rw}). It is from this perspective that bilateral trade balances in value added are collected and Johnson and Noguera (2012a) analyse trade in value added in this way. Alternatively we can focus on trade in value added from a particular origin to a specific final producer by taking the sum of all flows that leave the final producer ($\Gamma^{w}_{r\sigma}$). Looking at trade from this perspective emphasizes the productive use of value added imports by the final producer. It is mainly from this perspective that Koopman et al (2010) and Koopman et al (2013) analyse trade in value added. A third perspective is to focus on the pass-through of value added trade via a specific final producer by taking the alternating sums over origins ($\Gamma^{\rho}_{w\sigma}$) and final destinations ($\Gamma^{w}_{r\sigma}$). The former provide us with the value added exports by the final producer to specific destinations and the latter with its value added imports from specific origins. It is from this "pass-through" perspective that we analyse trade in value added in this paper.[12]

Our measures of value added exports are closely related to the value added export measures used by Johnson and Noguera (2012a), Koopman et al (2010) and Koopman et al (2013). But there are differences too. First, our value added exports

[12]Note that our triangular scheme only contains the first country of the global supply chain and the last-but-one and last country of that chain. All the intermediate countries between the final and last-but-one country of the chain are ignored in our analysis.

are somewhat larger than those of our colleagues because we both include value added exports for final output produced and used at home and value added exports that return home via final output imports. Second, we aggregate value added exports over sectors of origin whereas both Johnson and Noguera (2012a) and Koopman et al (2010) aggregate over sectors of final use.

2.4 Hubs and spokes indicators

The vertical specialization case that we focus on in this paper is the assembly of final output from imported intermediates. The production of iPods in China, the assembly of cars in Eastern Europe and the construction of airplanes in Europe and the USA are typical examples of this type of outsourcing. The decomposition of trade in value added provides us with the opportunity to examine the position of countries in global production networks. We focus on trade in value added for intermediates. These intermediates are converted into final products in the importing country and can then be diverted to third countries or reflected to the home country. The importance of redirected (i.e. diverted plus reflected) value added in a country's intermediate trade identifies its position in global production networks compared to other trade. We now define our indicators for detecting hubs and spokes in global supply chains at the industry level based on redirected value added trade.

We first present the bilateral value added trade flows of the final producer with both the origin and the final destination. The bilateral exports *to* final producer σ (the incoming spokes) are given by:

$$\Gamma^{w}_{r\sigma}(t,j) = \overbrace{\Gamma^{\sigma}_{r\sigma}(t,j)}^{\text{absorbed in } \sigma} + \underbrace{\overbrace{\sum_{\rho\neq\sigma,r}\Gamma^{\rho}_{r\sigma}(t,j)}^{\text{diverted by } \sigma} + \overbrace{\Gamma^{r}_{r\sigma}(t,j)}^{\text{reflected by } \sigma}}_{\text{redirected by } \sigma} \quad \forall(r,\sigma)\in M : r\neq\sigma \tag{14}$$

and the bilateral exports *from* final producer σ (the outgoing spokes) can be derived as:[13]

$$\Gamma^{\rho}_{w\sigma}(t,j) = \overbrace{\Gamma^{\rho}_{\sigma\sigma}(t,j) + \underbrace{\sum_{r\neq\sigma,\rho}\Gamma^{\rho}_{r\sigma}(t,j) + \Gamma^{\rho}_{\rho\sigma}(t,j)}_{\text{redirected by } \sigma}}^{\text{absorbed in } \rho} = f^{\rho}_{\sigma}(j) \quad \forall(\sigma,\rho)\in M : \sigma\neq\rho \tag{15}$$

Equation (14) shows that the final producer imports intermediate value added for own final output production that is consumed domestically and intermediate value added for final output exports. Equation (15) shows that the final output

[13]The last equality of (15) is based on $\gamma^{\rho}_{w\sigma}{}' = \sum_{r} \upsilon'_{r} B_{r\sigma}\hat{f}^{\rho}_{\sigma} = f^{\rho}_{\sigma}{}'$ because $\sum_{r}\upsilon'_{r}B_{r\sigma} = \iota'\sum_{r}(I-\sum_{s}A_{sr})B_{r\sigma} = \iota'$

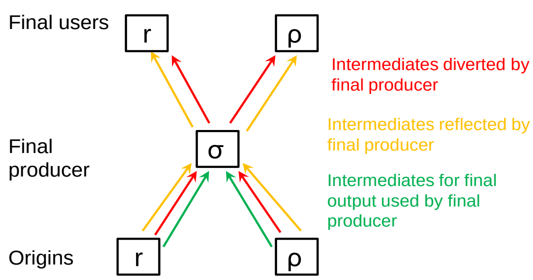
exports of the final producer consist of a bundle of own value added and the foreign intermediate value added that it redirects.

The incoming spokes and outgoing spokes are shown in Figure 1, where $\Gamma^{\rho}_{r\sigma}(int)$ and $\Gamma^{\rho}_{\rho\sigma}(int)$ are the incoming spokes and $\Gamma^{\rho}_{r\sigma}(fin)$ and $\Gamma^{\rho}_{\rho}(fin)$ are the outgoing spokes. If the incoming trade is large and the outgoing trade is small the final producer is just importing intermediates for own final use. However, if the outgoing trade is relatively large with respect to the incoming trade, we define the final producer as a hub. Thus, to identify if a region/country σ qualifies as a j-hub we use the following indicator:

$$SF_{\sigma}(j) = \frac{\sum_{r\neq\sigma}\sum_{\rho\neq\sigma}\Gamma^{\rho}_{r\sigma}(t,j)}{\sum_{r\neq\sigma}\Gamma^{w}_{r\sigma}(t,j)} \tag{16}$$

where SF measures foreign redirected value added as a share of total bilateral value added imports that region σ needs to produce final j-output. This is an intensity measure showing the relative importance of region σ in assembling final j-output for the world market. Figure 2 illustrates the calculation of SF. For a specific final producer (σ), we determine the share of outgoing foreign intermediates in final output exports (the arrows from the final producer to the final users) as a percentage of total imports of foreign intermediates (the arrows from the origins to the final producer).

Figure 2: Calculating the SF indicator



A large SF_{σ} value indicates that a large share of imported intermediate inputs is redirected by region σ and hence, that this region is integrated into an international supply chain. We consider region σ to be a hub in the global supply chain of industry j if its $SF_{\sigma}(j)$ value is above the global value $SF_{w}(j)$, which is a weighted average of the world's $SF(j)$ values. Thus, SF is our primary measure to identify hubs in global supply chains.

However, having a large SF value is not informative on the size of the hub, nor on the regional or global nature of the hub. To address the first point we use the GSF indicator:

$$GSF_{\sigma}(j) = \frac{\sum_{r\neq\sigma}\sum_{\rho\neq\sigma}\Gamma^{\rho}_{r\sigma}(t,j)}{\sum_{s}\sum_{r\neq s}\sum_{\rho\neq s}\Gamma^{\rho}_{rs}(t,j)} \tag{17}$$

$GSF_\sigma(j)$ represents the share of foreign redirected value added for exports of final j-output by region σ as a share of all globally redirected value added for final j-exports. This is a size measure indicating the importance of the assembly activity for final j-trade of region σ at the global level.

A relative large value of $GSF_\sigma(j)$ shows that region σ redirects a large share of globally redirected value added. However, a region with a large GSF value is not, per se, a hub. Note that regions with large internal markets (i.e. EU15, USA, China) can have both large GSF and low SF values, reflecting that the foreign value added embedded in intermediate imported inputs is absorbed locally, and only a relative small share is redirected, even when in absolute terms the amount of redirected value added can be large. On the other hand, having both large SF and GSF values does show that the region is a large hub in global supply chains.

To analyse the regional or global nature of the hub, we then decompose each GSF-measure into the different origins and final destinations of the value added involved to identify the incoming and outgoing spokes separately for each final producer. This last step allows us to analyse if the hubs are truly global –in the sense that the hub exports to many regions– or if the hub is more "regional" by exporting mostly to neighboring regions (e.g. NAFTA, EU27). Thus, we can determine the global or regional nature of a hub by looking at the destinations of the outgoing spokes.

In addition, we can use the information on the origin of the incoming spokes to detect the global supply spokes: the regions/countries that are important in supplying the j-hubs with intermediates. In particular, we define the j-spokes as those regions/countries for which the following expression is relatively large:

$$SD_r(j) = \frac{\sum_{\sigma \neq r} \sum_{\rho \neq \sigma} \Gamma^{\rho}_{r\sigma}(t,j)}{\sum_{\sigma \neq r} \Gamma^{w}_{r\sigma}(t,j)} \tag{18}$$

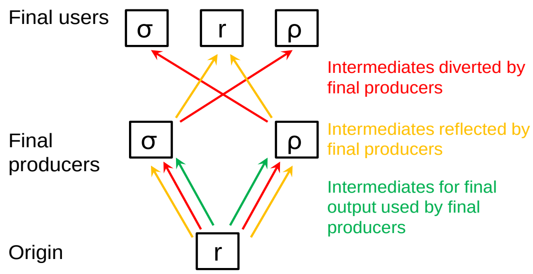
where $SD_r(j)$ indicates the share of domestic value added that is redirected by other countries producing final j-output for foreign use. This is an intensity measure showing the relative importance of region r as a spoke that supplies intermediates for assembly abroad of exports of final j-output. Figure 3 illustrates how SD is calculated. For a specific origin r, SD_r is the share of redirected intermediate value added by all final producers (the arrows from the final producers to the final destinations) as a percentage of intermediate value added exports from the origin (the arrows from the origin to the final producers).

We also calculate $GSD_r(j)$, which expresses the redirected domestic value added as a share of all globally redirected value added for final j-exports:

$$GSD_r(j) = \frac{\sum_{\sigma \neq r} \sum_{\rho \neq \sigma} \Gamma^{\rho}_{r\sigma}(t,j)}{\sum_s \sum_{r \neq s} \sum_{\rho \neq s} \Gamma^{\rho}_{rs}(t,j)} \tag{19}$$

This size measure indicates the importance of r's activity as a spoke that supplies intermediates for trade in final j-output at the global level.

Figure 3: Calculating the SD indicator



3 Identifying hubs and spokes using the GTAP data

Using our indicators based on redirected trade, we identify hubs (using the indicator in equation 16) and incoming spokes (using the indicator in equation 18). As an illustration on how to apply our indicators we use the GTAP database.[14] The GTAP databases provide information on more than one hundred regions and/or countries (depending on the database release) and 57 sectors.[15] Our initial matrix calculations are done at the most disaggregated level, but for presentation reasons we aggregate the data into 12 regions.[16]

3.1 Hubs and spokes for aggregate total output

First, we analyse the hubs and spokes at the aggregate (total output) level, and then we focus on specific sectors. From Figure 4 we can clearly identify the hub regions: EU12 (EU new member states), OWE (Other Western Europe), China, EAS (East Asia), SEA (South East Asia) and ONA (Other NAFTA). These regions have SF values above the global SF average (SF_w).

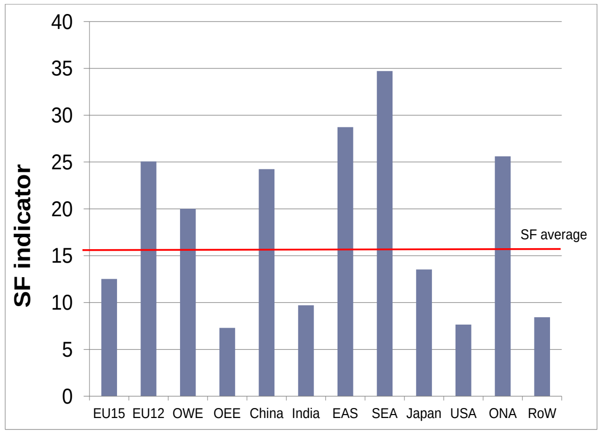
To obtain more information about the characteristics of these hubs we look at GSF. First, from Figure 5 we can distinguish between regional and global hubs by looking at the final destination of the outgoing spokes. For instance, the ONA region

[14] As mentioned before, our methodology can also be applied to other global input-output tables, such as WIOD.

[15] In using the GTAP database one has to employ a "proportionality" assumption that in a particular country of destination each bilateral import value is allocated to intermediate domestic demand sectors and final domestic demand in the same proportion, irrespective of the country of origin. Another feature of the GTAP data is that all production has the same imported content for exports as for domestically consumed final goods. This is problematic if one wants to measure DV in countries with large export processing sectors. For instance, Koopman et al (2010), Koopman et al (2013) and Johnson and Noguera (2012a) partially adjust the data to account for the large share of manufacturing exports from these export processing sectors in China and Mexico.

[16] Aggregation is explained in Appendix 5.1. The aggregation mapping into 12 regions is presented in Table 1 in Appendix 5.3. Note that the aggregation process will then ignore the "internal" trade between the aggregated regions. In particular, this makes a difference for the indicators estimated for the EU27.

Figure 4: Identifying hubs using the SF indicator, 2007



Source: Own estimations using GTAP database.

Notes: Region abbreviations are explained in Table 1 in the Appendix.

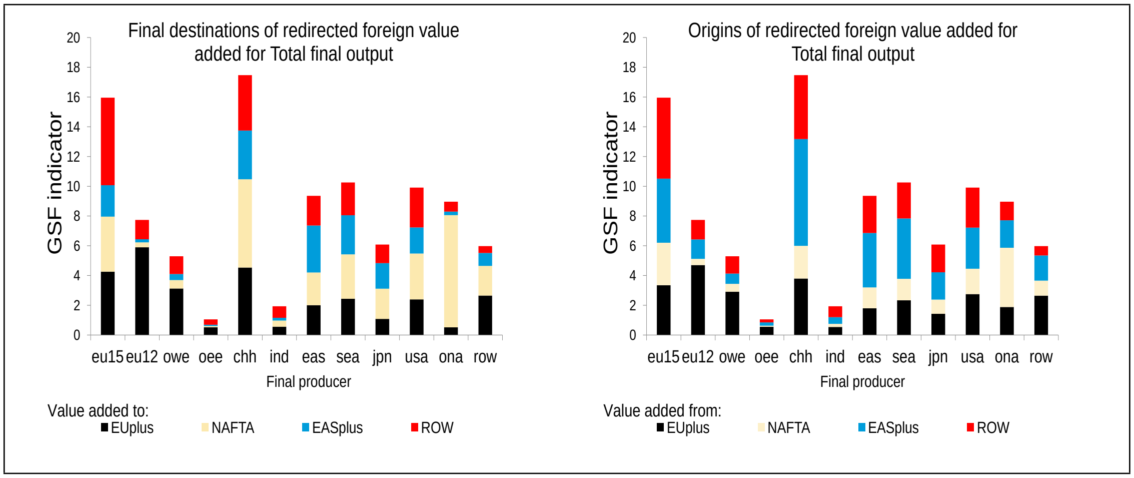
has a predominant share of value added trade being redirected to the aggregated NAFTA region (which is mainly the USA). This implies that ONA is a regional hub. Similarly, EU12 and OWE are also regional hubs that redirect mainly to the aggregated region EUplus (which is mainly EU15), while it also has a predominant share of intermediate inputs originated in EUplus (right-hand side graph in Figure 5). On the other hand, most of the East-Asian regions – China, EAS and SEA– can be defined as global hubs, since they redirect to many geographically different regions and are also supplied from many different regions.[17]

Second, GSF also provides information about the relative size of the regions as global trade redirectors. In Figure 5 we observe that China and EU15 are together responsible for redirecting about a third of all globally redirected value added. Both regions have large GSF values (vertical axis of the left panel). However, of the two regions only China has an above-average SF value. Hence, China can be considered as the main global hubs. On the other hand, the EU15 is an important part of global supply chains, in the sense that it redirects a large share of global value added, but it is not considered a hub because an above average share of the value added it imports its absorbed internally.

From the supply side, we can use the SD indicator to determine that the EU15, EAS, SEA, the USA, Japan and -to a lesser extent– China are the main incoming spokes in global supply chains (see Figure 6). In addition, using the GSD values we can determine relative sizes. We find that the EU15 is the main global incoming

[17]We also assessed whether the nature of a hub was global or regional by calculating the average distance from the hub to the origins supplying the hub and the average distance from the hub to the final users supplied by the hub, making use of the distance measures from the CEPII-website (Mayer and Zignago, 2011). The distance measure assessments confirm our results using only hubs and spoke indicators (results available upon request).

Figure 5: Identifying the size and scope of hubs using the GSF indicator, 2007

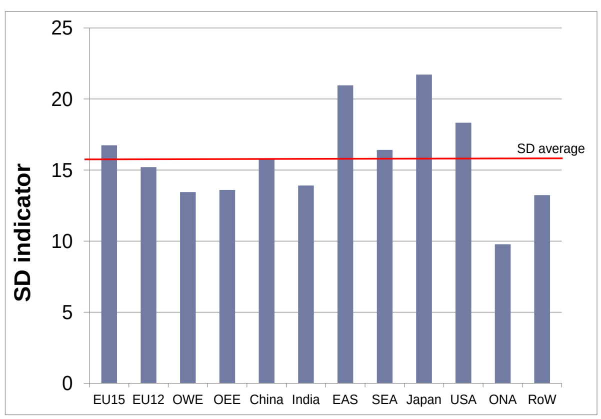


Source: Own estimations using GTAP database.

Notes: The left-hand side graph presents the final destinations of GSF and the right-hand side the origins. Region abbreviations are explained in Table 1 in the Appendix.

spoke ($GSD = 22$), followed by the USA ($GSD = 13$), Japan and China (both with $GSD = 9$). In other words, these four regions supply more than half of the value added in the intermediates that are globally redirected by the hubs.

Figure 6: Identifying spokes using the SD indicator, 2007



Source: Own estimations using GTAP database.

Notes: Region abbreviations are explained in Table 1 in the Appendix.

To sum up, at the aggregate total output level global production networks are located mainly in the EASplus region, while regional networks –that supply the global economy– are located in North America (NAFTA) and Europe (EUplus). On the other hand, India and OEE (Other Eastern Europe, which is mainly Russia) cannot be considered as hubs nor spokes in global supply chains, since both regions have relatively low values for all indicators. In addition, these patterns have been roughly the same when we analyse changes between 2001 and the results from 2007 presented above (see Table 3 in Appendix 5.3).

3.2 Relative importance of redirected trade by sector

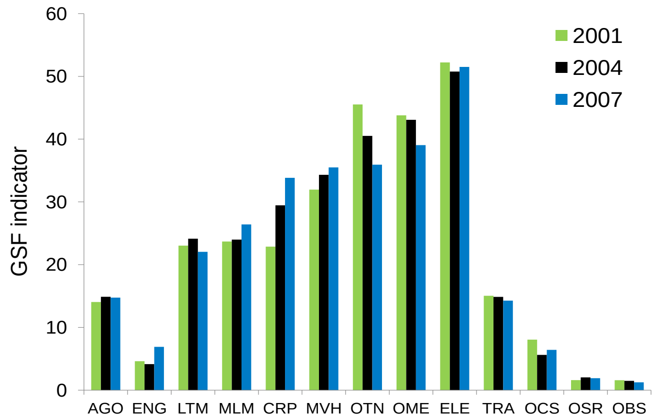
So far we focused on the redirection of aggregate total output. However, this macro approach hides substantial differences between sectors. Economic sectors differ in their contribution to value added in an economy, in their intensity of intra- and inter-sectoral trade, and in their position within global production chains. The Dreamliner and iPod are very specific examples of products in which a very large part of the production is outsourced to numerous countries. However, for many other products and services, such as personal services, most of the value added provided cannot be outsourced. In order to understand better the international linkages between global production chains we concentrate on specific economic sectors.

The GTAP data that we use distinguish 57 economic sectors. Although technically feasible it is too cumbersome to present results for all sectors. Thus, we aggregate all 57 GTAP sectors into 13 sectors. Moreover, we focus our analysis on five sectors that are among the most important in international trade flows. These are electronic equipment (ELE), other machinery and equipment (OME), other transport equipment (OTN), motor vehicles and parts (MVH), and chemicals, rubber and plastic products (CRP) (see Table 2 in Appendix 5.3 for all the sectoral classifications.)

The importance of global production networks varies by sector. Figure 7 presents the global share of redirected value added in total value added of traded intermediates (GSF) for all aggregated sectors. The results suggest that global production networks matter mostly for manufacturing sectors. For instance, GSF is above 20% for all manufacturing sectors, while lower than 15% for agriculture, energy and services sectors. In addition, our manufacturing sectors are classified by the technological level of each industry: from low-tech manufactures (LTM) to the electronic equipment (ELE), which has the highest technological level. From Figure 7 it is clear that the integration into global supply chains (represented by higher GSF values) increases by the technological content of the sector. The most globally integrated sector is electronic equipment, where more than half of global intermediate value added trade is redirected.

From Figure 7 we also find that the share of redirected value added has been relatively stable over the period between 2001 and 2007. The two exceptions are chemicals, rubbers and plastics (CRP) and other transport equipment (OTN), which have significant changes in their GSF values, suggesting relatively large changes in the organization of global production networks in both sectors. The GSF value for the CRP sector is increasing from 23% in 2001 to 34% in 2007, while the OTN sector has a decreasing value from 45% in 2001 to about 35% in 2007. Thus for OTN there is a concentration of production networks in a few countries.

Figure 7: Global share of foreign redirected value added trade in intermediate value added trade (GSF) by economic sector, 2001-2007



Source: Own estimations using GTAP database.
Notes: Sector abbreviations are explained in Table 2 in the Appendix.

3.3 Hubs and spokes for selected sectors

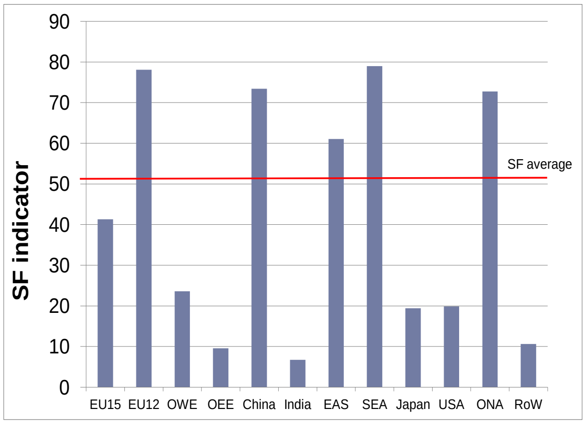
Even though the data allow us to analyse the redirected value added between our 12 aggregated regions for all 13 sectors, the amount of information is too large to be presented here. Instead, we focus our hubs and spokes analysis only on the two main globally integrated sectors: electronic equipment, and machinery and equipment (ELE and OME). In addition, we present the corresponding figures for the other three globally relevant sectors (i.e. OTN, MVH and CRP) in Appendix 5.3.

We start with the electronic equipment sector, which is the most globally integrated sector with more than half of its intermediate value added imports being redirected. From Figure 8 we find that EU12, China, EAS, SEA and ONA are the hubs in this sector, all with large redirection intensities with SF values between 60 and 80%.

When we look at the destinations of redirected value added in the left-hand side graph in Figure 9, we find again the EASplus is a global hub since the final destination of the redirected value added from China, EAS and SEA is evenly shared among the four global regions (EUplus, NAFTA, EASplus and ROW). When looking at the origins of redirected trade (right-hand side graph) we observe that these three Asian regions are using value added in intermediate inputs mainly from other Asian regions (EASplus, which includes Japan). ONA and EU12, on the other hand, are regional hubs that export their redirected value added mainly to the NAFTA region (i.e. USA) and the EUplus region, respectively.

From Figure 9 we can also analyse the relative size of each region using the GSF indicator. We observe that China is the most important hub with around a third of all redirected value added. Then SEA and EAS follow in order of importance.

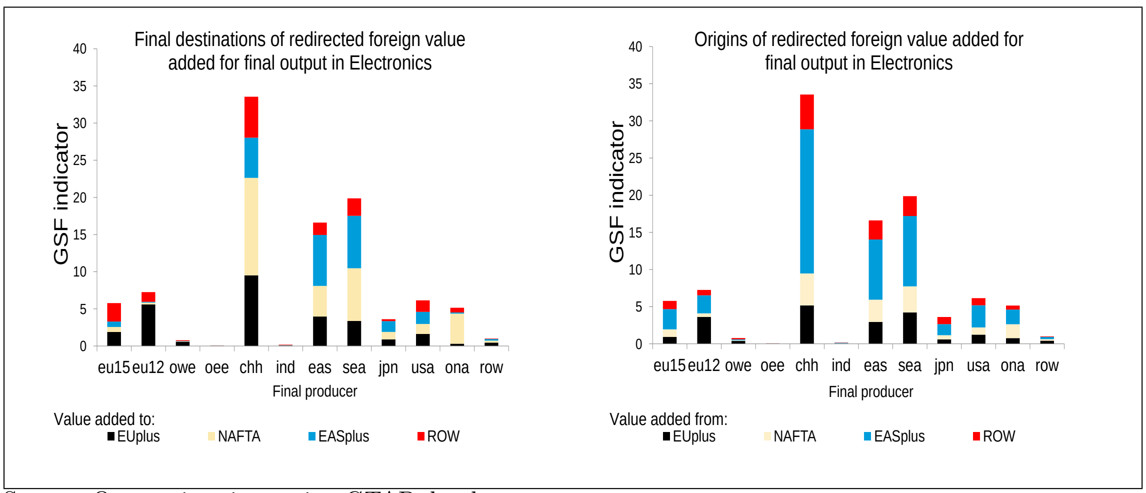
Figure 8: Identifying hubs in electronic equipment (ELE), 2007



Source: Own estimations using GTAP database.

Notes: Region abbreviations are explained in Table 1 in the Appendix.

Figure 9: Identifying the size and scope of hubs in electronic equipment (ELE) using the GSF indicator, 2007



Source: Own estimations using GTAP database.

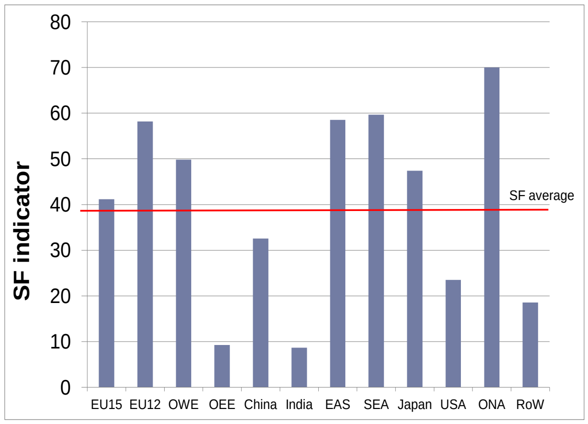
Notes: The left-hand side graph presents the final destinations of *GSF* and the right-hand side the origins. Region abbreviations are explained in Table 1 in the Appendix.

Moreover, about 70 percent of all redirected value added in electronic equipment takes place in Asia.

From the supply side, we find that EU15, Japan, USA and EAS are the main global spokes in this industry. These regions supply much of the value added which is redirected mainly by EASplus countries –in particular China– but also by EU12 and ONA (see Figure 12 in the Appendix).

The second sector we portray is OME: other machinery and equipment. From Figure 10 we observe that the EU15, EU12, OWE, EAS, SEA, Japan and ONA are the hubs in this sector.

Figure 10: Identifying hubs and spoke in other machinery and equipment (OME), 2007



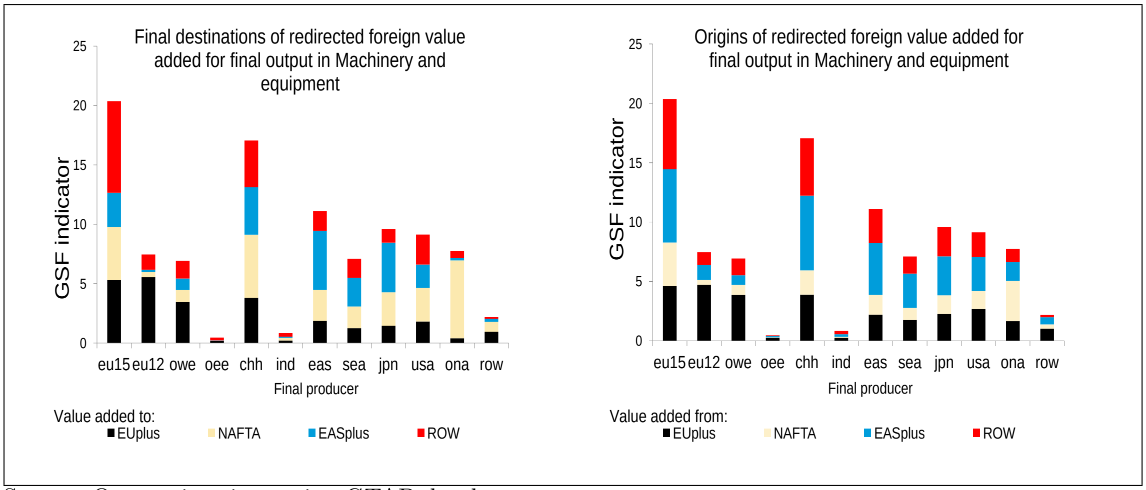
Source: Own estimations using GTAP database.

Notes: Region abbreviations are explained in Table 1 in the Appendix.

Observing the destination of the outgoing spokes from Figure 11 we find that the EU15, EAS, SEA and Japan are all global hubs redirecting value added to all four major regions, while EU12 and OWE are regional hubs exporting mainly to the EUplus region, and ONA is also a regional hub exporting to the NAFTA region. In addition, the EU15 is the most important global hub, with a GSF value above 20%. China is not a hub in OME, even when it has a high GSF value. This indicates that it is a major player in the global supply chain since it redirects a large share of global value added, but it also internally absorbs an above average share of the value added it imports. On the other hand, India, OEE (mainly Russia) and the rest of the world (RoW) are not integrated into the global supply chain of OME. From the supply side, we find that EU15 is the main global spoke, together with the USA and China (see Figure 13 in the Appendix).

In Appendix 5.3, Figures 14 and 15 present the results for the other three manufacturing industries that have extensive global supply chains: OTN, MVH and CRP. For other transport equipment (OTN) the EU15, EAS, Japan and the USA are the global hubs, while EU12 and ONA are regional hubs. By relative size, the USA and EU15 are the most important hubs. In contrast to the ELE and OME industries, the EASplus region does not play an important role in the OTN industry, with the exception of the EAS region (mainly Korea). In the motor vehicles and parts sector (MVH), all hubs are regional: EU12, OWE, EAS, Japan and ONA. This last region is the biggest with around 90% of its redirected value added going to the NAFTA region (i.e. USA). The EU15, on the other hand, is playing a dual role as a hub and

Figure 11: Identifying the size and scope of hubs in other machinery and equipment (OME) using the GSF indicator, 2007



Source: Own estimations using GTAP database.

Notes: The left-hand side graph presents the final destinations of *GSF* and the right-hand side the origins. Region abbreviations are explained in Table 1 in the Appendix.

as the destination for a large share of redirected trade. Finally, for the chemicals, rubber and plastics industry (CRP), there are many regions that are hubs (except India, USA and RoW), with the EU12, OWE and ONA being regional and the rest global: EU15 (that is also the biggest hub), OEE, China, EAS, SEA and Japan.

Even though each sector analyzed has its own peculiarities, we find certain patterns across these sectors. First, ONA (Mexico and Canada) are regional hubs with very strong ties with the USA. While ONA is sourced with intermediate inputs from (usually) many regions, the final destination of their redirected trade is mainly the USA. The same logic applies to EU12 and to a smaller extent to the OWE region, which are mainly integrated with EU15. On the other hand, the South-East Asia regions (EAplus) are usually very well integrated amongst themselves, but are also sourced by other regions and more importantly, redirect value added to most regions, especially to the main global consumer markets: USA and EU15. Thus, China, EAS and SEA are usually global hubs. The USA and EU15 (and to a lesser extent Japan) play a more complex role in global supply chains. They are generally the main incoming spokes that supply value added in intermediate inputs to the hubs, but sometimes they are also the main global hubs, and in addition, as the two biggest economies in the world, they are also the main outgoing spoke –i.e. the main final users of redirected trade. Moreover, they are the center of regional supply chains: USA using ONA as a manufacturing center, and EU15 using EU12 and also OWE as assembly locations.

Finally, Tables 4 through 8 in Appendix 5.3 show the changes over time –from 2001 to 2007– of our four indicators for total output and for the five industries we analyzed separately. When looking at total output we observe that the SF indicator has a slight decrease globally (from 17.6 to 15.8), which is mainly driven by declines in the EAS, SEA and ONA regions. This can be interpreted as a decrease in the role of these regions as hubs in global supply chains. In particular, the decrease in ONA as a hub is the most significant, given its relative size reduction: its GSF value for total output drops from 14.7 to 9.0 between 2001 and 2007. This reduction in relative importance is concentrated on the OTN and MVH sectors. On the other hand, China has increased its role as a global hub, in particular for the ELE and CRP sectors.

4 Conclusion

The recent literature on trade in value added has advanced in deriving informative measures from national input-output tables and international trade statistics. These trade in value added measures are used to compare bilateral trade gaps in value added and gross value terms and to derive indicators for vertical specialization. However, these papers do not track the value added generated in global supply chains, because they are focused on the origins and final destinations of value added, and not on the final producer that redirects traded value added. This is the main contribution of this paper. We developed indicators for redirected value added trade and are able to identify the sources of redirected value added, the redirecting region and the final destinations by industry of end-use. Our proposed indicators for redirected value added trade allow us to clearly identify the spokes and hubs in global supply chains. Using these indicators we find several interesting results. Some of these results are consistent with other studies looking at global supply chains, while we can also analyse sector-specific results. First, using our indicators we clearly observe that global production networks are mainly located in North America, Europe and the Asia-Pacific region (China, East Asia and Southeast Asia). However, not all sub-regions in these highly integrated regions are equally important, or have the same function, in these supply chains. For instance, some regions act mainly as regional hubs for a larger nearby region –i.e. other NAFTA serves as a hub for the USA; while EU12 and other Western Europe serve as local hubs for EU15. Therefore, these regions are more important as regional production networks than as global production networks. On the other hand, the Asia-Pacific region appears to have strong regional links as well as global links with both EU15 and the USA.

Secondly, global production networks matter only for manufacturing sectors, in particular for electronic equipment, other machinery and equipment, other transport equipment, motor vehicles and parts, and chemical, rubber and plastic products. However, there are significant differences between industries regarding the scope and nature of their global supply chains. A special case is electronic equipment, for which the major hubs are located in the Asia-Pacific region. The spokes, the USA and EU15 still supply much of the value added for electronic equipment that is redirected by the Asia-Pacific region –in particular by China. In the case of other machinery and equipment, the hubs in Europe and North America are relatively more important, and these hubs show less global integration than the electronic equipment hub in the Asia-Pacific region. Finally, there are also some changes over time. Production networks in chemicals, rubber and plastics have become much more global between 2001 and 2007, while the reverse is the case for other transport equipment. China has slightly increased its overall importance as a global production hub, while the other NAFTA region (Mexico and Canada) has experience a relative decrease as a production hub.

We believe that our contributions have much potential for deeper analyzes of global supply chains. First and foremost, we should deepen our analysis by also covering redirection of intermediate value added imports via intermediate exports. As our study indicates substantial changes in global supply chains in sectors like chemicals, rubber and plastics and other transport equipment between 2001 and 2007, it seems useful to make a longitudinal analysis over a longer time period. Finally, it is of interest to extend the analysis by also covering trade in different primary inputs (such as low- and high-skilled labour, and capital), thus linking the evolution of global supply chains to the possibly differential developments of internationals claims on production factors.

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5 Appendices

5.1 Aggregating over regions and sectors

From equation (9) it is immediately clear that aggregation over sectors does not affect the volume of global value added trade nor its composition. This is different for aggregation over regions. Since our datasets have 84 different regions in common, it is inevitable to aggregate over regions when we report the outcomes of our study. Although this regional aggregation does not affect the volume of global value added trade, it does change its composition. In particular, aggregation over regions reduces the share of redirected trade in total value added trade. To clarify this issue we use the example of aggregating over EU member states. First, in this aggregation we lose intra-EU redirection because all redirection of EU-value added by EU-countries towards other EU-countries is classified as $\Gamma^{\rho}_{r\rho}$. Moreover, all incoming trade from outside the EU that was first diverted by EU-countries towards final destinations in other EU-countries is classified as Γ^{ρ}_{rr}. Finally, all outgoing trade that was diverted by EU-countries before leaving the EU is also classified as Γ^{ρ}_{rr}. Thus, the shares of reflected and especially diverted trade in global value added trade are reduced when we aggregate over EU-countries to represent the EU as a single trading block.

In evaluating bilateral value added requirement at the sectoral level we have two options. The first option is to follow sectoral domestic value added required abroad for all final uses. We define this as the "horizontal" option, since it evaluates $\Gamma^{\rho}_{r\sigma}$ row-wise. This option allows the identification of the regions where final customers in the end pay for sectoral value added. The second is the "vertical" option: to evaluate $\Gamma^{\rho}_{r\sigma}$ column-wise. This option provides information on all value added that is needed for final output use abroad at the sectoral level. Thus, this option is relevant to identify the amounts of value added that are needed for sectoral final output trade. As this "vertical" information is the most relevant to our paper, we adopt this second option at the sectoral level. This is in contrast with the approach of Johnson and Noguera (2012a) who follow the "horizontal" approach in collecting bilateral value added exports at the sectoral level.

5.2 International transport margins

For simplicity we neglected international transport margins in the main text. In this appendix we explain how international transport margins are actually treated in our calculations. In contrast to the global input-output structure in (1), when we include international transport deliveries we obtain the following structure:

$$\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1m} & \check{S}_1 & f_1^1 & f_1^2 & \ldots & f_1^m & x_1 \\ S_{21} & S_{22} & \cdots & S_{2m} & \check{S}_2 & f_2^1 & f_2^2 & \cdots & f_2^m & x_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \iddots & \vdots & \vdots \\ S_{m1} & S_{m2} & \cdots & S_{mm} & \check{S}_m & f_m^1 & f_m^2 & \cdots & f_m^m & x_m \\ & & & & & & & & & \\ \widetilde{S}_1 & \widetilde{S}_2 & \cdots & \widetilde{S}_m & 0 & \bar{s}^1 & \bar{s}^2 & \cdots & \bar{s}^m & \tau \\ & & & & & & & & & \\ p_1' & p_2' & \cdots & p_m' & 0 & & & & & \\ x_1' & x_2' & \cdots & x_m' & \tau' & & & & & \end{bmatrix} \tag{20}$$

Compared to the table in the main text the extra entries in this table are: $\check{S}_r$ representing the $n \times o$ matrix with the supply of international transport services from country r, $\widetilde{S}_s$ denoting the $o \times n$ matrix with international transport margins on imported intermediate goods in country s, $\bar{s}^r$ indicating the o vector with international transport margins on imported final goods in country r and τ representing the o vector with global demands and supplies for international transport services. It is important to note that in the GTAP database the international transport services are special in the sense that they are supplied to and demanded from an international transport market. Therefore, (20) does not provide information on the regional origin of the transport services demanded.

For each region r total gross outputs equal the sum of intermediate outputs, final outputs and supplies of transport services:

$$\widetilde{S}(i,t) + \bar{s}^w(i) = \check{S}_w(t,i) = \tau(i) \quad \forall i \in O \tag{21}$$

and total demands for international transport services equal supplies:

$$\widetilde{S}(i,t) + \bar{s}^w(i) = \check{S}_w(t,i) = \tau(i) \quad \forall i \in O \tag{22}$$

To economize on notation we summarize (20) with:

$$\begin{bmatrix} S & \check{S} & F & x \\ \widetilde{S} & 0 & \bar{S} & \tau \\ p' & 0 & & \\ x' & \tau' & & \end{bmatrix} \tag{23}$$

In addition to the input coefficients A we also define matrices of input coefficients $\check{A}$ and $\widetilde{A}$. $\check{A}(r,i,i) = \check{S}(r,i,i)/\tau(i)$ represents the share of sector i in country r in global international transport supplies of service i and $\widetilde{A}(i,s,j) = \widetilde{S}(i,s,j)/x(s,j)$ indicates the use of international transport service i in sector j of country s per unit of gross output (of sector j in country s). The input coefficients for value added v are now arrived at as $v(s,j) = 1 - \sum_{r \in M} A(r,t,s,j) - \widetilde{A}(t,s,j)$

From (21) and (22) we have:

$$\begin{bmatrix} x \\ \tau \end{bmatrix} = \begin{bmatrix} S \\ \widetilde{S} \end{bmatrix}\iota + \begin{bmatrix} \check{S} \\ 0 \end{bmatrix}\iota + \begin{bmatrix} F \\ \bar{S} \end{bmatrix}\iota = \begin{bmatrix} A & \check{A} \\ \widetilde{A} & 0 \end{bmatrix}\begin{bmatrix} x \\ \tau \end{bmatrix} + \begin{bmatrix} F \\ \bar{S} \end{bmatrix}\iota = \begin{bmatrix} I-A & -\check{A} \\ -\widetilde{A} & I \end{bmatrix}^{-1}\begin{bmatrix} F \\ \bar{S} \end{bmatrix}\iota = \begin{bmatrix} \bar{B} & \check{B} \\ \widetilde{B} & \acute{B} \end{bmatrix}\begin{bmatrix} F \\ \bar{S} \end{bmatrix}\iota \tag{24}$$

which relates final demands to gross production. One may verify that the global Leontief inverse can be decomposed as follows:

$$\begin{bmatrix} \bar{B} & \check{B} \\ \widetilde{B} & \acute{B} \end{bmatrix} = \begin{bmatrix} (I-A-\check{A}\widetilde{A})^{-1} & (I-A)^{-1}\check{A}(I-\widetilde{A}(I-A)^{-1}\check{A})^{-1} \\ \widetilde{A}(I-A-\check{A}\widetilde{A})^{-1} & (I-\widetilde{A}(I-A)^{-1}\check{A})^{-1} \end{bmatrix} \tag{25}$$

where, as before, the elements of the matrix $\bar{B}$: $\bar{B}(r,i,s,j)$ represent the amount of gross output (of sector i in region r) that is directly and indirectly needed per unit of final output (of sector j in region s). However, $\bar{B}$ now also includes the gross output needed for international transport of intermediates per unit of final output. The entries of matrix $\check{B}$: $\check{B}(r,i,j)$, represent the additional gross output (of sector i in region r) needed for international transport service j for trade in final goods.

As before f^ρ is the ρ^{th} column of F and denotes the mn vector of final output use in region ρ. Now let $\bar{s}^\rho$ be the ρ^{th} column of $\bar{S}$, which is the o vector representing the value of the transport services on final good imports of ρ. Then $\bar{B}\hat{f}_\rho$ and $\check{B}\bar{s}^\rho$ together represent all gross outputs needed for final output use in ρ. However, their dimensionality – $mn \times mn$ and $mn \times o$ respectively– differs and this is inconvenient. The GTAP databases include full vectors of transport margins for final good imports in f^ρ, which we indicate with the $mn \times o$ matrix H^ρ, where $H'^\rho\iota = \bar{s}^\rho$. This allows us to expand the dimensionality of $\check{B}\bar{s}^\rho$ to $mn \times mn$ as well, because we can alternatively indicate gross outputs needed for international transport of f^ρ by $\sum_{k \in T} \check{B}\iota_k \iota'_k H'^\rho$.

Multiplying the gross output requirements for f^ρ and Λ with values added per unit of gross outputs yields the corresponding value added requirements of final demand in ρ:

$$\Theta(f^\rho, H^\rho) = \hat{v}(\bar{B}\hat{f}^\rho + \sum_{k \in T} \check{B}\iota_k \iota'_k H'^\rho) \tag{26}$$

since both $v'\bar{B}$ and $v'\check{B}$ are unit vectors,[18] it is easily verified that the column sum of $\Theta(f^\rho, H^\rho)$ equals transport-inclusive final demands in ρ and that the row sum equals the value added required for transport-inclusive final output use in ρ.

In our calculations we apply our trade in value added decomposition on this international transport-inclusive value added matrix $\Theta(f^\rho, H^\rho)$, instead of using the simpler $\Theta(f^\rho)$ described in the main text. Thus, all value added and final demand flows in our results include international transport services.

[18]The proof is by rewriting $v' = \iota'(I - A - \widetilde{A})$ and then evaluating $v'\bar{B}$ and $v'\check{B}$.

5.3 Additional tables and figures

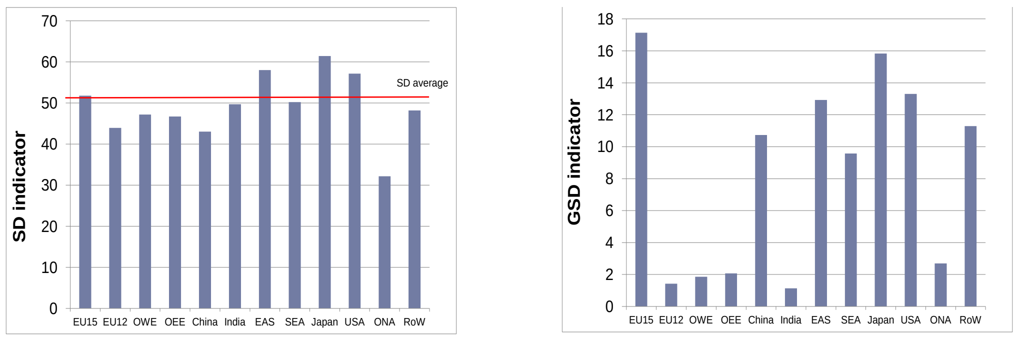
Table 1: Regional aggregation

Code	Region description	GTAP countries/regions
EU15	EU members before 2004	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Portugal, Spain, Sweden, UK
EU12	EU new members	Bulgaria, Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Romania
OWE	Other Western Europe	Switzerland, Norway, Iceland, Liechtenstein, Croatia, Serbia, Montenegro, Albania, Macedonia, Turkey
OEE	Other Eastern Europe	Russia, Belarus, Ukraine, Georgia, Azerbaijan, Armenia, Moldavia, Rest of Eastern Europe, Rest of Europe
CHH	China	China (including Hong Kong)
IND	India	India
EAS	East Asia	Korea, Taiwan, and Other East Asia
SEA	South East Asia	Cambodia, Indonesia, Laos, Myanmar, Malaysia, Philippines, Singapore, Thailand, Vietnam, and Rest of Southeast Asia
JPN	Japan	Japan
USA	USA	USA
ONA	Other NAFTA	Canada and Mexico
ROW	Rest of the World	Australia, New Zealand, Rest of South Asia, Rest of USSR, Iran, Rest of Middle East, Africa, South America and the Caribbean
Additional aggregations:		
EUplus	EU15 + EU12 + OWE	
NAFTA	USA + ONA	
EASplus	China + Japan + EAS + SEA	
ROWplus	OEE + IND + ROW	

Table 2: Sectoral aggregation

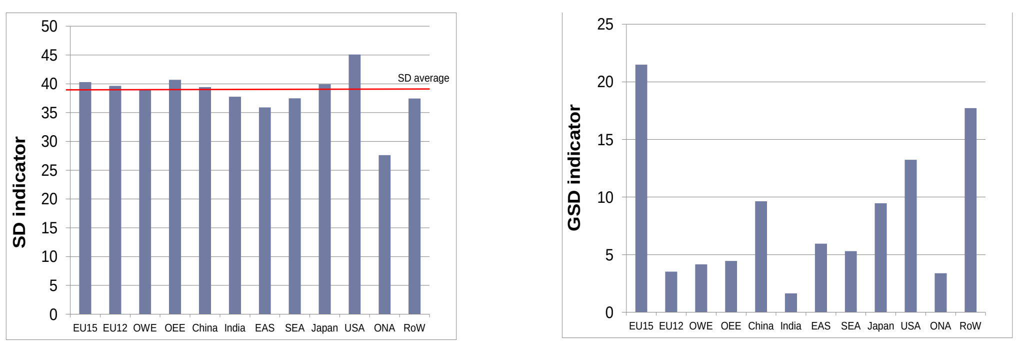
Code	Description
AGO	Agriculture and raw materials
ENG	Energy
LTM	Low technology manufacturing
MLM	Medium-low technology manufacturing
CRP	Chemical, rubber and plastic products
MVH	Motor vehicles and parts
OTN	Other transport equipment
OME	Other machinery and equipment
ELE	Electronic equipment
TRA	Transport services
OCS	Other commercial services
OSR	Other (government) services
OBS	Other business services

Figure 12: Identifying spokes in electronic equipment (ELE), 2007



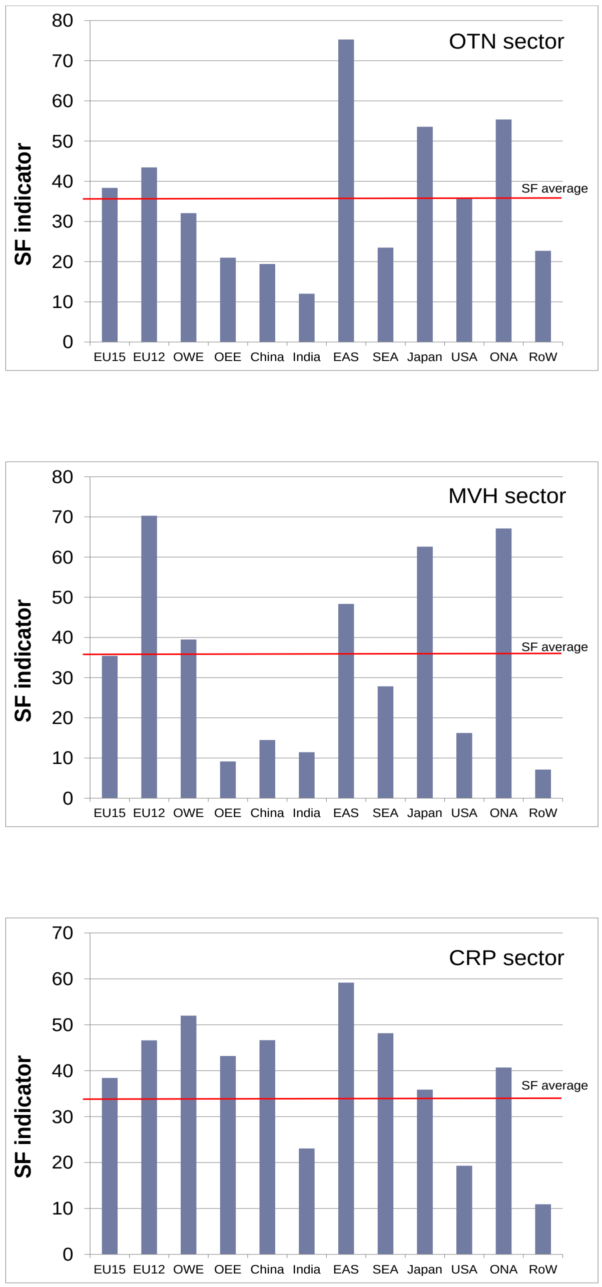
Source: Own estimations using GTAP database.

Figure 13: Identifying spokes in other machinery and equipment (OME), 2007



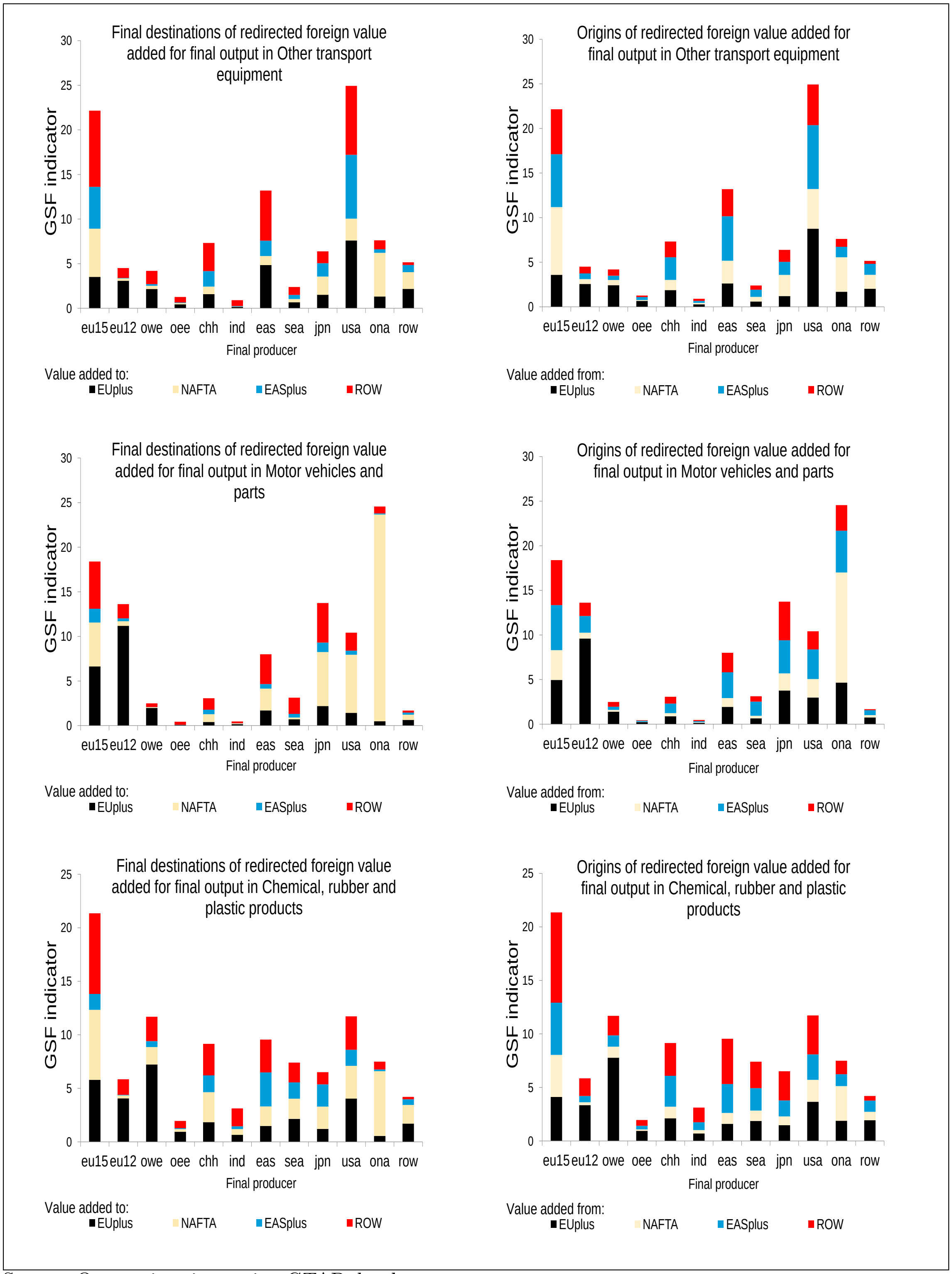
Source: Own estimations using GTAP database.

Figure 14: Identifying hubs in OTN, MVH and CRP, 2007



Source: Own estimations using GTAP database.

Figure 15: Identifying the size and scope of hubs in OTN, MVH and CRP using the GSF indicator, 2007



Source: Own estimations using GTAP database.

Table 3: Changes over time for all indicators for total output, 2001-2007

	SF indicator			SD indicator			GSF indicator			GSD indicator		
	2001	2004	2007	2001	2004	2007	2001	2004	2007	2001	2004	2007
EU15	14.1	11.4	12.5	18.2	19.0	16.7	16.6	13.7	16.0	23.3	24.4	21.9
EU12	27.2	26.7	25.1	16.2	15.2	15.2	6.2	6.6	7.7	2.2	2.5	2.9
Other Western Europe	24.0	24.5	20.0	15.4	13.6	13.5	4.5	5.6	5.3	4.0	3.7	3.9
Other Eastern Europe	9.2	10.8	7.3	14.0	14.3	13.6	0.6	1.0	1.1	2.5	3.5	4.8
China	22.5	26.8	24.2	16.1	17.2	15.8	10.4	16.4	17.5	6.1	7.4	9.0
India	10.1	10.9	9.7	16.8	16.2	13.9	0.9	1.4	1.9	1.2	1.2	1.8
East Asia	34.6	34.7	28.7	20.3	21.9	21.0	10.2	10.4	9.4	5.5	6.7	6.4
South East Asia	44.4	39.5	34.7	15.6	17.1	16.4	14.0	12.1	10.3	4.8	5.1	5.6
Japan	10.0	11.8	13.5	23.6	23.9	21.7	4.8	5.2	6.1	12.6	12.1	9.0
USA	7.4	7.7	7.7	22.3	21.2	18.3	9.6	9.5	9.9	21.9	16.6	13.3
Other NAFTA	35.4	30.6	25.6	9.3	9.6	9.8	14.7	11.3	9.0	3.7	3.2	3.5
RoW	11.0	11.5	8.4	13.8	12.9	13.2	7.4	6.7	6.0	12.1	13.4	17.9
World	17.6	17.4	15.8	17.6	17.4	15.8	100	100	100	100	100	100

Source: Own estimations using GTAP database.

Table 4: Changes over time for all indicators for electronic equipment (ELE), 2001-2007

	SF indicator			SD indicator			GSF indicator			GSD indicator		
	2001	2004	2007	2001	2004	2007	2001	2004	2007	2001	2004	2007
EU15	36.7	25.9	41.3	53.9	54.8	51.8	6.7	5.3	5.8	19.1	19.4	17.1
EU12	64.5	72.4	78.1	44.9	39.7	43.9	3.2	5.2	7.3	1.2	1.3	1.4
Other Western Europe	40.7	39.8	23.6	47.7	42.8	47.2	0.8	0.8	0.8	2.2	2.0	1.9
Other Eastern Europe	39.6	16.2	9.6	43.4	44.3	46.7	0.0	0.1	0.1	1.2	1.7	2.1
China	57.3	62.7	73.4	47.8	44.3	43.0	11.9	27.8	33.6	6.8	8.5	10.7
India	6.0	7.0	6.8	55.5	49.0	49.7	0.1	0.1	0.2	0.7	0.7	1.1
East Asia	66.4	70.0	61.1	49.1	51.0	58.0	20.3	19.4	16.6	7.4	11.2	12.9
South East Asia	84.5	78.6	79.0	42.2	45.6	50.2	32.1	24.5	19.9	6.8	7.9	9.6
Japan	21.4	22.7	19.4	60.4	58.4	61.5	5.0	4.2	3.6	20.8	21.2	15.8
USA	28.5	26.6	19.8	56.9	54.5	57.1	8.5	8.3	6.1	22.8	14.6	13.3
Other NAFTA	66.3	62.8	72.7	36.8	35.3	32.2	9.8	3.2	5.1	3.2	2.9	2.7
RoW	21.2	16.7	10.6	48.4	46.3	48.2	1.6	1.2	1.0	7.7	8.7	11.3
World	52.2	50.8	51.5	52.2	50.8	51.5	100	100	100	100	100	100

Source: Own estimations using GTAP database.

Table 5: Changes over time for all indicators for other machinery and equipment (OME), 2001-2007

	SF indicator			SD indicator			GSF indicator			GSD indicator		
	2001	2004	2007	2001	2004	2007	2001	2004	2007	2001	2004	2007
EU15	49.0	38.7	41.2	44.9	47.1	40.3	22.0	19.3	20.4	23.4	24.3	21.5
EU12	60.1	59.5	58.2	48.4	40.4	39.7	6.3	5.9	7.5	2.6	3.0	3.5
Other Western Europe	70.7	73.6	49.8	45.8	38.7	39.0	7.1	9.1	6.9	4.4	4.0	4.2
Other Eastern Europe	79.3	16.1	9.2	42.3	41.2	40.7	0.5	0.5	0.5	2.7	3.6	4.4
China	31.7	39.5	32.6	41.2	40.8	39.4	8.1	11.5	17.1	6.1	8.0	9.6
India	9.5	10.5	8.6	43.1	40.6	37.8	0.4	0.8	0.8	0.9	1.0	1.6
East Asia	52.3	63.1	58.6	38.8	39.5	35.9	8.0	12.6	11.1	4.8	5.7	6.0
South East Asia	67.2	64.1	59.7	38.7	40.4	37.5	9.0	7.5	7.1	4.3	4.8	5.3
Japan	40.9	43.1	47.4	42.9	45.3	39.9	7.9	8.8	9.6	12.6	12.5	9.5
USA	23.0	23.8	23.5	53.5	50.3	45.1	11.8	9.6	9.1	22.6	16.9	13.2
Other NAFTA	75.0	70.1	70.0	26.8	27.8	27.6	16.0	11.8	7.8	3.9	3.1	3.4
RoW	25.4	23.0	18.6	41.3	39.4	37.4	3.0	2.5	2.2	11.6	13.1	17.7
World	43.8	43.1	39.1	43.8	43.1	39.1	100	100	100	100	100	100

Source: Own estimations using GTAP database.

Table 6: Changes over time for all indicators for other transport equipment (OTN), 2001-2007

	SF indicator			SD indicator			GSF indicator			GSD indicator		
	2001	2004	2007	2001	2004	2007	2001	2004	2007	2001	2004	2007
EU15	65.7	39.6	38.3	41.9	40.8	34.0	19.1	17.3	22.1	24.8	25.1	21.6
EU12	52.2	57.8	43.5	55.9	41.6	35.5	4.2	4.8	4.5	2.2	2.7	3.0
Other Western Europe	73.4	58.9	32.1	50.8	40.8	36.7	4.7	4.5	4.2	3.6	3.6	3.7
Other Eastern Europe	50.7	47.0	21.0	43.2	41.7	36.7	1.5	2.5	1.3	2.2	3.3	3.5
China	16.9	24.6	19.4	45.5	41.7	39.6	3.5	7.9	7.3	5.6	7.1	9.4
India	7.7	8.0	12.0	45.5	39.2	35.0	0.2	0.5	0.9	0.7	0.9	1.4
East Asia	77.4	77.7	75.3	38.4	33.5	29.9	11.7	15.0	13.2	4.1	4.7	4.7
South East Asia	44.5	30.6	23.5	43.5	40.4	36.2	2.8	3.5	2.4	3.5	3.7	4.1
Japan	55.4	53.5	53.6	41.5	40.2	35.8	5.4	6.5	6.4	11.2	11.4	8.8
USA	26.0	31.2	35.7	62.2	46.5	39.3	20.5	22.2	24.9	25.9	20.1	19.0
Other NAFTA	80.4	68.3	55.4	29.3	32.1	34.0	19.1	9.2	7.6	5.4	5.5	6.4
RoW	47.0	38.6	22.7	43.6	38.6	35.9	7.1	6.2	5.2	10.7	11.9	14.4
World	45.5	40.5	35.9	45.5	40.5	35.9	100	100	100	100	100	100

Source: Own estimations using GTAP database.

Table 7: Changes over time for all indicators for motor vehicles and parts (MVH), 2001-2007

	SF indicator			SD indicator			GSF indicator			GSD indicator		
	2001	2004	2007	2001	2004	2007	2001	2004	2007	2001	2004	2007
EU15	29.1	26.8	35.4	30.9	36.3	38.3	15.7	14.9	18.4	22.4	23.5	23.7
EU12	61.5	65.5	70.3	29.5	30.3	36.2	11.4	11.1	13.6	2.4	3.2	4.2
Other Western Europe	19.1	45.1	39.5	30.4	30.4	35.9	1.4	2.5	2.5	3.5	3.5	4.1
Other Eastern Europe	5.6	12.9	9.1	27.9	31.7	37.4	0.3	0.4	0.4	1.7	2.8	4.0
China	12.2	24.9	14.5	26.3	30.4	33.2	0.6	2.4	3.1	4.6	6.3	8.2
India	6.7	13.9	11.4	25.7	28.9	31.2	0.1	0.3	0.5	0.6	0.8	1.4
East Asia	42.4	47.1	48.3	24.9	29.1	30.0	6.0	7.5	8.0	3.4	4.1	4.3
South East Asia	15.1	23.1	27.8	28.4	32.3	35.1	1.3	2.2	3.1	3.3	3.5	4.2
Japan	45.0	53.9	62.6	24.1	27.1	27.9	8.6	10.7	13.7	10.4	10.2	8.7
USA	8.9	12.3	16.2	53.2	51.3	48.8	8.7	8.9	10.4	34.8	28.1	18.9
Other NAFTA	71.6	64.6	67.1	11.6	14.8	18.7	43.8	36.9	24.6	3.1	3.0	3.6
RoW	10.7	9.4	7.1	28.5	31.8	35.4	2.3	2.2	1.7	9.7	11.1	14.7
World	32.0	34.3	35.5	32.0	34.3	35.5	100	100	100	100	100	100

Source: Own estimations using GTAP database.

Table 8: Changes over time for all indicators for chemicals, rubber and plastic products (CRP), 2001-2007

	SF indicator			SD indicator			GSF indicator			GSD indicator		
	2001	2004	2007	2001	2004	2007	2001	2004	2007	2001	2004	2007
EU15	29.1	25.1	38.4	22.4	33.9	35.7	26.7	20.5	21.4	24.2	27.1	24.0
EU12	28.9	35.6	46.6	26.4	28.6	36.5	4.9	5.2	5.8	2.5	2.5	2.7
Other Western Europe	45.2	57.8	52.0	24.5	25.5	32.9	9.1	11.8	11.7	6.0	4.8	4.8
Other Eastern Europe	53.4	50.7	43.2	22.3	26.6	33.6	1.0	2.0	2.0	3.6	4.8	6.7
China	25.0	37.4	46.6	22.3	28.2	32.3	5.3	8.6	9.2	5.3	5.7	6.9
India	13.6	21.6	23.1	22.0	28.0	31.9	1.3	2.0	3.1	1.2	1.2	1.9
East Asia	45.8	58.9	59.2	21.8	30.2	34.7	8.8	9.0	9.6	3.8	4.1	3.6
South East Asia	40.4	49.1	48.2	22.3	28.8	34.1	8.2	9.3	7.4	4.2	4.3	4.6
Japan	19.5	30.6	35.9	26.6	33.8	39.3	5.2	5.8	6.5	8.9	8.3	6.2
USA	10.2	18.3	19.3	25.3	29.2	34.8	10.2	12.2	11.7	20.8	15.2	11.9
Other NAFTA	26.8	27.3	40.7	13.1	19.7	21.1	12.3	8.5	7.5	3.9	3.8	3.7
RoW	11.0	14.2	10.9	22.7	27.9	33.9	6.9	5.1	4.2	15.6	18.1	23.1
World	22.9	29.5	33.8	22.9	29.5	33.8	100	100	100	100	100	100

Source: Own estimations using GTAP database.