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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 extend this analytical framework to create indicators that identify hubs and spokes in international supply chains. Using these indicators and the GTAP databases for 2001, 2004 and 2007 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 by the general phenomenon of increased international trade in intermediate inputs. It 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 chains in which the tasks required to produce goods and services are performed at several locations all over the world.[1]

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[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

Traditional trade statistics reporting the sales value –which is closely related to 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.

The recent literature on trade in value added has overcome some of these problems by bringing together two old topics in international economics.[2] The first draws on the old literature on input-output (IO) accounting in multi-region 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 other 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 create indicators that can map out the economic relations that underlie global supply chains. In particular, we create indicators that can easily and consistently identify which are the hubs and spokes in these global chains by sector and country. For this purpose we define global supply hubs as those industries in particular countries that use a relatively large share of imported value added in producing final output which they -to a relatively large extent - export again. With our indicators we can also identify global supply spokes, which are those countries that either supply the intermediate inputs to the hubs or are the final destination of the value added that is redirected by the hubs. 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. In addition, by focusing on specific economic sectors we can also identify the importance of hubs and spokes and the location of global supply chains at the sectoral level. We emphasize in our analysis the "pass-through" via a specific country of incoming foreign intermediate value added imports that are leaving the country again in the

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).

[2] Cf. Hummels *et al.* (2001); Daudin *et al.* (2011); Johnson and Noguera (2012a)

form of final output exports. We call the part of intermediate value added imports that leaves the country again as final output exports "redirected value added" and the country in question the "redirector".

The first general measure of foreign inputs in global production chains was provided by Hummels *et al.* (2001). Their seminal paper introduced the first measure of vertical specialization: their VS measure (a concept equivalent to outsourcing and fragmentation) which is defined as the foreign intermediate content of exports.[3] However, the data employed and the VS indicator proposed in Hummels *et al.* (2001) was 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 by three recent papers on trade in value-added: Daudin *et al.* (2011), Johnson and Noguera (2012a), and Koopman *et al.* (2010). In addition, these papers have also overcome its data and methodological shortcomings. On the empirical side the data limitations so far have been overcome by using the GTAP dataset,[4] which combines input-output tables with integrated trade flows for the global economy for multiple years (cf. Dimaranan, 2006; Narayanan and Walmsley, 2008; Aguiar *et al.*, 2012). This database can track production processes within different countries and provide measures of the value added required for trade flows.[5] These 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.[6]

The main results of these three papers are relatively similar. They find that the average foreign content of domestic exports is between 20 to 30% (the VS measure).[7] In addition, bilateral trade balances are substantially different when comparing trade in value-added and gross trade. For instance, the US deficit with China is around 30% smaller when using trade in value-added. These analyzes have successfully dealt

[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] Global Trade Analysis Project: www.gtap.agecon.purdue.edu/databases/default.asp

[5] However, 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. For the details of the construction process of global input-output tables from the GTAP-datasets we refer to Annex B of Lejour *et al.* (2012). 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) 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.

[6] Trefler and Zhu (2010) also use the same methodology.

[7] 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%.

with the double-counting issue. However, from their analysis it is not straightforward to observe clear patterns with respect to hubs and spokes in global supply chains.[8]

In this paper we use the GTAP database for multiple years (in our case for 2001, 2004 and 2007). We are the first authors that explicitly take account of the international transport margins that the GTAP-datasets provide, thus introducing the transport component in the value added analysis of international trade. We find similar results regarding bilateral trade balances. The main contribution of our paper is our usage of a decomposition of trade in value-added to create indicators that clearly show the hubs and spokes in international supply chains.[9] 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.

Using these indicators for redirected value added trade we identify the spokes and hubs in global supply chains. We find that 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 serves as a hub for the US, and the region EU12 is a hub for the EU15.[10] Hub and spoke relationships are mainly found for manufacturing sectors, such as electronic equipment, other machinery and equipment, motor vehicles and other transport equipment. In particular, electronic equipment is an example of a globally integrated supply chain which has its production core in the Asia-Pacific region, while the US and EU15 are important spokes for the hubs in Asia. In the sector other machinery and equipment, the EU15 and China are the global hubs and have strong regional linkages. 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 in sectoral trade in Section 3. We conclude in Section 4.

[8]Daudin *et al.* (2011) emphasize rationalisation and use their "Trade Intensity Bilateral Index" between regions. However, this indicator is based only on value added exports and does not use the implicit relations between reflected and diverted trade we use in our paper.

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

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

2 Methodological framework

We first 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, N, and O, upper-case letters denote matrices (e.g. Z). All other 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 sth 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 $N = \{1, 2, \cdots, n\}$. International transport services are provided by transport sectors indexed with $O = \{1, 2, \cdots, o\}$, which is a subset of 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^{ρ}_{rs} 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

In our exposition we make use of global input-output matrices that have the following structure:[11]

$$\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1m} & f^1_1 & f^2_1 & \cdots & f^m_1 & x_1 \\ S_{21} & S_{22} & \cdots & S_{2m} & f^1_2 & f^2_2 & \cdots & f^m_2 & x_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \iddots & \vdots & \vdots \\ S_{m1} & S_{m2} & \cdots & S_{mm} & f^1_m & f^2_m & \cdots & f^m_m & x_m \\ p'_1 & p'_2 & \cdots & p'_m & & & & & \\ x'_1 & x'_2 & \cdots & x'_m & & & & & \end{bmatrix} \tag{1}$$

where S_{rs} denotes the $n \times n$ sectoral matrix of intermediate deliveries from region r to region s, f^s_r is the n vector with final outputs produced in region r that are

[11] In fact, the input-output tables that we derived from the GTAP datasets for 2001, 2004 and 2007 are somewhat more complicated as they also include specific entries for 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 A.1.

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:

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

To economize on notation we summarize equation (1) as:

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

and define matrices of input coefficients A and v, where $A_{rs}(i,j) = S_{rs}(i,j)/x_s(j)$ 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).

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:

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

Because we know that at the global level value added exactly matches final demand, $v'B$ must be equal to the unit vector.[12] 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:

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

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

where we expressed both gross output x and value added p as a function of the final demand vector f^ρ.

These results are summarized in (9), which is a disaggregated representation of the matrix $\Theta(f^\rho)$.

$$\Theta(f^\rho) = \begin{bmatrix} \hat{v}_1 B_{11} \hat{f}_1^\rho & \hat{v}_1 B_{12} \hat{f}_2^\rho & \cdots & \hat{v}_1 B_{1r} \hat{f}_r^\rho & \cdots & \hat{v}_1 B_{1\rho} \hat{f}_\rho^\rho & \cdots & \hat{v}_1 B_{1m} \hat{f}_m^\rho \\ \hat{v}_2 B_{21} \hat{f}_1^\rho & \hat{v}_2 B_{22} \hat{f}_2^\rho & \cdots & \hat{v}_2 B_{2r} \hat{f}_r^\rho & \cdots & \hat{v}_2 B_{2\rho} \hat{f}_\rho^\rho & \cdots & \hat{v}_2 B_{2m} \hat{f}_m^\rho \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \iddots & \vdots \\ \hat{v}_r B_{r1} \hat{f}_1^\rho & \hat{v}_r B_{r2} \hat{f}_2^\rho & \cdots & \hat{v}_r B_{rr} \hat{f}_r^\rho & \cdots & \hat{v}_r B_{r\rho} \hat{f}_\rho^\rho & \cdots & \hat{v}_r B_{rm} \hat{f}_m^\rho \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \iddots & \vdots \\ \hat{v}_\rho B_{\rho 1} \hat{f}_1^\rho & \hat{v}_\rho B_{\rho 2} \hat{f}_2^\rho & \cdots & \hat{v}_\rho B_{\rho r} \hat{f}_r^\rho & \cdots & \hat{v}_\rho B_{\rho\rho} \hat{f}_\rho^\rho & \cdots & \hat{v}_\rho B_{\rho m} \hat{f}_m^\rho \\ \vdots & \vdots & \iddots & \vdots & \iddots & \vdots & \ddots & \vdots \\ \hat{v}_m B_{m1} \hat{f}_1^\rho & \hat{v}_m B_{m2} \hat{f}_2^\rho & \cdots & \hat{v}_m B_{mr} \hat{f}_r^\rho & \cdots & \hat{v}_m B_{m\rho} \hat{f}_\rho^\rho & \cdots & \hat{v}_m B_{mm} \hat{f}_m^\rho \end{bmatrix} \overbrace{\begin{bmatrix} p_1(f^\rho) \\ p_2(f^\rho) \\ \vdots \\ p_r(f^\rho) \\ \vdots \\ p_\rho(f^\rho) \\ \\ p_m(f^\rho) \end{bmatrix}}^{\text{Row sums}}$$

$$\underbrace{\begin{bmatrix} f'^\rho_1 & f'^\rho_2 & \cdots & f'^\rho_r & \cdots & f'^\rho_\rho & \cdots & f'^\rho_m \end{bmatrix}}_{\text{Column sums}} \tag{9}$$

Note that there is only one block in this matrix where domestic value added remains at home. This is $\hat{v}_\rho B_{\rho\rho} \hat{f}_\rho^\rho$, which represents domestic values added needed to produce domestic final output that is used at home. Excluding this block, we find along the columns of $\Theta(f^\rho)$ the value added inputs needed in a specific country to produce final output for ρ. In each column the diagonal matrix elements denote domestic inputs and the off-diagonal ones indicate foreign inputs. Along the rows of $\Theta(f^\rho)$ we find the domestic value added imports from a specific country into final output production for ρ in the different countries producing this output.

2.2 Decomposing bilateral trade in value added

We now show how we distinguish different varieties of trade in value added by a simple labeling of the various entries of $\Theta(f^\rho)$, which represents the value added requirements for final output use in region ρ. We attach four different labels to the different export flows that are included in the matrix $\Theta(f^\rho)$.

First, we consider the blocks on the main diagonal:

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

These flows represent domestic value added from region r that is needed to produce final output exports in r for final destination ρ. We label them as G_r^ρ. Note that G has only one subscript since there is no intermediate destination between r and ρ for the domestic value added exported as final output directly to ρ.

Second, turning to the off-diagonal elements we consider the following blocks:

$$\hat{v}_r B_{r\rho} \hat{f}_\rho^\rho = D_r^\rho \quad \forall (r, \rho) \in M : r \neq \rho \tag{11}$$

These exports indicate values added generated in r for intermediates used by region ρ to produce final output consumed domestically. We label them as D_r^ρ. Note again that there is no intermediate destination in this case.

Third, we consider the blocks:

$$\hat{v}_r B_{rs} \hat{f}_s^\rho = R_{rs}^\rho \quad \forall (r,s,\rho) \in M : r \neq \rho, r \neq s, s \neq \rho \tag{12}$$

These exports represent values added generated in r that are diverted by region s via final output exports from s to ρ. We label them as R_{rs}^ρ.

Fourth, we inspect the blocks:

$$\hat{v}_\rho B_{\rho r} \hat{f}_r^\rho = R_{\rho r}^{*\rho} \quad \forall (r,\rho) \in M : r \neq \rho \tag{13}$$

These exports indicate value added generated in ρ that is reflected by r –through its final output exports– back again to ρ. We label them as $R_{\rho r}^{*\rho}$.

We conclude that four different types of value added exports can be distinguished. The value added requirements defined as G are for direct final output exports. The requirements in D are for intermediates converted to final use in the final destination region, while R represents the requirements for intermediates diverted to third countries. Finally, R^* 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

Using these four labels of the previous section, and not taking into account the element $\hat{v}_\rho B_{\rho\rho} \hat{f}_\rho^\rho$ from $\Theta(f^\rho)$, which does not contain any traded value added, we obtain the matrix Γ^ρ. This matrix provides the cross-border bilateral value added requirements for final output use in region ρ.

$$\Gamma^\rho = \begin{bmatrix} G_1^\rho & R_{12}^\rho & \cdots & R_{1r}^\rho & \cdots & D_1^\rho & \cdots & R_{1m}^\rho \\ R_{21}^\rho & G_2^\rho & \cdots & R_{2r}^\rho & \cdots & D_2^\rho & \cdots & R_{2m}^\rho \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \iddots & \vdots \\ R_{r1}^\rho & R_{r2}^\rho & \cdots & G_r^\rho & \cdots & D_r^\rho & \cdots & R_{rm}^\rho \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \iddots & \vdots \\ R_{\rho 1}^{*\rho} & R_{\rho 2}^{*\rho} & \cdots & R_{\rho r}^{*\rho} & \cdots & - & \cdots & R_{\rho m}^{*\rho} \\ \vdots & \vdots & \iddots & \vdots & \iddots & \vdots & \ddots & \vdots \\ R_{m1}^\rho & R_{m2}^\rho & \cdots & R_{mr}^\rho & \cdots & D_m^\rho & \cdots & G_m^\rho \end{bmatrix} \tag{14}$$

Strictly, entry $\Gamma_{r\sigma}^\rho(i,j) = \hat{v}_r(i) B_{r\sigma}(i,j) \hat{f}_\sigma^\rho(j)$ represents the value added from sector i in region r that is needed by redirector σ for final j-output use in ρ. In our description, we abstract from sector-specific flows and we loosely describe the entries of this matrix as bilateral value added trade needed for final output use in ρ. Therefore, $\Gamma^{\rho}_{r\sigma}$ provides information on the region r generating the value added, the intermediate redirector σ (if any), and the final destination ρ. Note that in the case of the blocks G and D there are no redirectors and the subsequent Γ entry has only one subscript.

We can also summarize the information on these four blocks using Figure 1. Note that the redirector is importing –either directly or indirectly– intermediates from the origin: $R(int)$ and $R^*(int)$, while it exports final output: $R(fin)$ and $R^*(fin)$. Also, by definition the final destination of $R^*(fin)$ is the same region as the origin.

Figure 1: Triangular trading scheme

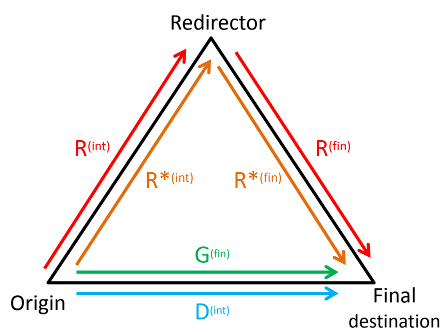


Figure 1 shows that we can look at bilateral trade in value added from different perspectives. For instance, we can focus on trade in value added from a particular origin to a specific destination by taking the sum of all flows that pass through the redirectors (Γ^{ρ}_{rw}). It is from this perspective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

Finally, it is important to 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.

2.4 Aggregating over regions and sectors

From equation (14) 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 D. 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 G. Finally, all outgoing trade that was diverted by EU-countries before leaving the EU is also classified as G. 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.[13] This choice also means that we can condense our accounting system by taking the column-sums of all matrices in equation (14). Hence, $G^{\rho}_{r}(t,j)$ represents national (t) value added needed for the use in ρ of final j-output. In accordance, $R^{\rho}_{rs}(t,j)$ represents national value added from r that is diverted by s to ρ and required for the use in ρ of final j-output from s.

For region r we collect bilateral domestic value added exports e^{ρ}_{r} at the sectoral level as:

$$e^{\rho}_{r}(j) = \Gamma^{\rho}_{rw}(t,j) = \overbrace{\overbrace{G^{\rho}_{r}(t,j)}^{\text{Directly}} + D^{\rho}_{r}(t,j) + \overbrace{R^{\rho}_{rw}(t,j)}^{\text{Diverted to } \rho}}^{\text{Absorbed in } \rho} \quad \forall (r,\rho) \in M : r \neq \rho \qquad (15)$$

All value added trade is absorbed in the region of final destination. This decomposition partly reveals whether value added trade is absorbed directly in the region of destination or whether it has traveled via other countries before reaching its final

[13] 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.

destination (i.e. diverted trade in value added). Finally, aggregating over sectors and regions, total value added trade for region r can be derived from (15).[14]

2.5 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 US are typical examples of this type of outsourcing. We present two pairs of indicators based on redirected value added trade that are useful in detecting hubs and spokes in global supply chains at the sectoral level.

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

$$e_{r\sigma}(j) = \Gamma^{w}_{r\sigma}(t,j) = \overbrace{D^{\sigma}_{r}(t,j)}^{\text{absorbed in } \sigma} + \underbrace{\overbrace{R^{w}_{r\sigma}(t,j)}^{\text{diverted by } \sigma} + \overbrace{R^{*r}_{r\sigma}(t,j)}^{\text{reflected by } \sigma}}_{\text{redirected by } \sigma} \quad \forall (r,\sigma) \in M : r \neq \sigma \tag{16}$$

and the bilateral exports *from* redirector σ (the outgoing spokes) can be derived as:[15]

$$e^{\rho}_{\sigma}(j) = \Gamma^{\rho}_{w\sigma}(t,j) = \overbrace{G^{\rho}_{\sigma}(t,j) + \underbrace{R^{\rho}_{w\sigma}(t,j) + R^{*\rho}_{\rho\sigma}(t,j)}_{\text{redirected by } \sigma}}^{\text{absorbed in } \rho} = f^{\rho}_{\sigma}(j) \quad \forall (\sigma,\rho) \in M : \sigma \neq \rho \tag{17}$$

Equation (16) shows that the redirector imports intermediate value added for own final output production that is consumed domestically and intermediate value added for final output exports. The final output exports of the redirector 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 $R(int)$ and $R^{*}(int)$ are the incoming spokes and $R(fin)$ and $R^{*}(fin)$ are the outgoing spokes. If the incoming trade is large and the outgoing trade is small the redirector is just importing intermediates for his own final use. However, if both the incoming

[14] Moreover, it can be verified that the aggregate balance of value added trade $e^{w}_{r}(t) - e^{r}_{w}(t)$ equals the aggregate gross trade balance. This result follows from using (15) together with (7) and (8) for the first equality and the accounting relations implicit in (1) for the second equality. However, even though at *aggregate* region/country conventional (gross) trade balances are equal to value added trade balances, *bilateral* trade balances (between any two given regions/countries) usually differ when they are evaluated at gross, instead of value added terms. The only exception is the hypothetical case where final exports from and to both regions do not include intermediates from a third country.

[15] The last equality of (17) is based on ${\gamma^{\rho}_{w\sigma}}' = \sum_{r} {v'}_{r} B_{r\sigma} \hat{f}^{\rho}_{\sigma} = {f^{\rho}_{\sigma}}'$ because $\sum_{r} {v'}_{r} B_{r\sigma} = \iota' \sum_{r} (I - \sum_{\sigma} A_{\sigma r}) B_{r\sigma} = \iota'$

and the outgoing trade are large we define the redirector as a hub that produces final output exports from substantial intermediate imports.

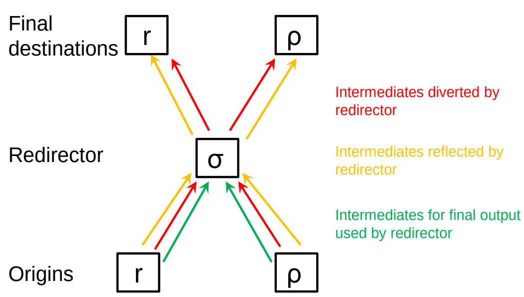
Thus, region/country σ qualifies as a j-hub if one or both of the following expressions are relatively large:

$$\begin{aligned} SFRV_{\sigma}(j) &= \frac{R^{w}_{w\sigma}(t,j)+R^{*w}_{w\sigma}(t,j)}{e_{w\sigma}(j)} \\ GSFRV_{\sigma}(j) &= \frac{R^{w}_{w\sigma}(t,j)+R^{*w}_{w\sigma}(t,j)}{R^{w}_{ww}(t,j)+R^{*w}_{ww}(t,j)} \end{aligned} \tag{18}$$

where $SFRV_{\sigma}(j)$ indicates the share of foreign redirected value added in total bilateral value added imports that region σ needs to produce exports of final j-output. This is an intensity measure showing the relative importance of region σ in assembling final j-output for the world market. $GSFRV_{\sigma}(j)$ 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.

Figure 2 illustrates the calculation of $SFRV$. For a specific redirector (σ), we determine the share of outgoing foreign intermediates in final output exports (the arrows from the redirector to the final destinations) as a percentage of total imports of foreign intermediates (the arrows from the origins to the redirector).

Figure 2: Calculating SFRV



A large $SFRV_{\sigma}$ 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 sector j if its $SFRV_{\sigma}(j)$ value is above the global value $SFRV_{w}(j)$, which is a weighted average of the world's $SFRV(j)$ values. However, having a large $SFRV$ 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 $GSFRV$ indicator. A relative large value of $GSFRV_{\sigma}(j)$ shows that region σ redirects a large share of globally redirected value added and is thus, a relatively large hub in the global supply chain of sector j. Note that regions with large internal markets (i.e. EU15, USA, China) can have both large $GSFRV$ and low $SFRV$ values, reflecting that the foreign value added embedded in its 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. Because of this we define a j-hub as a region with either a relatively large $SFRV(j)$ and/or a relatively large $GSFRV(j)$ (i.e. when at least one of the indicators is above the world average).

Finally, the nature of the hub is addressed by using the information on the final destinations of the redirected trade and distance measures. When a majority of the final destinations are in regions geographically adjacent to the redirecting region (for instance, Other NAFTA and the USA) we define it as a regional hub. On the other hand, if the redirecting region's final destinations are geographically mixed, then we define it as a global hub. This evaluation is confirmed by the use of distance measures, which have been calculated as follows. We take the bilateral (population-weighted) distances that are available at the CEPII-website (Mayer and Zignago, 2011) and we aggregate these with GDP-weights to a bilateral distance matrix for our twelve-region aggregation.[16] We use this matrix to calculate the average distance traveled by both redirected value added imports and redirected value added exports for each redirector.

In addition, we can also 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 one of the following expressions is relatively large:

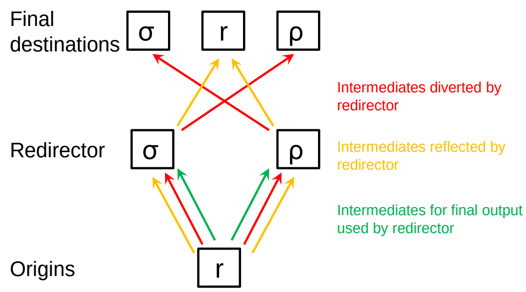
$$\begin{aligned} SDRV_r(j) &= \tfrac{R^w_{rw}(t,j)+R^{*r}_{rw}(t,j)}{e_{rw}(t,j)} \\ GSDRV_r(j) &= \tfrac{R^w_{rw}(t,j)+R^{*r}_{rw}(t,j)}{r^w_{ww}(t,j)+r^{*w}_{ww}(t,j)} \end{aligned} \tag{19}$$

where $SDRV_r(j)$ indicates the share of domestic value added that is redirected by another country with respect to total bilateral value added exports for final j-production. 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. $GSDRV_r(j)$ expresses this redirected domestic value added as a share of all globally redirected value added for final j-exports. 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. In this case, we also apply the distance measure to the geographical concentration of the origin as a way to classify the incoming spokes as regional or global.

Figure 3 illustrates how $SDRV$ is calculated. For a specific origin (r), $SDRV$ is the share of redirected intermediate value added by all redirectors (the arrows from the redirectors to the final destinations) as a percentage of intermediate value added exports from the origin (the arrows from the origin to the redirectors).

[16] Denoting the distance between country r and s from the CEPII-database as d_{rs} and the GDP of country r as y_r we calculate the distance between aggregate regions ρ and σ as: $d_{\rho\sigma} = \frac{\sum_{r\in\rho}\sum_{s\in\sigma} y_r d_{rs} y_s}{y_\rho y_\sigma}$

Figure 3: Calculating SDRV



3 Identifying hubs and spokes using the GTAP data

The GTAP databases provide information on more than one hundred regions and/or countries (depending on the database release) and 57 sectors. As explained in Section 2.4 our calculations are done at the most disaggregated level, but for presentation reasons we aggregate the data into 12 regions.[17]

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.[18] 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. Using our indicators based on redirected trade, we identify hubs (using the indicators in equation 18) and incoming spokes (using the indicators in equation 19).

3.1 Hubs and spokes for aggregate total output

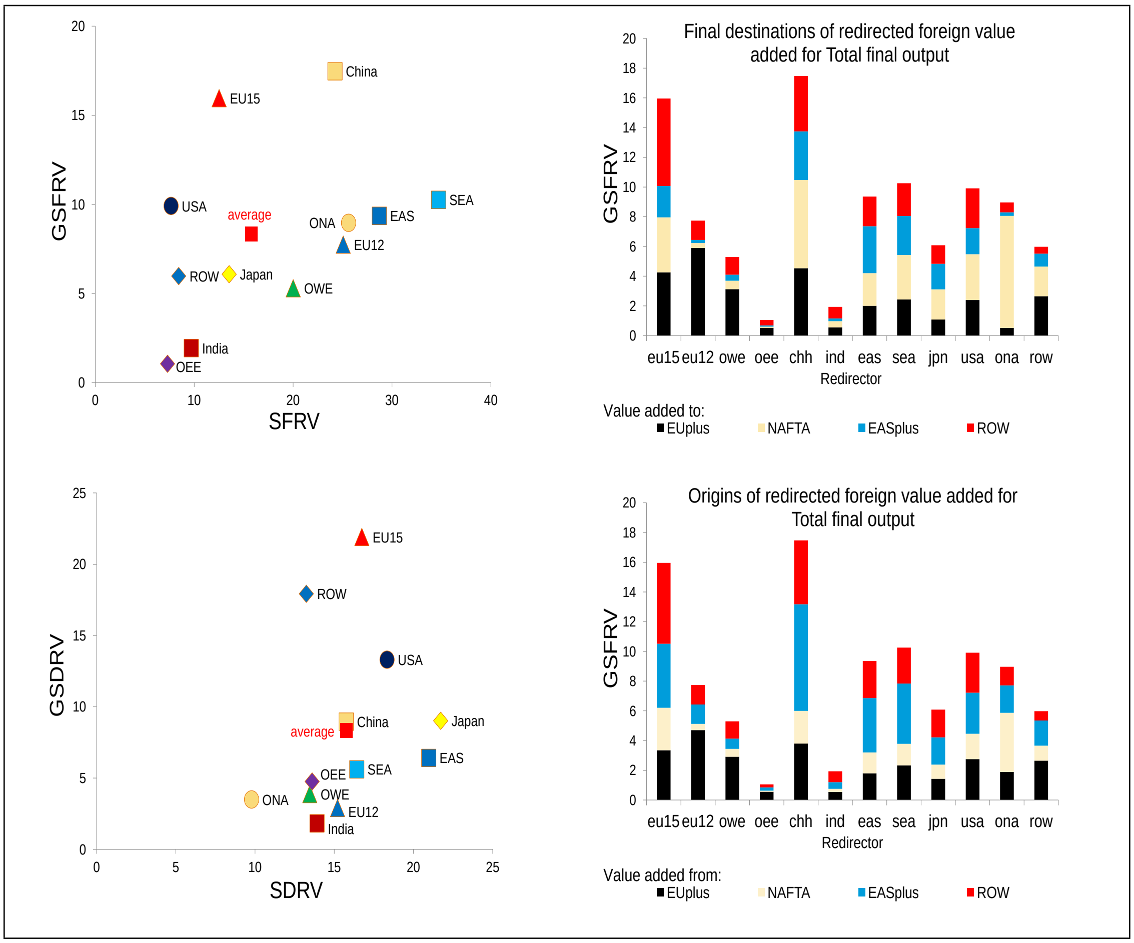
First, we analyze the hubs and spokes at the aggregate (total output) level, and then we focus on specific sectors. From Figure 4 we observe that China and the EU15 are together responsible for redirecting about a third of all globally redirected value added. Both regions have large $GSFRV$ values (vertical axis of the left panel). Both regions can be considered as the big global hubs. In addition, the ONA, EAS and SEA regions have relatively large $GSFRV$ values, but also have above-average

[17]The aggregation mapping into 12 regions is presented in Table 1 in Appendix A.2. Using the methodological framework discussed above we estimate trade in value added for our aggregated regions and sectors. The first results we produce are the bilateral trade gaps in both gross and value added terms. These results already provide a first impression of the role of countries in the chain of vertical specialization. However, our results are similar to others in the literature and we do not discuss them here, apart from the separate treatment of international transport. The tables can be found in Lejour *et al.* (2012).

[18]We focus on external trade, ignoring trade within regions. Including internal trade would drastically change the position of the EU.

$SFRV$ indicators that show high redirecting intensities. Finally, OWE and EU12 have below-average $GSFRV$ values, but above-average $SRFV$. This indicates that even though both regions are not global redirectors, they are highly integrated into global supply chains. From the supply side, we can use $GSDRV$ to determine that the EU15, ROW, USA, Japan and China are the main incoming spokes in global supply chains. The information contained in Figure 4 shows that India and OEE (a region mainly comprised by Russia) cannot be considered as hubs nor spokes in global supply chains, since the values for the four indicators are relatively low for both regions. Using the same logic, Japan and ROW can be defined as incoming spokes, but not as hubs.

Figure 4: Redirected foreign and domestic value added for total final output, 2007



Source: Own estimations using GTAP database.

Notes: On the left-hand side graphs, we have our four indicators: $SFRV$ against $GSFRV$, and $SDRV$ against $GSDRV$. The right-hand side graphs present the corresponding final destinations and origins of $GSFRV$.

Moreover, using the right-hand side graphs in Figure 4 we can distinguish between regional and global hubs. For instance, the Other NAFTA (ONA) region has a predominant share of value added trade being redirected to the aggregated NAFTA region (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 EUplus (mainly the EU15 region), while it also has a predominant share of intermediate inputs originated in the EUplus (lower right-hand side graph in Figure 4). On the other hand, most of the east Asian regions –namely 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. These results are also confirmed by our average distance measures (see first graph in Figure 8 in Appendix A.2) where EU12, OWE and ONA have all outgoing trade with significantly smaller average distances than the Asian regions and the USA.[19]

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). In addition, these patterns have been roughly the same when we analyze changes between 2001 and the results from 2007 presented above. In Table 3 in Appendix A.2 we present the changes in our four indicators over this period. The main change that we can observe is that China has become more important as a global hub, since its $GSFRV$ value has increased from 10% in 2001 to 17.5% in 2007, while the relative importance of ONA and SEA has diminished in this period. From the supply side, the USA has become a less predominant global spoke, since its $GSDRV$ value has decreased from 22% to 13%.

3.2 Hubs and spokes for selected sectors

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 intersectoral 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.[20] Although technically feasible it is too cumbersome to present results for all sectors. We analyze 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

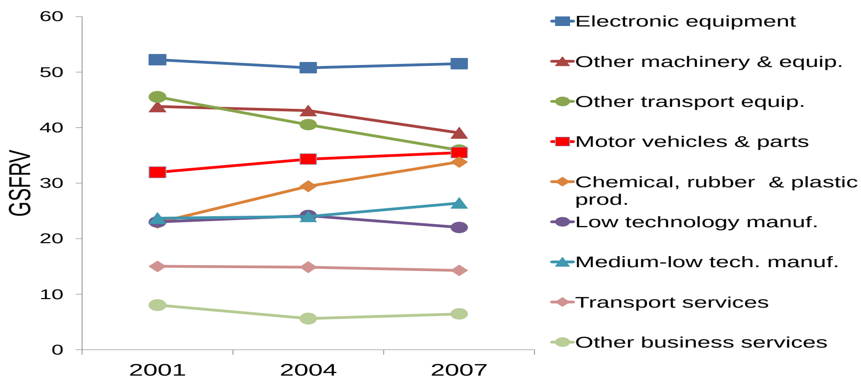
[19]Note from the same Figure 8 that this pattern is also very similar when we analyze specific sectors.

[20]However, about 25 sectors are in agriculture and food processing.

and plastic products (CRP). We also distinguish eight additional aggregated sectors (see Table 2 in Appendix A.2 for all the sectoral classifications.)

The importance of global product networks varies by sector. Figure 5 present the global share of redirected value added in total value added of traded intermediates ($GSFRV$) for most sectors. The results suggest that global production networks matter only for manufacturing sectors. For instance, $GSFRV$ is above 20% for all manufacturing sectors, while lower than 15% for agriculture, energy and services sectors (some of them are not shown in the Figure).

Figure 5: Global share of foreign redirected value added trade in intermediate value added trade (GSFRV) by economic sector, 2001-2007



Source: Own estimations using GTAP database. Notes: Agricultural, energy and most services sectors are not shown. Their $GSFRV$ values are below 15%.

We find that the share of redirected value added in other business services is slightly increasing in particular between 2004 and 2007, but it is still much lower than in manufacturing. For the manufacturing sectors the global share of redirected trade also varies much by specific sector. It is relatively low for low-tech and medium-low tech manufacturing. For the latter it increases over time. In chemicals, rubbers and plastics the share of redirected value added increases quickly, suggesting large changes in the organization of global production networks. It increases from 23% in 2001 to 34% in 2007, in particular the increase between 2001 and 2004 is significant. In motor vehicles and parts and other transport equipment, the share of redirection is also about 35% in 2007, but the change over time is different. In other transport equipment the share of redirected value added decreased from 45% in 2001, suggesting a concentration of production networks in a few countries. In motor vehicles it increases slightly. Also in other machinery and equipment the share of redirected value added decreased to about 39 percent. Finally, the most globally integrated sector is electronic equipment, where more than half of global intermediate value added trade is redirected.

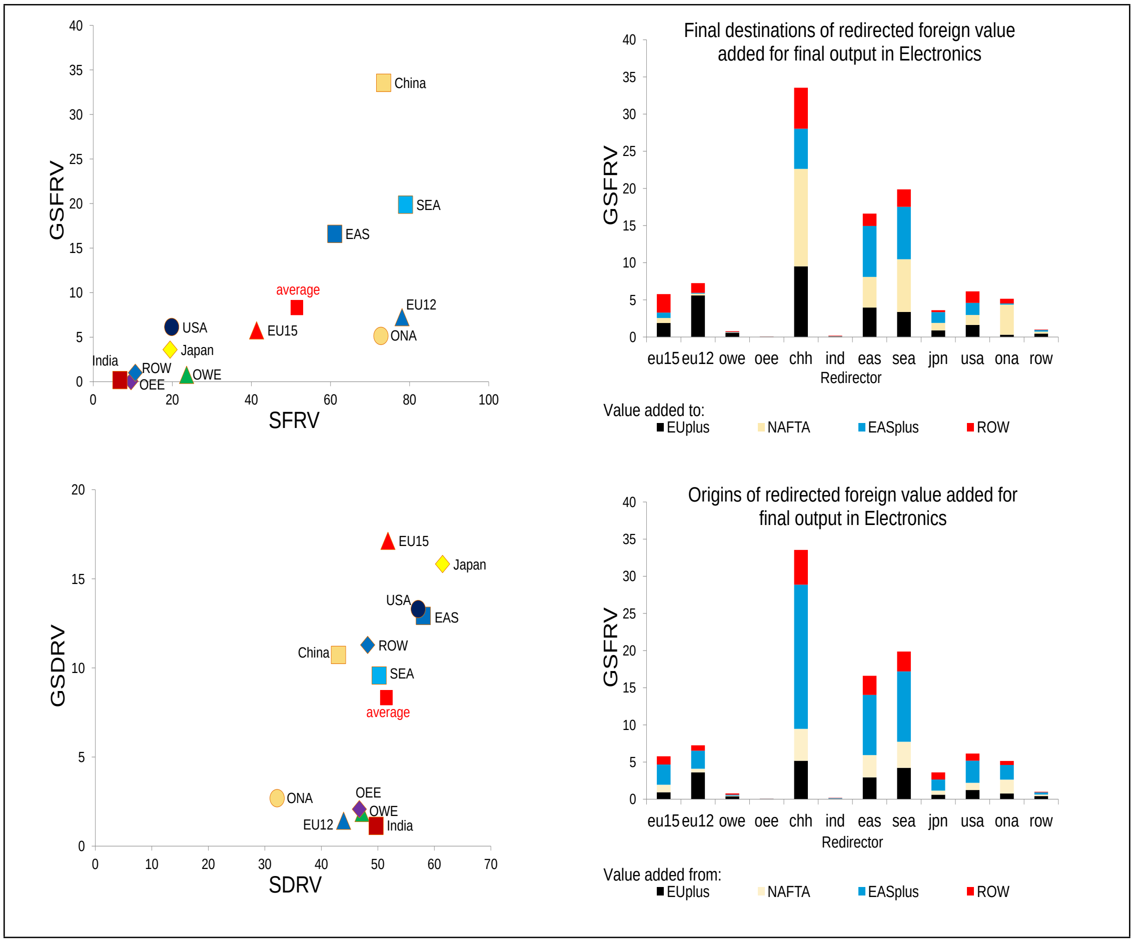
Even though the data allow us to analyze the redirected value added between our 12 aggregated regions for all 13 sectors, the amount of information is too large to be presented here. Instead, we focus our hubs and spokes analysis only on the two main globally integrated sectors: electronic equipment,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

We start with the electronic equipment sector, which is the most globally integrated sector with more than half of the intermediate value added being redirected. From Figure 6 we find that China is the most important hub, with around a third of globally redirected intermediate value added and also with a large redirecting intensity (with $SFRV$ close to 75%). Then SEA and EAS follow in importance. About 70 percent of all redirected value added in electronic equipments takes place in Asia. All three Asian hubs are global hubs, since their final destinations are spread between the four global regions (EUplus, NAFTA, EASplus and ROW). However, these three Asian regions (mainly China) are using value added in intermediate inputs mainly from the other Asian regions (EASplus, which includes Japan). EU12 and ONA are regional hubs, with their redirected trade going mainly to the EUplus and the NAFTA regions, respectively. The division between global hubs and regional hubs is also confirmed by the average distance measure in Figure 8 in Appendix A.2. 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.

The second sector we analyze is OME: other machinery and equipment. From Figure 7 we observe that EU15 and China redirect much of the foreign value added in this sector, with each region redirecting about 20% of global redirected value added. Thus, we define both regions as the main global hubs in machinery and equipment. In addition, regions such as ONA, EU12, EAS, SEA and Japan are also hubs in this sector. We find again that ONA and EU12 are regional hubs, strongly linked to the NAFTA and EUplus regions, respectively. The EASplus regions (EAS, SEA, Japan, China) are global hubs. On the other hand, India and OEE (mainly Russia) are not integrated into the global supply chain of OME, while ROW is important only as a supply spoke for intermediate inputs. The USA is important as a supply spoke and also as a final destination.

In the Appendix we present the figures for the other three manufacturing sectors that have extensive global supply chains: OTN, MVH and CRP. For other transport equipment (OTN) we observe in Figure 9 that the EU15 and USA are the main hubs and spokes for this sectors, which are more regional than global. In contrast to the ELE and OME sectors, the EASplus regions are not important players in the OTN sector, with the exception of EAS (mainly Korea), which is an important hub. In Figure 10 we present the information for the motor vehicles and parts sector (MVH). Here we observe that ONA is the most important hub, but around 90% of its redirected value added goes to the NAFTA region (i.e. USA). EU15, EU12 and Japan are also important hubs. But while EU12 is mainly a regional hub, the other two regions are global hubs. Finally, for the chemicals, rubber and plastic products

Figure 6: Redirected foreign and domestic value added for final output in electronic equipment, 2007



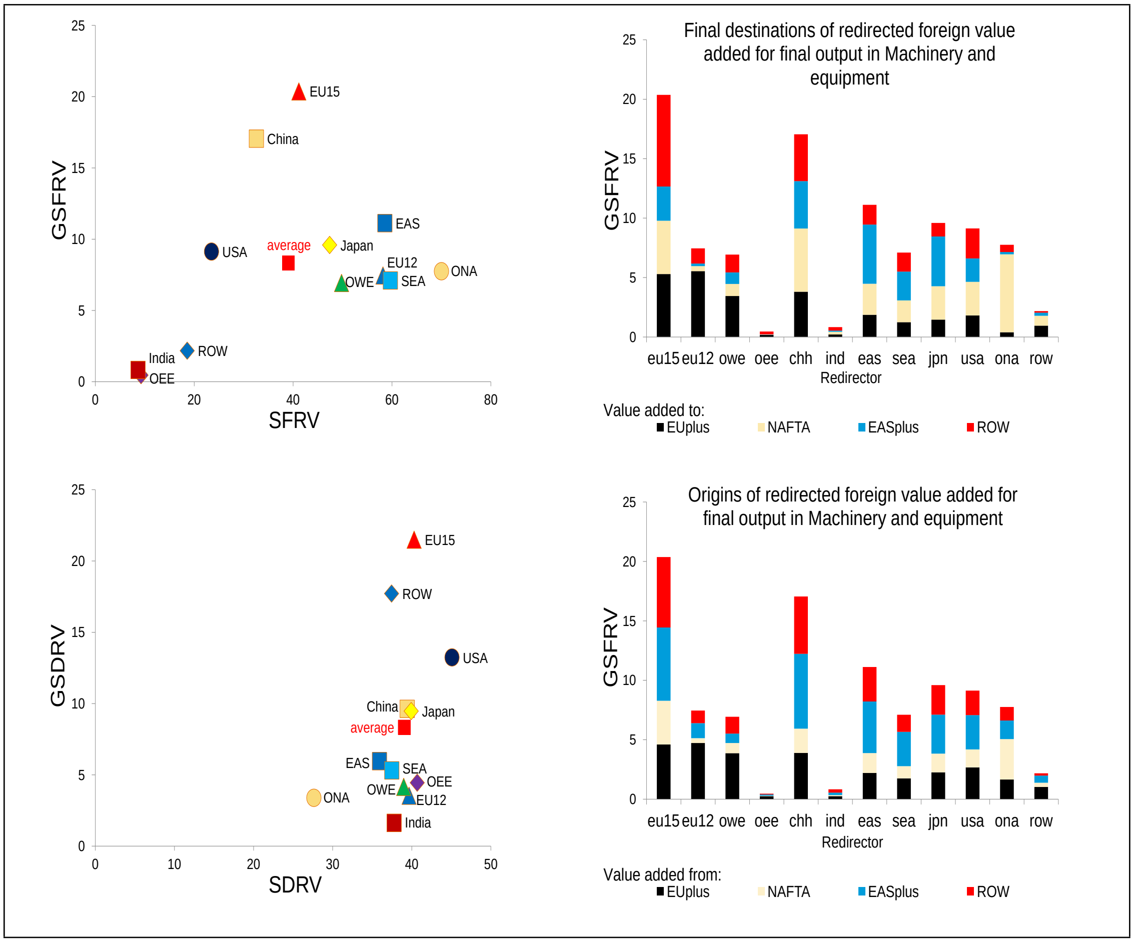
Source: Own estimations using GTAP database.

Notes: On the left-hand side graphs, we have our four indicators: $SFRV$ against $GSFRV$, and $SDRV$ against $GSDRV$. The right-hand side graphs present the corresponding final destinations and origins of $GSFRV$.

sector (CRP), Figure 11 shows that EU15 is the main hub and spoke of the sector, and that it is redirecting value added on a global scale.

Even though each sector analyzed has its own particularities, we find certain patterns across these sectors. First, ONA (Mexico and Canada) are regional hubs with very strong ties to the USA. While ONA are sourced with intermediate inputs from (usually) many regions, their final destination of redirected trade is mainly the USA. The same logic applies to the EU12 (EU new member states) and to a smaller extent to the OWE region, which are mainly integrated with the EU15 (EU old member states). On the other hand, the South-East Asia regions (EAplus)

Figure 7: Redirected foreign and domestic value added for final output in other machinery and equipment, 2007



Source: Own estimations using GTAP database.

Notes: On the left-hand side graphs, we have our four indicators: $SFRV$ against $GSFRV$, and $SDRV$ against $GSDRV$. The right-hand side graphs present the corresponding final destinations and origins of $GSFRV$.

are usually very well integrated amongst themselves, but are also sourced by other regions and more importantly, redirect value added to most regions, specially 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 spokes that source 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 final destinations for redirected trade. Moreover, they are the center of regional supply chains: USA using ONA as a manufacturing center, and the EU15 using the EU12 and also the OWE as their manufacturing centers.

Finally, we also present the changes over time for each of the five main manufacturing sectors. In Tables 4 to 8 in the Appendix we show the four main indicators for these sectors. We observe that for electronic equipment China increased its global share of redirected foreign value added ($GSFRV$) from 13% in 2001 to 34% in 2007, while the share of EAS declined from 32% in 2001 to 20% in 2007. For other machinery and equipment both China and EAS increased their $GSFRV$ values, while USA and ONA experienced a decrease between 2001 and 2007. Finally, we also find that ONA was even a bigger hub in the motor vehicles and parts industry in 2001, when it redirected 44% of globally redirected value added trade. This share then declined to 25% in 2007, but in that year it was still the biggest redirecting hub in the world.

4 Summary

The recent literature on trade in value added has advanced in deriving trade in value added measures from national input-output tables and international trade statistics. In most cases the GTAP data, developed for global trade analysis with CGE models, are used. 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 did not track the value added generated in global supply chains. This is the main contribution of this paper. We have 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 economic sector. 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. First, 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. Some regions, for instance, mainly serve other nearby regions –i.e. other NAFTA serves as a hub for the US; while EU12, and other Western Europe serve as local hubs for EU15. Therefore, these regions are important in regional production networks, but not in global production networks. On the other hand, the Asia-Pacific region appears to have strong regional links as well as global links with both the EU15 and the US.

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. 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. A special case is electronic equipment, for which –when compared with other sectors or the average– the hubs are located in the Asia-Pacific region. The spokes, US 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.

Apart from these results we have also contributed to the methodology. We took explicitly account of the international transport margins that the GTAP-datasets provide, thus introducing the transport component in the value added analysis of international trade.

We believe that our contributions have much potential for deeper analyzes of global supply chains. First of all, we could 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 could be interesting to extend the analysis by also covering trade in different primary inputs (such as low- and high-skilled labor, 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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A Appendices

A.1 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:

$$\begin{gathered}\left[\begin{array}{c} x \\ \tau \end{array}\right] = \left[\begin{array}{c} S \\ \widetilde{S} \end{array}\right]\iota + \left[\begin{array}{c} \check{S} \\ 0 \end{array}\right]\iota + \left[\begin{array}{c} F \\ \bar{S} \end{array}\right]\iota = \left[\begin{array}{cc} A & \check{A} \\ \widetilde{A} & 0 \end{array}\right]\left[\begin{array}{c} x \\ \tau \end{array}\right] + \left[\begin{array}{c} F \\ \bar{S} \end{array}\right]\iota = \\ \left[\begin{array}{cc} I-A & -\check{A} \\ -\widetilde{A} & I \end{array}\right]^{-1}\left[\begin{array}{c} F \\ \bar{S} \end{array}\right]\iota = \left[\begin{array}{cc} \bar{B} & \check{B} \\ \widetilde{B} & \acute{B} \end{array}\right]\left[\begin{array}{c} F \\ \bar{S} \end{array}\right]\iota\end{gathered} \tag{24}$$

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

$$\left[\begin{array}{cc} \bar{B} & \check{B} \\ \widetilde{B} & \acute{B} \end{array}\right] = \left[\begin{array}{cc} (I-A-\check{A}\widetilde{A})^{-1} & (I-A)^{-1}\check{A}(I-\widetilde{A}(I-A)^{-1}\check{A})^{-1} \\ \widetilde{A}(I-A-\check{A}\widetilde{A})^{-1} & (I-\widetilde{A}(I-A)^{-1}\check{A})^{-1} \end{array}\right] \tag{25}$$

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,[21] 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

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

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.

A.2 Additional tables and figures

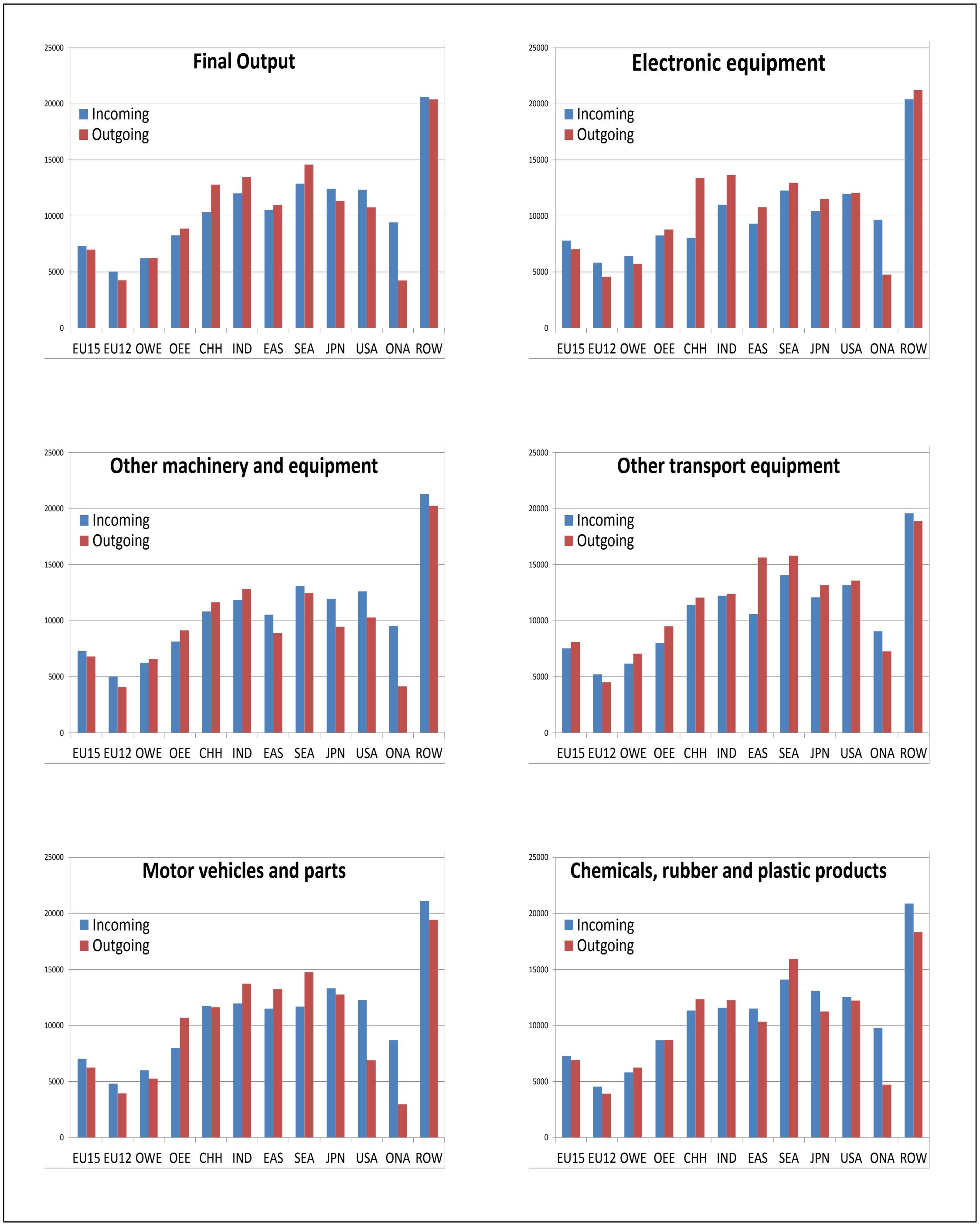
Table 1: Regional aggregation

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

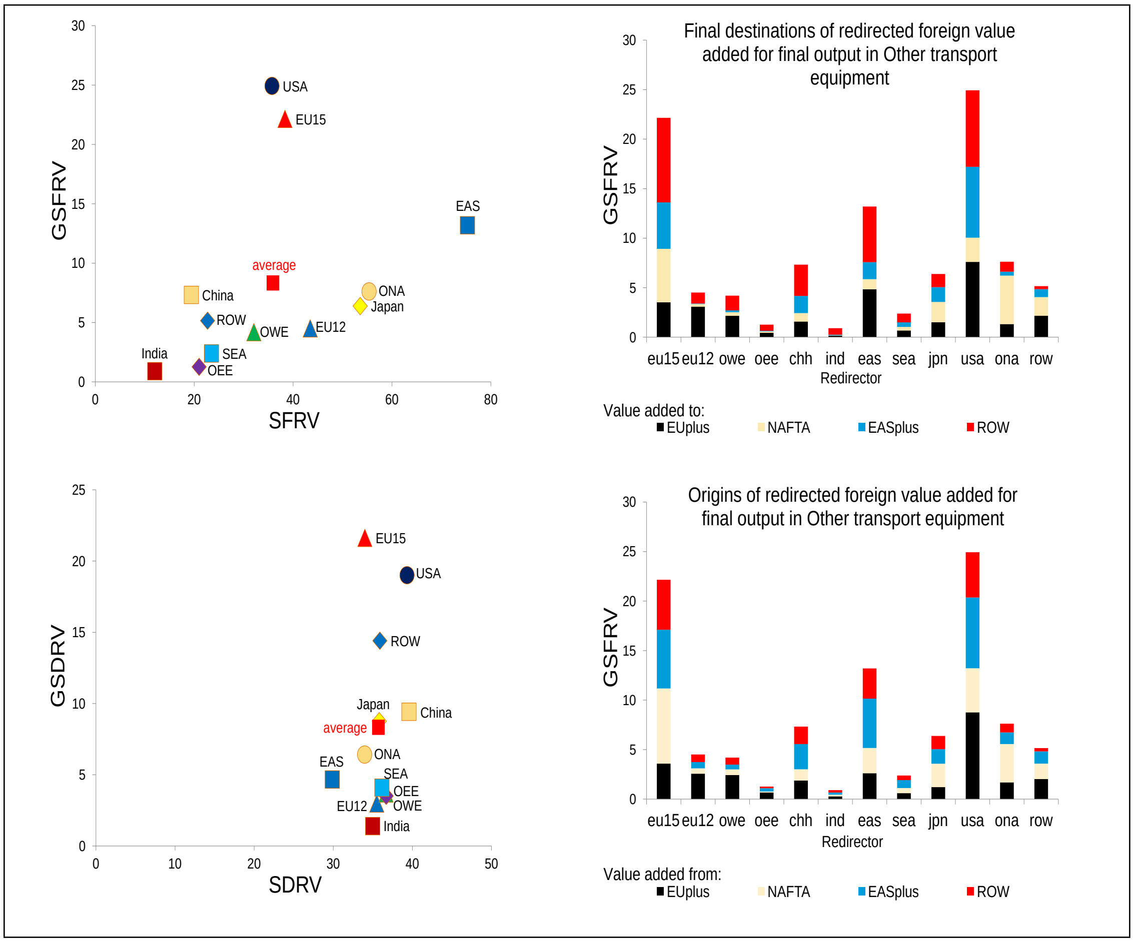
Code	Description
AGO	Agriculture and raw materials
ENG	Energy
LTM	Low technology manufacturing
MLM	Medium-low technology manufacturing
CRP	Chemical, rubber and plastic products
MVH	Motor vehicles and parts
OTN	Other transport equipment
OME	Other machinery and equipment
ELE	Electronic equipment
TRA	Transport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

Figure 8: Average distance (in km) traveled by incoming and outgoing redirected total value added by region, 2007



Source: Own estimations using GTAP database and CEPII data on average distance.

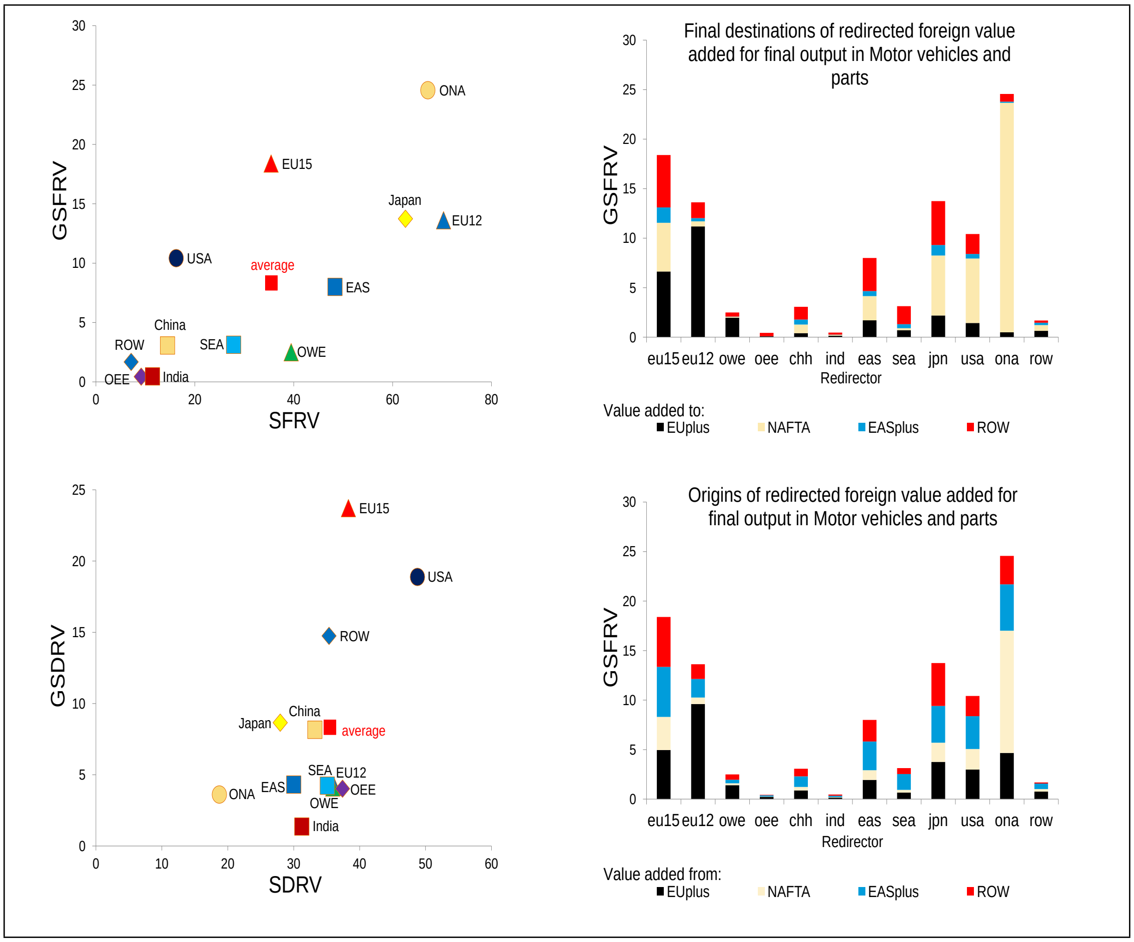
Figure 9: Redirected foreign and domestic value added for final output in other transport equipment, 2007



Source: Own estimations using GTAP database.

Notes: On the left-hand side graphs, we have our four indicators: $SFRV$ against $GSFRV$, and $SDRV$ against $GSDRV$. The right-hand side graphs present the corresponding final destinations and origins of $GSFRV$.

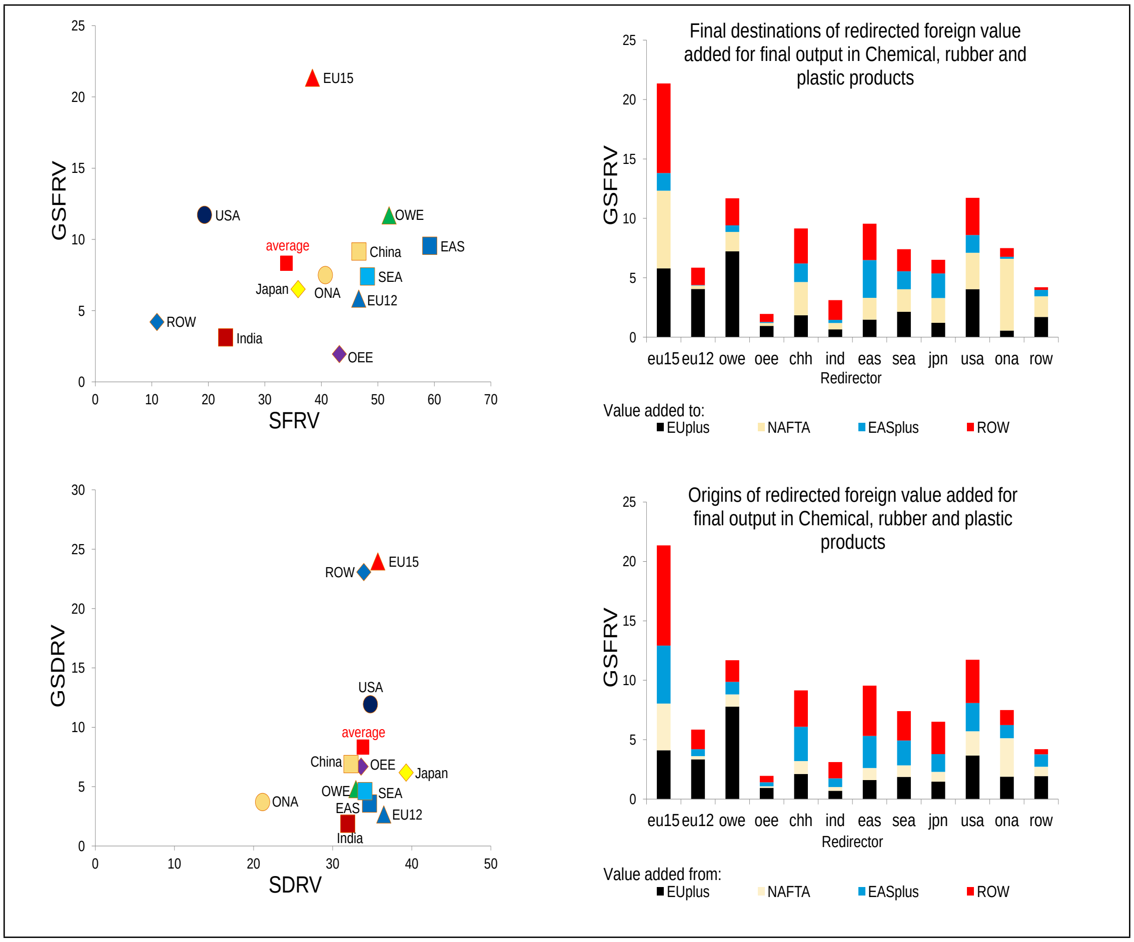
Figure 10: Redirected foreign and domestic value added for final output in motor vehicles and parts, 2007



Source: Own estimations using GTAP database.

Notes: On the left-hand side graphs, we have our four indicators: $SFRV$ against $GSFRV$, and $SDRV$ against $GSDRV$. The right-hand side graphs present the corresponding final destinations and origins of $GSFRV$.

Figure 11: Redirected foreign and domestic value added for final output in chemical, rubber and plastic products, 2007



Source: Own estimations using GTAP database.

Notes: On the left-hand side graphs, we have our four indicators: $SFRV$ against $GSFRV$, and $SDRV$ against $GSDRV$. The right-hand side graphs present the corresponding final destinations and origins of $GSFRV$.

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

	SFRV indicator			SDRV indicator			GSFRV indicator			GSDRV 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 four indicators for electronic equipment, 2001-2007

	SFRV indicator			SDRV indicator			GSFRV indicator			GSDRV 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 four indicators for other machinery and equipment, 2001-2007

	SFRV indicator			SDRV indicator			GSFRV indicator			GSDRV 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 four indicators for other transport equipment, 2001-2007

	SFRV indicator			SDRV indicator			GSFRV indicator			GSDRV 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 four indicators for motor vehicles and parts, 2001-2007

	SFRV indicator			SDRV indicator			GSFRV indicator			GSDRV 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 four indicators for chemicals, rubber and plastic products, 2001-2007

	SFRV indicator			SDRV indicator			GSFRV indicator			GSDRV 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.

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