

# Identifying hubs and spokes in global supply chains with 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, because traditional trade measures (in gross value) cannot track the origin and destination of value added produced in different countries. This paper follows a recently created methodological framework for analyzing trade in value added, but extends it to identify the spokes and hubs in these global supply chains. In particular, we create indicators that measure the origin of value added which is redirected by hubs and the destinations of redirected value added. Using these indicators and the GTAP database for 2001, 2004 and 2007 we identify the importance of redirected value added and the hub and spoke relationships at the industry level.

*Keywords:* Trade in value added, vertical specialization, global supply chains, global input-output tables

*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. This process has been defined in the literature with different names: vertical specialization, offshoring/outsourcing, international value chains, slicing up the value chain, production fragmentation, and multi-stage production. 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 organised along global supply chains in which the tasks required to produce goods and services are performed at several locations all over the world.<sup>1</sup>

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<sup>1</sup>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 this well. This was no problem when the production processes were only split up within a single country. In that case the value added was generated in one country and the value of exports mirrored reasonably the value added included in production –except maybe for raw materials. However, this changes 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. Therefore it is hard to identify the international trade relations underlying global production networks.

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 multi-region models. The second relies on the more recent literature that measures vertical specialization and the domestic value added content of trade. 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 the link of domestic value added with all other trading partners.

The main purpose of this paper is to move beyond recently constructed indicators of vertical specialisation –that measure the importance of international inputs as a share of gross trade– and create additional indicators that can map out the economic relations that underlie global supply chains. In particular, we want to create indicators that can easily and consistently identify which are the hubs and spokes in these global chains by industry and country. For this purpose we identify global supply hubs: countries that have a relatively large share of imported value added that is used for the production of intermediate and/or final goods that are later –in a relatively large share– exported to third countries. 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 redirected value added by the hubs. The key element in identifying both hubs and spokes is the importance of redirected value added, either as a share of outgoing intermediate value added exports or as a share of incoming intermediate value added imports.

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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).

By distinguishing various economic sectors we can identify the importance of hubs and spokes by sector and the location of global supply chains.

The first general measure of foreign value added 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 value-added content in direct exports.<sup>2</sup> 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.<sup>3</sup> These drawbacks have been highlighted by three recent papers on trade in value-added: Daudin *et al.* (2011), Johnson and Noguera (2012), 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, 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.<sup>4</sup> On the methodological side, these papers have constructed a similar methodological framework that can account for trade in value-added in the presence of multiple country and multi-stage production processes.<sup>5</sup>

The main results of these three papers are relatively similar. They find that foreign value-added content is between 20 to 30% of domestic exports (the VS measure).<sup>6</sup> 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 analyses have suc-

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<sup>2</sup>In particular, VS is the share of foreign value-added in domestic gross exports. If we define  $DV$  as the domestic value-added share in domestic gross exports then:  $VS+DV=1$ . Therefore, a higher VS value is associated with higher amounts of imported intermediates (more vertical specialization) in exports, and therefore lower domestic value added content. They also defined VS1 as the domestic value-added of exports that is indirectly exported through third countries, while VS1\* is the part of VS1 that returns to the domestic country.

<sup>3</sup>Their input-output datasets did not have integrated trade data between countries, so they could not estimate VS1 or VS1\*.

<sup>4</sup>However, to use 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 when dealing with countries with large export processing sectors. For instance, Koopman *et al.* (2010) and Johnson and Noguera (2012) partially adjust the data to account for the large share of manufacturing exports from these export processing sectors in China and Mexico.

<sup>5</sup>Trefler and Zhu (2010) also use the same methodology but to estimate the factor content of trade –not trade in value added.

<sup>6</sup>Johnson and Noguera (2012) construct a similar indicator –their VAX-ratio– which is the ratio of value-added exports to gross exports.

cessfully dealt 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.<sup>7</sup>

In this paper we also use the GTAP database for multiple years (in our case for 2001, 2004 and 2007).<sup>8</sup> 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. In general, we find similar results regarding VS indicators and bilateral trade balances. However, the main contribution of our paper is that we go a step further in this analysis and use the decomposition of the trade in value-added for both exports and imports, to create indicators that clearly show the production hubs and spokes in international supply chains.<sup>9</sup> In particular, we develop a methodology that allows us to estimate trade in value added instead of in production (gross) value, which is then decomposed 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 can identify the spokes and hubs in global supply chains. For instance, global production networks are mainly located in North America, Europe and the Asia-Pacific region (China, East Asia and Southeast Asia). Within these regions, we find that some sub-regions act like spokes or hubs in a regional network (i.e. the EU12, other Western Europe and other Eastern Europe serve as spokes for the EU15 hub in machinery while EU12 is a hub in electronics for EU15; other NAFTA is mainly a hub serving the US). On the other hand in electronics, the Asia-Pacific region appears to be a hub with global links to both EU15 and the US. However, the identification of these hubs and spokes matter only for certain 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 supply a substantial share of the value added for this sector. In other machinery and equipment, production shows less global integration and the regional hubs are located in Europe, Asia and North America. In services, agriculture or energy we do not find substantial global supply chains as measured by the shares of redirected value added.

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<sup>7</sup>Daudin *et al.* (2011) emphasize on 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.

<sup>8</sup>Some of the cited papers use one or more years, including 1997.

<sup>9</sup>In this respect, our paper is closest to Johnson and Noguera (2012), who also decompose trade in value-added between reflection, diversion (which they call redirection) and absorption. However, their methodology fails to clearly identify the countries that are important as a redirector, as we explain in section 2.2.

Another characteristic of our paper is that we analyse trade in value added rather than the value added content of trade. Most papers aim to find content of value added in gross trade. Their main reference is gross trade and these papers try to measure the share of own and foreign value added in gross trade. This is very interesting from a statistical perspective, but less useful from an economic perspective. From the latter point of view, all that matters is trade in value added, more specifically the locations where value added is generated and between which countries it is traded.

The paper is organized as follows. In Section 2 we start with the general concepts and relations of global input-output analysis, and we then explain our labelling method of bilateral value added trade in section 2.2. Section 2.3 is devoted to explaining our indicators on global supply chains, which are based on value added trade accounting and we suggest that these indicators can identify hubs and spokes in sectoral trade. We then present our results for trade in value added and our identification of hubs and spokes in global supply chains in Section 3. We conclude in Section 4.

## 2 Methodological framework

We first provide both background and details of the methodology used to identify value-added trade. To make the exposition easier, we start with some remarks on notation. With upper-case symbols we denote matrices (e.g.  $Z$ ). To represent diagonal matrices we use the hat sign as in  $\hat{z}$ , which denotes a matrix with  $z$  on its main diagonal and zeroes elsewhere. All other lower-case symbols represent vectors or scalars.  $Z'$  indicates the transpose of matrix  $Z$ . The unit or summation vector is denoted by  $\iota$  and  $\iota_s$  is used as a selection vector (the  $s$ th entry of  $\iota_s$  being one and all other entries being zero). The unit matrix is denoted by  $I$ . Countries or regions are indexed by a set  $R$  while sectors are indexed by  $N$ . International transport services are provided by transport sectors, indexed with  $T$  which is a subset of  $N$ . Entries of matrices or vectors are between brackets as in  $Z(i, j)$  or  $z(i)$ . We use  $w$  as a subscript that defines a variable with a global total, obtained via summation of subscripted variables over  $R$ . For example,  $Z_{rw} = \sum_{s \in R} Z_{rs}$ . Similarly, we use  $t$  for an entry of a variable that represents results for the total economy, obtained via summation of entries over  $N$ . Thus,  $z_r(t) = \sum_{i \in N} z_r(i)$ . Finally, we use the scalar  $\delta_{r,s}$  as a toggle that is one if  $r = s$  and zero otherwise.

## 2.1 Global input-output arithmetic

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

$$\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1R} & f_{11} & f_{12} & \cdots & f_{1R} & x_1 \\ S_{21} & S_{22} & \cdots & S_{2R} & f_{21} & f_{22} & \cdots & f_{2R} & x_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ S_{R1} & S_{R2} & \cdots & S_{RR} & f_{R1} & f_{R2} & \cdots & f_{RR} & x_R \\ w'_1 & w'_2 & \cdots & w'_R & & & & & \\ x'_1 & x'_2 & \cdots & x'_R & & & & & \end{bmatrix} \quad (1)$$

where all entries are in million euros.<sup>10</sup>  $S_{rs}$  denotes the  $N \times N$  matrix of intermediate deliveries from country  $r$  to country  $s$ ,  $w'_s$  is the row-vector of length  $N$  with value added used for production in country  $s$ , while  $x_s$  is the vector containing gross output or gross input values of country  $s$ , and  $f_{rs}$  is the  $N$  vector with final outputs produced in country  $r$  that are used in country  $s$ .

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

$$x_r(i) = S_{rw}(i, t) + f_{rw}(i) \quad (2)$$

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

$$x_s(j) = S_{ws}(t, j) + w_s(j) \quad (3)$$

Summing equations (2) and (3) over sectors and countries we obtain that the global value-added used in production equals the global value of final demands:

$$w_w(t) = f_{ww}(t) \quad (4)$$

To economize on notation we summarize (1) as:

$$\begin{bmatrix} S & F & x \\ w' & & \\ x' & & \end{bmatrix} \quad (5)$$

and define matrices of input coefficients  $A$  and  $v$  where  $A(r, i, s, j) = S(r, i, s, j)/x(s, j)$  denotes the delivery from sector  $i$  in country  $r$  to sector  $j$  in country  $s$  per unit of gross input (of sector  $j$  in country  $s$ ) and  $v(s, j) = w(s, j)/x(s, j)$  represents the use of value added in sector  $j$  of country  $s$  per unit of gross input (of sector  $j$  in country  $s$ ). From (2) and the definition of  $A$  we have:

$$x = S\iota + F\iota = Ax + f_w = (I - A)^{-1}f_w = Bf_w \quad (6)$$

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<sup>10</sup>In fact, the 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 explained in Appendix A

which relates global final demands  $f_w$  to gross production. The elements of the global Leontief inverse  $B(r, i, s, j)$  represent the amount of gross output (of sector  $i$  in country  $r$ ) that is directly and indirectly needed per unit of final output (of sector  $j$  in country  $s$ ).

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

$$\Theta(f_\rho) = \hat{v}B\hat{f}_\rho \quad (7)$$

Because we know that at the global level value added exactly matches final demand (see equation 4),  $v'B$  must be equal to the unit vector; otherwise, the global sum of all values added required for all final demands ( $\sum_{\rho \in R} \iota' \Theta(f_\rho) \iota$ ) does not equal global final demands.<sup>11</sup> Then, it is easily verified that the column sum of  $\Theta(f_\rho)$  equals final output use in  $\rho$  and that the row sum equals the value added required for this final output use

$$\iota' \Theta(f_\rho) = v' B \hat{f}_\rho = f'_\rho \quad (8)$$

and

$$\Theta(f_\rho) \iota = \hat{v} B f_\rho = \hat{v} x(f_\rho) = w(f_\rho) \quad (9)$$

where we expressed both gross output  $x$  and value added  $w$  as a function of the final demand vector  $f_\rho$ .

## 2.2 Decomposing bilateral trade in value added

We now show how we can distinguish different varieties of trade in value added by a simple labelling of the various entries of  $\Theta(f_\rho)$ , which represents the value added requirements for final output use in country  $\rho$ . It is helpful to consider the following disaggregated representation of this matrix:

$$\Theta(f_\rho) = \begin{array}{c} \left[ \begin{array}{cccccccc} \hat{v}_1 B_{11} \hat{f}_{1\rho} & \hat{v}_1 B_{12} \hat{f}_{2\rho} & \cdots & \hat{v}_1 B_{1r} \hat{f}_{r\rho} & \cdots & \hat{v}_1 B_{1\rho} \hat{f}_{\rho\rho} & \cdots & \hat{v}_1 B_{1R} \hat{f}_{R\rho} \\ \hat{v}_2 B_{21} \hat{f}_{1\rho} & \hat{v}_2 B_{22} \hat{f}_{2\rho} & \cdots & \hat{v}_2 B_{2r} \hat{f}_{r\rho} & \cdots & \hat{v}_2 B_{2\rho} \hat{f}_{\rho\rho} & \cdots & \hat{v}_2 B_{2R} \hat{f}_{R\rho} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{v}_r B_{r1} \hat{f}_{1\rho} & \hat{v}_r B_{r2} \hat{f}_{2\rho} & \cdots & \hat{v}_r B_{rr} \hat{f}_{r\rho} & \cdots & \hat{v}_r B_{r\rho} \hat{f}_{\rho\rho} & \cdots & \hat{v}_r B_{rR} \hat{f}_{R\rho} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{v}_\rho B_{\rho 1} \hat{f}_{1\rho} & \hat{v}_\rho B_{\rho 2} \hat{f}_{2\rho} & \cdots & \hat{v}_\rho B_{\rho r} \hat{f}_{r\rho} & \cdots & \hat{v}_\rho B_{\rho\rho} \hat{f}_{\rho\rho} & \cdots & \hat{v}_\rho B_{\rho R} \hat{f}_{R\rho} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{v}_R B_{R1} \hat{f}_{1\rho} & \hat{v}_R B_{R2} \hat{f}_{2\rho} & \cdots & \hat{v}_R B_{Rr} \hat{f}_{r\rho} & \cdots & \hat{v}_R B_{R\rho} \hat{f}_{\rho\rho} & \cdots & \hat{v}_R B_{RR} \hat{f}_{R\rho} \end{array} \right] \begin{array}{c} \overbrace{\left[ \begin{array}{c} w_1(f_\rho) \\ w_2(f_\rho) \\ \vdots \\ w_r(f_\rho) \\ \vdots \\ w_\rho(f_\rho) \\ \vdots \\ w_R(f_\rho) \end{array} \right]}^{\text{Row sums}} \end{array} \\ \underbrace{\left[ \begin{array}{cccccccc} f'_{1\rho} & f'_{2\rho} & \cdots & f'_{r\rho} & \cdots & f'_{\rho\rho} & \cdots & f'_{R\rho} \end{array} \right]}_{\text{Column sums}} \end{array} \quad (10)$$

<sup>11</sup>The direct proof is by rewriting  $v' = \iota'(I - A)$  and then evaluating  $v'B = \iota'(I - A)B = \iota'$ .

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. Except for this block we find along the rows the domestic value added exports into  $\rho$  and along the columns the bilateral value added imports by  $\rho$  that are needed to cover  $\rho$ 's final output use. We attach four different labels to the different blocks in this matrix.

First, consider the blocks on the main diagonal  $\hat{v}_r B_{rr} \hat{f}_{r\rho} \forall r \neq \rho$ . These represent values added in country  $r$  that are needed to produce final output exports from  $r$  to  $\rho$ . We label these blocks  $G_r^\rho$ . They contain all domestic value added required for final output exports from  $r$ .

Next, turning to the off-diagonal blocks, we emphasize that all of these represent value added requirements for trade in intermediate outputs rather than for trade in final output. This does not only follow from intuition but also from the structure of the Leontief-inverse. In Appendix B we proof that –in a three country world– the off-diagonal blocks  $B_{rs}$  ( $r \neq s$ ) will only be nonzero if there are –either directly or indirectly– intermediate output exports from  $r$  to  $s$ .<sup>12</sup> We distinguish three varieties of value added trade here. First, consider the blocks  $\hat{v}_r B_{r\rho} \hat{f}_{\rho\rho} \forall r \neq \rho$ . These indicate values added in  $r$  for intermediates used by country  $\rho$  to produce final output used at home. We label these blocks  $D_r^\rho$ . They represent domestic value added from  $r$  required for final output use in the foreign country of production. Second, consider the blocks  $\hat{v}_r B_{rs} \hat{f}_{s\rho} \forall (r \neq \rho, s \neq r, s \neq \rho)$ . These represent values added in  $r$  that are diverted by country  $s$  via final output exports from  $s$  to  $\rho$ . We label them  $R_{rs}^\rho$ . They represent domestic value added from  $r$  that is diverted to a third country. Third and last, consider  $\hat{v}_\rho B_{\rho r} \hat{f}_{r\rho} \forall r \neq \rho$ . These blocks indicate values added from  $\rho$  that are reflected by  $r$  via its final output exports to  $\rho$ . We label these  $R_{\rho r}^{*\rho}$  (domestic value added that is reflected by country  $r$ ). Thus, we attach the following interpretation to the cross-border bilateral claims on value added for final output use in country  $\rho$ :

$$\Gamma^\rho = \begin{bmatrix} G_1^\rho & R_{12}^\rho & \cdots & R_{1r}^\rho & \cdots & D_1^\rho & \cdots & R_{1R}^\rho \\ R_{21}^\rho & G_2^\rho & \cdots & R_{2r}^\rho & \cdots & D_2^\rho & \cdots & R_{2R}^\rho \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ R_{r1}^\rho & R_{r2}^\rho & \cdots & G_r^\rho & \cdots & D_r^\rho & \cdots & R_{rR}^\rho \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ R_{\rho 1}^{*\rho} & R_{\rho 2}^{*\rho} & \cdots & R_{\rho r}^{*\rho} & \cdots & - & \cdots & R_{\rho R}^{*\rho} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ R_{R1}^\rho & R_{R2}^\rho & \cdots & R_{Rr}^\rho & \cdots & D_R^\rho & \cdots & G_R^\rho \end{bmatrix} \quad (11)$$

The claims defined as  $G$  are for direct final output exports and those by  $D$  for intermediates converted to final use in the country of destination, while  $R$  represents them for intermediates diverted to third countries and  $R^*$  for intermediates that are reflected. We use the term "redirected" value added trade to refer to the sum total

<sup>12</sup>We show in Appendix B that in a three-country world of  $r$ ,  $s$  and  $\rho$ , the off-diagonal block  $B_{rs} = 0$  if a)  $S_{rs} = 0$  and b)  $S_{r\rho} = 0$  or  $S_{\rho s} = 0$  (or both).



of diverted and reflected trade in value added. Strictly, entry  $\Gamma^\rho(r, i, s, j)$  represents the value added from sector  $i$  in country  $r$  that is required for the use in  $\rho$  of final  $j$ -output from  $s$ . In our description we loosely describe the entries of this matrix as bilateral value added trade needed for final output use in  $\rho$ .

Consider  $\Gamma_{rs}^\rho$ . These are bilateral value added exports from origin  $r$  via redirector  $s$  to final destination  $\rho$ . For  $r \neq s$  we obtain intermediate value added exports from  $r$  to  $\rho$ , i.e.  $\Gamma_{r\rho}^\rho = D_r^\rho (\rho \neq r)$  and  $\Gamma_{rs}^\rho = R_{rs}^\rho (\rho \neq (r, s))$ , and for  $r = s$  the value added for direct final output exports, i.e.  $\Gamma_{rr}^\rho = G_r^\rho$ . Thus we can look at bilateral trade from three different perspectives. The first is the traditional one from origin to redirector ( $\Gamma_{rs}^w$ ). It is from this perspective that trade flows are recorded in gross trade statistics. The second is the trade in value added perspective from origin to final destination ( $\Gamma_{rw}^\rho$ ). It is from this perspective that bilateral trade balances in value added are collected. The third is the perspective from redirector to final destination ( $\Gamma_{ws}^\rho$ ). It is this perspective that has been largely neglected thus far. The focus of Koopman *et al.* (2010) is on the first perspective. They look primarily at the production process of the importer. The focus of Johnson and Noguera (2012) is on the second perspective. They mainly analyse trade in value added. We combine in particular the first and third perspective. Thus  $\Gamma_{rs}^w$  provides us with the incoming spokes into the redirector and  $\Gamma_{ws}^\rho$  with the outgoing spokes to final destinations.

From (11) it is immediately clear that aggregation over industries will neither affect the volume of global value added trade nor its composition. When we report the outcomes of our study aggregation over countries is inevitable. We choose to let this not affect the volume of global value added trade and collect intra-regional trade in value added as  $D_r^r$ , which is the intra-regional value added trade for regional production that is used within the region itself. Thus, when we report for aggregate regions only the composition of global value added trade is affected. In fact, aggregation over countries reduces the share of redirected trade in total value added trade. We use the example of aggregating over EU member states to clarify this. First, we loose intra-EU redirection because all redirection of EU-value added by EU-countries towards other EU-countries will be 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 will be classified as  $G$ . Finally, all outgoing trade that was diverted by EU-countries before leaving the EU will be classified as  $G$  as well. Thus, the shares of reflected and especially diverted trade in global value added trade will fall when we aggregate over EU-countries to represent the EU as a single trading block.

In evaluating bilateral claims on value added at the industry level we have a choice from two options. One option is to follow sectoral domestic value added required abroad for all final uses; one may call this the "horizontal" option as one would then evaluate  $\Gamma_{rs}^\rho$  row-wise; this option is relevant if one wants to identify the final customers abroad that in the end pay for sectoral value added. The other, "vertical", option is to evaluate  $\Gamma_{rs}^\rho$  column-wise; one would then take stock of all values added that are needed for final output use abroad at the industry level; this option is relevant if one wants to identify the amounts of value added that are needed

for sectoral final output trade. As this information is most relevant to our paper, we adopt the vertical option at the sector level.<sup>13</sup>

This choice means that we can condense our accounting system, taking the column-sums of all matrices in (11). Rather than representing these as, for example,  $G_r^\rho(t, j)$  we will drop the entry for  $t$  and simply denote the sum as  $g_r^\rho(j)$ . It is to be kept in mind that  $j$  does not point to sectoral value added but to national value added needed for the use in  $\rho$  of final  $j$ -output. Thus  $r_{rs}^\rho(j)$  represents value added from  $r$  that is diverted by  $s$  to  $\rho$  and required for the use in  $\rho$  of final  $j$ -output from  $s$ .

In the literature redirection estimates are given for trade in gross outputs. Thus, Johnson and Noguera (2012) present in their Table 4 the most important final destinations of selected bilateral gross exports. Their implicit definition of absorption, reflection and diversion differs from our definitions given above. They estimate absorption, reflection and diversion (which they call redirection) as follows. Let  $\tilde{X}^\rho = B\hat{f}_\rho$  be the imputed gross outputs needed for final output use in  $\rho$ . They<sup>14</sup> estimate the final destinations of bilateral exports from  $r$  to  $s$  as

$$\alpha_{rs}^\rho = \sum_{j \in N} A_{rs}(t, j) \tilde{X}_{sw}^\rho(j, t) + \delta_{s\rho} f_{rs}(t) \quad (r \neq s) \quad (12)$$

They first calculate the gross output vector that is needed from  $s$  for all final output use in  $\rho$  and then use the bilateral import coefficient matrix to calculate the claims on intermediate output from  $r$ . Our approach to answer the same question would be more direct

$$\beta_{rs}^\rho = \tilde{X}_{rs}^\rho(t, t) + \delta_{s\rho} \tilde{X}_{rr}^\rho(t, t) \quad (r \neq s) \quad (13)$$

Comparison of equations (12) and (13) clearly shows that Johnson and Noguera (2012) do not explicitly address the outgoing spokes from redirector  $s$  in contrast to our approach which defines reflection and diversion with explicit reference to the redirector.

For country  $r$  we collect bilateral domestic value added exports  $e_r^\rho$  at the industry level as:

$$e_r^\rho(j) = \Gamma_{rw}^\rho(t, j) = \overbrace{\underbrace{g_r^\rho(j)}_{\text{Directly}} + \underbrace{d_r^\rho(j)}_{\text{Diverted to } \rho}}^{\text{Absorbed in } \rho} + \underbrace{r_{rw}^\rho(j)}_{\text{Diverted to } \rho} \quad (r \neq \rho) \quad (14)$$

All value added trade is absorbed in the country of final destination. Yet, our decomposition partly reveals whether value added trade is absorbed directly in the country of destination or whether it has travelled via other countries before reaching its final destination (diverted trade in value added). Note that we cannot conclude

<sup>13</sup>This is in contrast with the approach of Johnson and Noguera (2012) who follow the "horizontal" approach in collecting bilateral value added exports at the industry level.

<sup>14</sup>Also Koopman *et al.* (2010) make use of this decomposition.

whether value added trade for domestic use of domestic final output ( $d_r^\rho$ ) is absorbed directly or first diverted via other countries.

Via aggregation over sectors and over countries aggregate value added trade for country  $r$  can be derived from (14). One may verify that the aggregate balance of value added trade  $e_r^w(t) - e_w^r(t)$  equals the aggregate gross trade balance:<sup>15</sup>

$$e_r^w(t) - e_w^r(t) = w_r(t) - f_{wr}(t) = \sum_{s \neq r} [f_{rs}(t) + s_{rs}(t, t) - f_{sr}(t) - s_{sr}(t, t)] \quad (15)$$

and it is at this point that conventional trade statistics meet value added trade accounting.

We are especially interested in the industries that redirect incoming value added trade. Thus we will make use of intermediate value added exports from  $r$  into redirector  $s$

$$e_{rs}(j) = \Gamma_{rs}^w(t, j) = \underbrace{d_r^s(j)}_{\text{Absorbed in } s} + \overbrace{r_{rs}^w(j) + r_{rs}^{*r}(j)}^{\text{Redirected by } s} \quad (r \neq s) \quad (16)$$

which indicates all intermediate value added from  $r$  that is needed for the production of final  $j$ -output in  $s$  and splits these into the part that finds its final use in  $s$  itself ( $d_r^s(j)$ ) and the part that is shipped to other markets ( $r_{rs}^w(j)$  plus  $r_{rs}^{*r}(j)$ ). The difference in representing redirected trade in (14) and (16) is that the former shows  $\rho$  as the final destination of redirected domestic value added exports while the latter shows domestic value added exports that are redirected by  $s$  to other final destinations.

### 2.3 Indicators for detecting hubs and spokes in cross-border assembly using redirected trade in value added

The vertical specialisation 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. In this section we present two indicator pairs, based on redirected value added trade, that help detecting hubs and spokes in global supply chains at the industry level.

We saw that  $\Gamma_{rs}^w$  provides us with the incoming spokes into the redirector and  $\Gamma_{ws}^\rho$  with the outgoing spokes. If the incoming traffic is large and the traffic going out is small the redirector is just importing intermediates for his own final use. If the incoming and the outgoing traffic are both large we may call the redirector a hub that produces final output to be used abroad from imported intermediates. We define a  $j$ -hub as a country that:

<sup>15</sup> Using the definition (14) together with (8) and (9) for the first equality and the accounting relations implicit in (1) for the second equality.

- redirects a relatively large part of the value added imports it needs to produce final  $j$ -output, and
- has a relatively large share in globally redirected value added trade for final  $j$ -output.

It should be mentioned that we do not know whether a  $j$ -hub is a production hub or a trading hub, because a country with a sizable share of re-exports of final  $j$ -output might qualify as a hub too. Thus country  $s$  would qualify as a  $j$ -hub if the following two expressions are relatively large:

$$sfrv_s(j) = \frac{r_{ws}^w(j) + r_{ws}^{*w}(j)}{e_{ws}(j)} \quad (17)$$

$$gsfrv_s(j) = \frac{r_{ws}^w(j) + r_{ws}^{*w}(j)}{r_{ww}^w(j) + r_{ww}^{*w}(j)}$$

where  $sfrv_s(j)$  indicates the share of foreign redirected value added in total bilateral value added imports that country  $s$  needs to produce final  $j$ -output. This is an intensity measure showing the relative importance of country  $s$  in assembling final  $j$ -output for the world market. While  $gsfrv_s(j)$  represents the share of foreign redirected value added for exports of final  $j$ -output by country  $s$  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 country  $s$  at the global level.

In addition, we can detect the countries that are important in supplying the  $j$ -hubs with intermediates as those countries for which the following expressions are relatively large:

$$sdrv_r(j) = \frac{r_{rw}^w(j) + r_{rw}^{*r}(j)}{e_{rw}(j)} \quad (18)$$

$$gsdrv_r(j) = \frac{r_{rw}^w(j) + r_{rw}^{*r}(j)}{r_{ww}^w(j) + r_{ww}^{*w}(j)}$$

where  $sdrv_r(j)$  indicates the share of redirected domestic value added in total bilateral value added exports for final  $j$ -production. This is an intensity measure showing the relative importance of country  $r$  in supplying intermediates for assembly abroad of final  $j$ -output. While  $gsdrv_r(j)$  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 supplier of intermediates for  $j$ -trade at the global level.

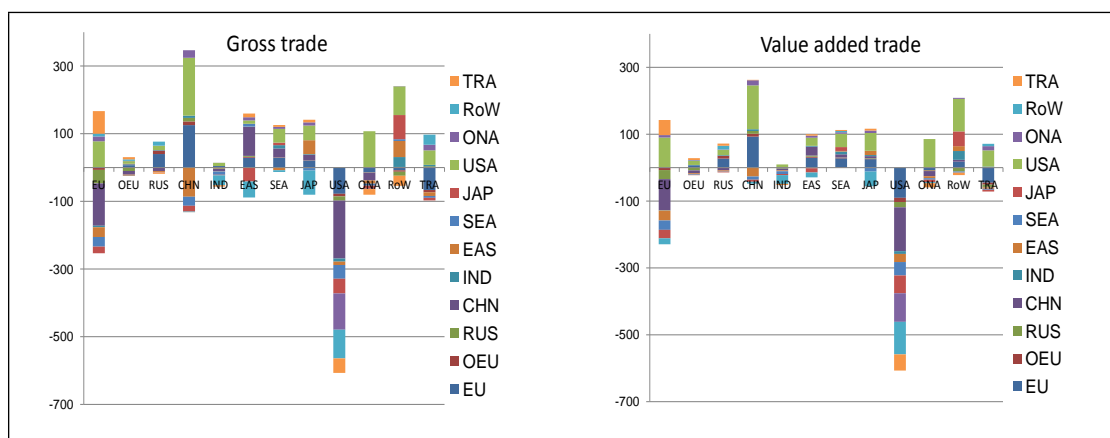
### 3 Trade in value added results

#### 3.1 Bilateral trade gaps

The bilateral trade gaps give already a first impression of the role of countries in the chain of vertical specialization. Figure 1 presents the bilateral trade gaps in 2007

in gross value and value added.<sup>16</sup> These data are of a more recent date than most other studies which use 2004. The trade deficit of the US is 607 billion euro. It has a trade deficit with every region in the world, which is the largest with China, other NAFTA countries (mainly Mexico) and the EU. In value added terms the trade deficits with China, and other NAFTA are substantially smaller, while the deficits with the EU, Japan, East Asia and RoW are larger. This suggests that a part of the value added exported from EU, Japan, East Asia and RoW towards the US is redirected via China and other NAFTA. This is the net effect of exports and imports. It could also be the case that part of the value added exports of the US is redirected via EU, Japan, East Asia and RoW towards China and other NAFTA.

Figure 1: Bilateral trade gaps in gross value (left) and value added (right) in bln euro, 2007



Source: Own estimations using GTAP database.

The 87 billion euro trade deficit of the EU is mainly due to trade with China and the other Asian regions (Japan, East Asia and South East Asia). The EU has a trade surplus with the NAFTA countries, in particular the US. In value added terms, the deficit with China is much smaller. The surplus with the US is larger suggesting that China redirects EU value added to the US.

China is the largest surplus country of 215 billion euro due to the large trade surpluses with the EU and the US. It has trade deficits with the other Asian regions. These deficits are much smaller in value added terms (in particular from East Asia). This pattern suggests that Asian countries deliver value added to China, which is send to Europe and the US after processing. Pula and Peltonen (2009) and Koopman *et al.* (2010) also point to the strong linkages within Asia. For East Asia we also find large changes in the trade surplus with China and the trade deficit

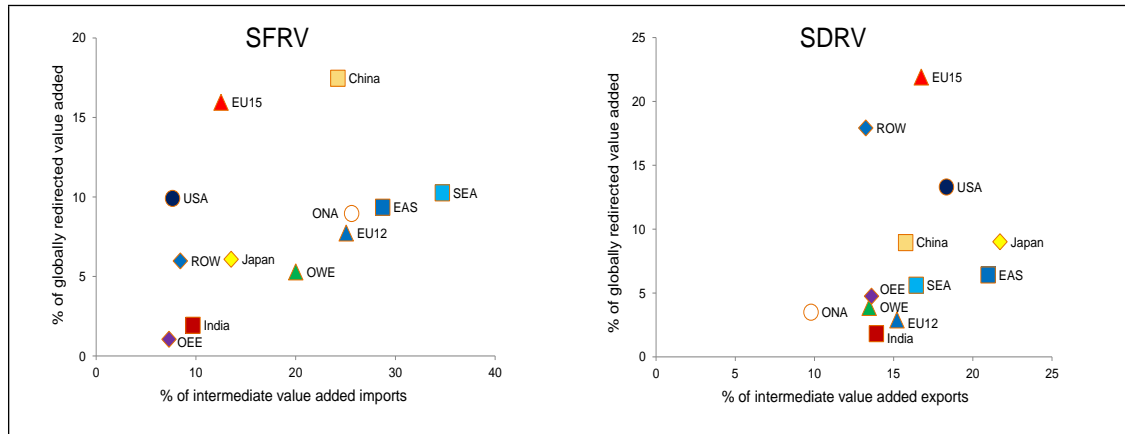
<sup>16</sup>Tables 3 and 4 in Appendix C show the values for these bilateral trade gaps. Both tables are symmetric: the diagonal is zero and the elements below this diagonal are the exact negative of the equivalent elements above the diagonal. The first matrix shows gross trade balances, while the matrix below has the value-added trade gaps. Note that the bilateral trade gaps do not include international transport services (which cannot be assigned to specific regions).

with Japan comparing the gross values and value added. Comparisons with the years 2001 and 2004 reveal that the trade pattern in value added is quite persistent. Johnson and Noguera (2012) find similar results using 2004 data

### 3.2 Identifying hubs and spokes

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.<sup>17</sup> These intermediates can be converted to final products in the importing country or diverted to third countries or reflected to the home country. The importance of redirected value added in a country's intermediate trade identifies its position in global production networks compared to other trade. By comparing this to the share of a country in global redirected value added it also identifies the position of a country in the world. This can be analysed for incoming foreign value added and outgoing domestic value added. First, we analyse this for countries at the aggregate level, then we focus on economic sectors at the global level and finally we analyse the electronics and other machinery sectors at the country level as examples.

Figure 2: Share of foreign (SFRV) and domestic (SDRV) redirected value added used for final output, 2007



Source: Own estimations using GTAP database.

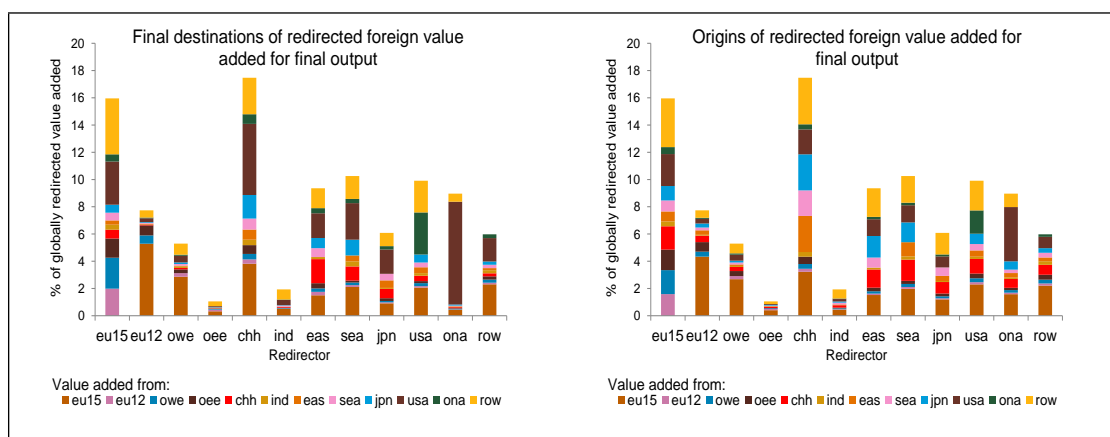
Together, China and the EU are responsible for redirecting about a third of all globally redirected value added. The US, East and South-East Asia add each another ten percent as can be seen in Figure 2 (left panel). The shares of India and Russia and other Eastern Europe are only a few percent. To put it differently global production networks are located in North America, Europe and Asia. Redirected value added as a share of intermediate value added imports is high for the Asian

<sup>17</sup>We ignore value added of traded final products and focus on external trade, ignoring trade within regions. Including internal trade would drastically change the position of the EU.

regions (except Japan), the EU12 and other NAFTA. However, the amounts of the latter two regions do not add much at the global level. This suggests that these regions are hubs or spokes in regional production networks. Quite often they are mainly connected to a single neighbour such as EU15, the US or China. For EU15, the US and Japan, redirected value added is relatively unimportant as a share of imported intermediate value added.

In terms of intermediate domestic value added exports the differences between the regions are much smaller. It varies from 10 percent for other NAFTA to slightly more than 20 percent for Japan and South-East Asia. For most other regions redirected value added is close to 15 percent of intermediate value added exports. EU15, US and Japan export 45% of all redirected value added, which is substantially higher than the foreign share they redirect. However, their global share in exporting domestic value added which is redirected is declining between 2001 and 2007 (see table 6 in Appendix C) reflecting also the shift in manufacturing production towards Asia and the rest of the world. The other European, Asian and North-American regions have a relatively larger share in redirecting foreign value added than in supplying value added to redirectors. The shift of production towards Asia is also reflected by the increasing role of China over time in redirecting foreign value added and the declining role of other NAFTA. The fact that the US generates a smaller share of global redirected value added while it still exports much intermediate value added is an important reason for the smaller share of redirection in intermediate value added exports over time. In spite of the absolute increase in trading intermediate value added via various countries to its final destination the direct bilateral relations in value added trade are still the most important ones

Figure 3: Final destinations and origins of foreign value added used for final output, 2007



Source: Own estimations using GTAP database.

Figure 3 presents the origins and final destinations of foreign value added used for final output. EU15 sends about a quarter to the EU12 and other Western

Europe, a quarter to the NAFTA countries and a quarter to Asia and the Russian Federation. EU12 and other Western Europe ship most of their redirected foreign value added to EU15. We also find this regional connection for other NAFTA with the US and between the Asian regions (apart from China). China redirects much foreign value added to EU15 and the US. For nearly all regions EU15 and the US are important destinations. These findings are confirmed in the figure of origins of redirected value added. China receives most from the other Asian regions, EU12 and other Western Europe from EU15 and other NAFTA receives most redirected value added from the US. The US is less important as a source of redirected value added than as its destination. For the Asian regions, other Western Europe and the EU12 and other NAFTA it is the other way around. Not all regions in North America, Europe and Asia are equally important. Some regions, such as other NAFTA, EU12, other Western Europe and Russia and other Eastern Europe, mainly serve nearby regions only. They are important in regional production networks, but not in global production networks. This seems to be different for the Asian regions: these seem to rely both on regional links and on global links with EU15 and the US.

So far we focused on the decomposition of trade in value added and bilateral trade for each region and aggregated all sectors within a region. This macro approach hides substantial differences between sectors. Economic sectors differ in their contribution to value added in an economy, in their trade intensity and decomposition of intra and inter industry trade, and in their position within global production chains. The Dreamliner and iPod are very specific examples in which a very large part of the production is outsourced to numerous countries while for other products, 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 advantage is that it is relatively easy to link the results of an approach by economic sector to the total economy, while this is not the case for individual product analyses.

The GTAP data that we use distinguish 57 economic sectors.<sup>18</sup> Although technically feasible it is too cumbersome to present results for all sectors. We analyse six sectors which are among the most important in Europe's international trade flows. These are motor vehicles and parts, machinery and equipment, chemicals, rubber and plastic products, electronic equipment, other transport equipment and business services. We also distinguish seven aggregated sectors: agriculture, energy, transport services, other commercial services (excluding business services), other services and low-tech and medium low-tech manufacturing. See Table 2 in Appendix C for the sectoral codes and Table 1 for the regional codes and aggregations.

The importance of global product networks varies by sector. In services sectors (excluding transport) and energy, the share of redirected value added in the value added of traded intermediates is less than ten percent and for transport services and agriculture it is about 15 percent. Figure 4 presents these results for the most important sectors and suggests that global production networks matter only for

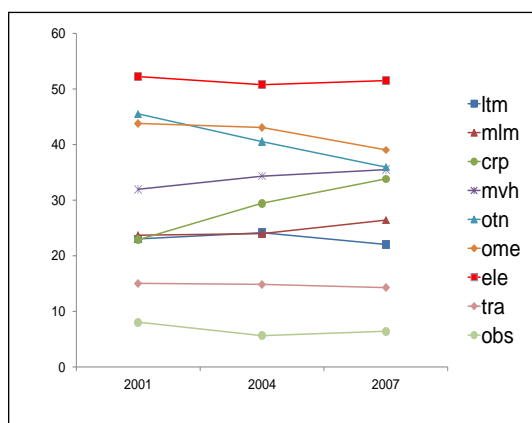
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<sup>18</sup>However, about 25 sectors are in agriculture and food processing.



manufacturing sectors. We do 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 share of redirected trade is higher but varies 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 organisation of global production networks. It increases from 23% in 2001 to 34% in 2007, in particular the increase between 2001 and 2004 is astonishing. 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. Only in electronic equipment more than half of intermediate value added trade is redirected.

Figure 4: Global share of redirected value added trade in intermediate value added trade by economic sector, 2001-2007



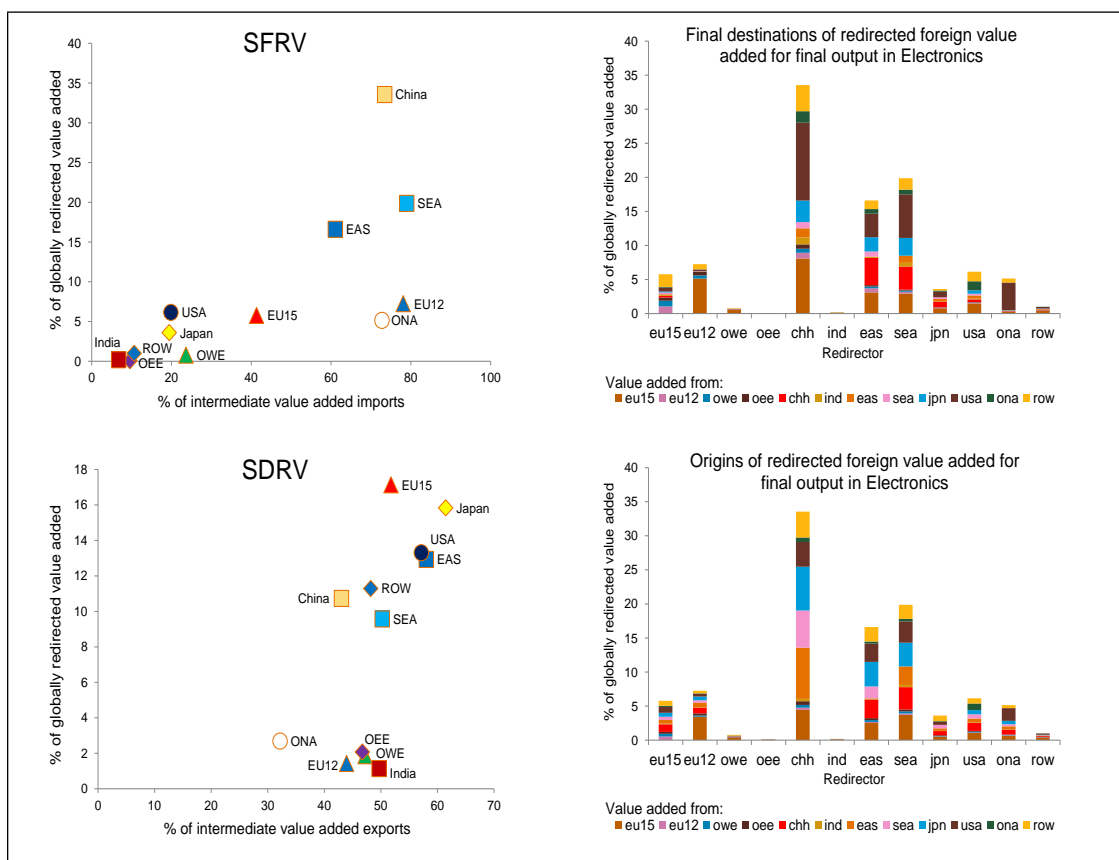
Source: Own estimations using GTAP database.

We could analyse the redirected value added between the regions for all these sectors as we have done for aggregated value added. Instead we focus only on two sectors and a few indicators. These are the most important sectors in EU-trade: electronic equipment, and machinery and equipment. The indicators represent the share of total foreign value added imports that is being redirected by the importer and the share of total domestic value added exports that is being redirected by the trading partners.

Much of the intermediate value added in electronic equipment is redirected. For China, South-East Asia, EU12 and Other NAFTA it is more than 70 percent of their imported intermediate value added. Only a small share of the imported intermediates is thus used for final consumption in the own region. For East Asia

this is 60 percent and for EU15 it is still 40 percent. For the other regions it is much lower. China is responsible for 35 percent of the global redirected value added in electronics, while East and South-East Asia contribute each another 20 percent. About 70 percent of all redirected value added takes place in Asia. Also the origins of value added in the Asian regions are mainly from the other Asian regions. That is also the case for EU15 and US, but less so for EU12, other Western Europe and other NAFTA. These latter regions depend heavily on their big neighbours also in Electronic equipment.

Figure 5: Redirected foreign and domestic value added for electronic equipment, 2007



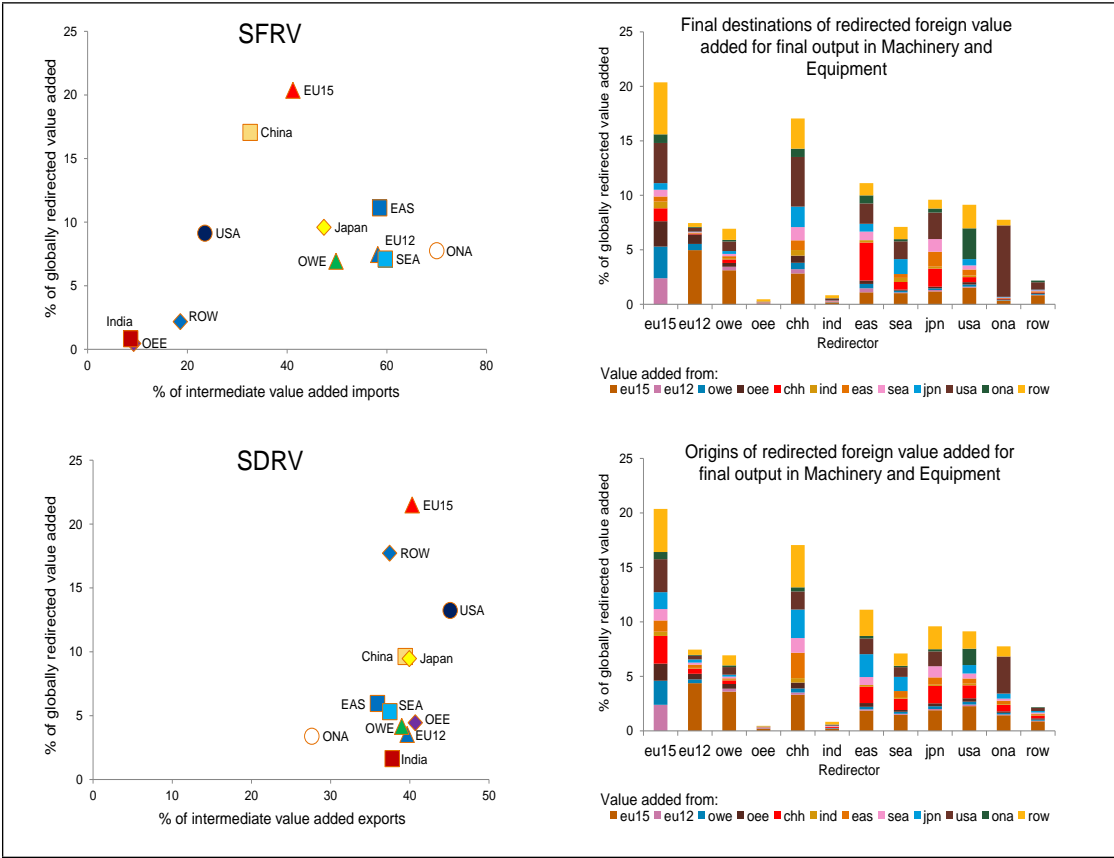
Source: Own estimations using GTAP database.

The differences in redirected domestic value added are smaller than in foreign value added. The share in intermediate value added exports varies between 40 and 60 percent, with the exception of other NAFTA, which has a smaller share. EU15, US, Japan and East Asia are the largest exporters of redirected value added. China, South-East Asia and RoW export also a substantial share, but the shares of the other regions are negligible. EU15 and the US are important destinations of redirected value added exports and China is an important destination for the exports of other

Asian regions. For EU12 and Other Western Europe the EU15 is by far the most important destination as is the US for other NAFTA.

Much more than for other sectors or the average, the core of electronic equipment production is located in Asia. The US and EU15 still supply a lot of value added which is redirected by Asian countries and China in particular, but large parts of the production chains are located in Asia.

Figure 6: Redirected foreign and domestic value added for machinery and equipment, 2007



Source: Own estimations using GTAP database.

EU15 and China redirect much of the foreign value added in other machinery and equipment, each about twenty percent. India and Russia do not redirect foreign value added at all. Regions such as other NAFTA, EU12, East and South-East Asia redirect about 60 percent or even more of their intermediate imports. About 30 percent of the foreign value added imports for other machinery and equipment goes to Europe and an equal part to North America. Asia is slightly less important as a final destination. We also find this pattern if we inspect the redirecting regions. EU15 redirects relatively a lot of foreign value added to EU12, other Western Europe and the Former Soviet Union and the US a lot to other NAFTA. The Other European

regions (OWE and OEE) serve EU15 as destination, but most Asian regions are not important as redirector of foreign value added for the EU15. All these regions do redirect foreign value added to the US. Compared to electronic equipment, the European regions form a regional production network and are less connected to Asia. For nearly all regions 40 percent of their exports in intermediate value added is redirected to other countries. The EU15, RoW and the US are responsible for the greater part of the global flow of redirected domestic value added. Asia is important for redirecting intermediate value added from RoW but less so from the US and the EU15. The nearby regions of the EU15 and the US are important in this respect. Overall it seems that less intermediate value added is redirected between Europe, Asia and the US. The regional networks are relatively more important for other machinery and equipment, while for electronic equipment Asia seems to be the global hub with strong ties to EU15 and the US.

## 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, other Western Europe and Russia and other Eastern Europe serve either as spokes for the EU15 hub or 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, motor vehicles and other transport equipment. 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 production core

is located in the Asia-Pacific region. The 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 in various ways. 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. Moreover, in our analysis we emphasize trade in value added rather than the value added content of trade. Most papers in this field aim to find content of value added in gross trade. Their main reference is gross trade and these papers try to measure the share of own and foreign value added in gross trade. This is useful from a statistical perspective, but less useful from an economic perspective. From the latter point of view, all that matters is value added, more specifically the locations where value added is generated and between which countries it is traded.

We believe that our contributions have much potential for deeper analyses of global supply chains. First of all, we could analyse bilateral value added trade in more detail. We could, for instance, analyse the role of the internal market in Europe and assess the positions of individual member states in global supply chains. Our analysis indicates substantial changes in global supply chains in sectors like chemicals, rubber and plastics and other transport equipment between 2001 and 2007. This suggests two interesting extensions. The first is a longitudinal analysis by incorporating earlier years of the GTAP data base. The second is a study of the determinants of locations in global supply chains.

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## A International transport margins

For simplicity we neglected international transport margins in the main text. It is the purpose of this Annex to explain how they are treated in our calculations. In contrast to the main text (see (1)) the global input-output matrices inclusive of international transport deliveries have the following structure:

$$\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1R} & S_1^s & f_{11} & f_{12} & \cdots & f_{1R} & x_1 \\ S_{21} & S_{22} & \cdots & S_{2R} & S_2^s & f_{21} & f_{22} & \cdots & f_{2R} & x_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ S_{R1} & S_{R2} & \cdots & S_{RR} & S_R^s & f_{R1} & f_{R2} & \cdots & f_{RR} & x_R \\ S_1^d & S_2^d & \cdots & S_R^d & 0 & s_1^f & s_2^f & \cdots & s_R^f & \tau \\ w'_1 & w'_2 & \cdots & w'_R & 0 & & & & & \\ x'_1 & x' & \cdots & x'_R & \tau' & & & & & \end{bmatrix} \quad (19)$$

Compared to the table in the main text the extra entries in this table are:  $S_r^s$  representing the  $N \times T$  matrix with the supply of international transport services from country  $r$ ,  $S_r^d$  denoting the  $T \times N$  matrix with international transport margins on imported intermediate goods in country  $s$ ,  $s_r^f$  indicating the  $T$  vector with international transport margins on imported final goods in country  $r$  and  $\tau$  representing the  $T$  vector with global demands and supplies for international transport services. The international transport services are special in the sense that they are supplied to and demanded from an international transport market. Thus the table does not disclose the regional origin of the transport services demanded.

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

$$x_r(i) = S_{rw}(i, t) + f_{rw}(i) + S_r^s(i, t) \quad i \in N \quad (20)$$

and total demands for international transport services equal supplies

$$S_w^d(i, t) + s_w^f(i) = S_w^s(t, i) = \tau(i) \quad i \in T \quad (21)$$

To economize on notation we summarize (19) with:

$$\begin{bmatrix} S & S^s & F & x \\ S^d & 0 & S^f & \tau \\ w' & 0 & & \\ x' & \tau' & & \end{bmatrix} \quad (22)$$

In addition to the input coefficients  $A$ , we also define matrices of input coefficients  $A^s$  and  $A^d$ ; where  $A^s(r, i, i) = S^s(r, i, i)/\tau(i)$  represents the share of sector  $i$  in country  $r$  in global international transport supplies of service  $i$  and  $A^d(i, s, j) = S^d(i, s, j)/x(s, j)$  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  $v(s, j) = 1 - \sum_{r \in R, i \in N} A(r, i, s, j) - \sum_{i \in T} A^d(i, s, j)$ .

From (20) and (21) we have:

$$\begin{aligned} \begin{bmatrix} x \\ \tau \end{bmatrix} &= \begin{bmatrix} S \\ S^d \end{bmatrix} \iota + \begin{bmatrix} S^s \\ 0 \end{bmatrix} \iota + \begin{bmatrix} F \\ S^f \end{bmatrix} \iota = \begin{bmatrix} A & A^s \\ A^d & 0 \end{bmatrix} \begin{bmatrix} x \\ \tau \end{bmatrix} + \begin{bmatrix} F \\ S^f \end{bmatrix} \iota = \\ & \begin{bmatrix} I - A & -A^s \\ -A^d & I \end{bmatrix}^{-1} \begin{bmatrix} F \\ S^f \end{bmatrix} \iota = \begin{bmatrix} B^t & B^s \\ B^d & B^\tau \end{bmatrix} \begin{bmatrix} F \\ S^f \end{bmatrix} \iota \end{aligned} \quad (23)$$

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

$$\begin{bmatrix} B^t & B^s \\ B^d & B^\tau \end{bmatrix} = \begin{bmatrix} (I - A - A^s A^d)^{-1} & (I - A)^{-1} A^s (I - A^d (I - A)^{-1} A^s)^{-1} \\ A^d (I - A - A^s A^d)^{-1} & (I - A^d (I - A)^{-1} A^s)^{-1} \end{bmatrix} \quad (24)$$

where the elements of the matrix  $B^t$ :  $B^t(r, i, s, j)$ , represent the amount of gross output (of sector  $i$  in country  $r$ ) that is directly and indirectly needed per unit of final output (of sector  $j$  in country  $s$ ), and they include the gross output needed for international transport of intermediates per unit of final output. The entries of matrix  $B^s$ :  $B^s(r, i, j)$ , represent the additional gross output (of sector  $i$  in country  $r$ ) needed for international transport service  $j$  for trade in final goods.

Let  $f_\rho$  be the  $\rho^{th}$  column of  $F$  and  $s_\rho^f$  be the  $\rho^{th}$  column of  $S^f$ , the  $RN$  vector  $f_\rho$  denoting final output use in country  $\rho$  and the  $T$  vector representing the value of the transport services on final good imports of  $\rho$ . Then  $B^t \hat{f}_\rho$  and  $B^s s_\rho^f$  together represent all gross outputs needed for final output use in  $\rho$ . Their dimensionality,  $RN \times RN$  and  $RN \times T$  respectively, differs and this is inconvenient. The GTAP-data include full vectors of transport margins for final good imports in  $f_\rho$ , which we indicate with the  $RN \times T$  matrix  $T_\rho$  with  $T'_\rho \iota = s_\rho^f$ . This allows us to expand the dimensionality of  $B^s s_\rho^f$  to  $RN \times RN$  as well, because we can alternatively indicate gross outputs needed for international transport of  $f_\rho$  by  $\sum_{t \in T} B^s \iota_t \iota'_t T'_\rho$ .

Multiplying the gross output requirements for  $f_\rho$  and  $T_\rho$  with values added per unit of gross outputs yields the corresponding value added requirements of final demand in  $\rho$ :

$$\Theta(f_\rho, T_\rho) = \hat{v} (B^t \hat{f}_\rho + \sum_{t \in T} B^s \iota_t \iota'_t T'_\rho) \quad (25)$$

Because both  $v' B^t$  and  $v' B^s$  are unit vectors<sup>19</sup>, it is easily verified that the column sum of  $\Theta(f_\rho, T_\rho)$  equals transport-inclusive final demands in  $\rho$  and that the row sum equals the value added required for transport-inclusive final output use in  $\rho$ . We apply the labelling procedure on this transport-inclusive value added matrix  $\Theta(f_\rho, T_\rho)$  in stead of the simpler  $\Theta(f_\rho)$  in the main text. Thus all value added and final demand flows in the main text are actually to be interpreted as being transport-inclusive.

There is only one exception to this. When we compare gross and value added trade balances in Section 3 it is more convenient to have transport-exclusive bilateral

<sup>19</sup>The proof is by rewriting  $v' = \iota'(I - A) - \iota' A^d$  and then evaluating  $v' B^t$  and  $v' B^s$ .



value added flows. To arrive at these we calculate the transport-exclusive Leontief-matrix  $B = (I - A)^{-1}$ , which we border with value added transport demands and supplies from and to the international transport market as in:

$$\begin{bmatrix} B & (\sum_{t \in T} B^s \iota_t \iota'_t T'_\rho + B^t) \iota \\ \iota' (\sum_{t \in T} B^s \iota_t \iota'_t T'_\rho + B^t) & \end{bmatrix} \quad (26)$$

## B The global Leontief inverse in a world of three regions

In this Annex we develop a partitioned global Leontief inverse for a three-region world. We conclude that in such a world the off-diagonal blocks of the global Leontief inverse depend on direct and indirect bilateral trade in intermediates. If no such trade would exist, the off-diagonal block would be zero. Let  $M$  be a nonsingular matrix in which both  $A$  and  $D$  are square matrices, such that:

$$M = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \quad (27)$$

Then the Schur complement of  $A$  in  $M$  is  $M/A = D - CA^{-1}B$  and the Schur complement of  $D$  in  $M$  is  $M/D = A - BD^{-1}C$ . Because they both exist we can via Gaussian block diagonalization arrive at the following alternative and well-known expressions for the inverse:

$$M^{-1} = \begin{bmatrix} A^{-1} + A^{-1}B(M/A)^{-1}CA^{-1} & -A^{-1}B(M/A)^{-1} \\ -(M/A)^{-1}CA^{-1} & (M/A)^{-1} \\ (M/D)^{-1} & -(M/D)^{-1}BD^{-1} \\ -D^{-1}C(M/D)^{-1} & D^{-1} + D^{-1}C(M/D)^{-1}BD^{-1} \end{bmatrix} = \quad (28)$$

We can also combine the two equivalent expressions as is done in Cottle (1974) and obtain:

$$M^{-1} = \begin{bmatrix} I & -A^{-1}B \\ -D^{-1}C & I \end{bmatrix} \begin{bmatrix} (M/D)^{-1} & 0 \\ 0 & (M/A)^{-1} \end{bmatrix} \quad (29)$$

An expression of the global Leontief matrix of a two-region world in this format yields:

$$M^{-1} = \begin{bmatrix} I - A_{11} & -A_{12} \\ -A_{21} & I - A_{22} \end{bmatrix}^{-1} = \begin{bmatrix} \Delta_{11} & -A_{12} \\ -A_{21} & \Delta_{22} \end{bmatrix}^{-1} = \begin{bmatrix} I & \Delta_{11}^{-1}A_{12} \\ \Delta_{22}^{-1}A_{21} & I \end{bmatrix} \begin{bmatrix} (\Delta_{11} - A_{12}\Delta_{22}^{-1}A_{21})^{-1} & 0 \\ 0 & (\Delta_{22} - A_{21}\Delta_{11}^{-1}A_{12})^{-1} \end{bmatrix} \quad (30)$$

The entries of this expression have a clear-cut interpretation. The diagonal blocks indicate the domestic gross output required per unit of final output produced at home. They include the gross output needed for deliveries to the other region that are required for the imports from that region to serve the production of one unit of final output at home. The off-diagonal blocks represent domestic gross output required abroad for the production of the foreign gross output needed per unit of final output produced abroad.

In developing a similar expression for the global Leontief inverse in a three-region world we make use of the so-called quotient property of the Schur complement.

Consider

$$M = \begin{bmatrix} A & B & C \\ D & E & F \\ G & H & I \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} & C \\ K_{21} & K_{22} & F \\ G & H & I \end{bmatrix} \quad (31)$$

The quotient rule tells us that we can find the Schur complement of  $K$  in  $M$  in two alternative ways  $M/K = (M/A)/(K/A) = (M/E)/(K/E)$ . Thus, we obtain two different expressions for the three Schur complements of the three-dimensional case, depending on the block pivot we use (either  $A$  or  $E$ ). We apply this rule to:

$$M = \begin{bmatrix} \Delta_{11} & -A_{12} & -A_{13} \\ -A_{21} & \Delta_{22} & -A_{23} \\ -A_{31} & -A_{32} & \Delta_{33} \end{bmatrix} \quad (32)$$

and we denote the two alternative Schur complements as  $\Lambda_{rr}^{ss}$  and  $\Lambda_{rr}^{\rho\rho}$ , where the subscript indicates the complement and the superscript the block pivot used. Thus, for example,  $\Lambda_{33}^{11}$  is the Schur complement of  $K$  in  $M$  where:

$$K = \begin{bmatrix} \Delta_{11} & -A_{12} \\ -A_{21} & \Delta_{22} \end{bmatrix} \quad (33)$$

that is arrived at as  $(M/\Delta_{11})/(K/\Delta_{11})$  and the alternative expression is:  $\Lambda_{33}^{22} = (M/\Delta_{22})/(K/\Delta_{22})$ .

Thus, we obtain as a general form for the Schur complements:

$$\begin{aligned} \Lambda_{rr}^{ss} &= \Delta_{rr} - A_{rs}\Delta_{ss}^{-1}A_{sr} - (A_{r\rho} + A_{rs}\Delta_{ss}^{-1}A_{s\rho}) \\ &(\Delta_{\rho\rho} - A_{\rho s}\Delta_{ss}^{-1}A_{s\rho})^{-1}(A_{\rho r} + A_{\rho s}\Delta_{ss}^{-1}A_{sr}) \end{aligned} \quad (34)$$

The expression of the global Leontief inverse that we want to arrive at has the form:

$$M^{-1} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix} = \begin{bmatrix} I & C_{12} & C_{13} \\ C_{21} & I & C_{23} \\ C_{31} & C_{32} & I \end{bmatrix} \begin{bmatrix} \Lambda_{11}^{-1} & 0 & 0 \\ 0 & \Lambda_{22}^{-1} & 0 \\ 0 & 0 & \Lambda_{33}^{-1} \end{bmatrix} \quad (35)$$

Hence, the blocks  $C$  will depend on the expression chosen for the diagonal blocks. We indicate this with the same superscript notation as we used for the Schur complements. Thus, for example,  $C_{12}^{11}$  is the off-diagonal block that matches  $(\Lambda_{22}^{11})^{-1}$  and  $C_{12}^{33}$  meets  $(\Lambda_{22}^{33})^{-1}$ .

The blocks  $C$  come in two varieties:

$$C_{rs}^{rr} = \Delta_{rr}^{-1}A_{rs} + \Delta_{rr}^{-1}A_{r\rho}(\Delta_{\rho\rho} - A_{\rho r}\Delta_{rr}^{-1}A_{r\rho})^{-1}(A_{\rho s} + A_{\rho r}\Delta_{rr}^{-1}A_{rs}) \quad (36)$$

and

$$C_{rs}^{\rho\rho} = (\Delta_{rr} - A_{r\rho}\Delta_{\rho\rho}^{-1}A_{\rho r})^{-1}(A_{rs} + A_{r\rho}\Delta_{\rho\rho}^{-1}A_{\rho s}) \quad (37)$$

One may verify that, for example:

$$M^{-1} = \begin{bmatrix} I & C_{12}^{11} & C_{13}^{22} \\ C_{21}^{22} & I & C_{23}^{22} \\ C_{31}^{22} & C_{32}^{11} & I \end{bmatrix} \begin{bmatrix} (\Lambda_{11}^{22})^{-1} & 0 & 0 \\ 0 & (\Lambda_{22}^{11})^{-1} & 0 \\ 0 & 0 & (\Lambda_{33}^{22})^{-1} \end{bmatrix} \quad (38)$$

is indeed an expression of the inverse of  $M$ .

Thus, there is a rich choice of alternative expressions for the global Leontief inverse in a three-region world. As they are all equivalent we choose the most compact one in which  $B_{rs}$  has the general form:

$$B_{rs} = C_{rs}^{\rho\rho} (\Lambda_{ss}^{\rho\rho})^{-1} = (\Delta_{rr} - A_{r\rho} \Delta_{\rho\rho}^{-1} A_{\rho r})^{-1} (A_{rs} + A_{r\rho} \Delta_{\rho\rho}^{-1} A_{\rho s}) (\Lambda_{ss}^{\rho\rho})^{-1} \quad (39)$$

As in the two-dimensional case  $B_{rs}$  represents gross output from  $r$  required in  $s$  for the production of the gross output in  $s$  that is needed per unit of final output produced in  $s$ . No such gross output will be needed if  $A_{rs} = 0$  and either  $A_{r\rho} = 0$  or  $A_{\rho s} = 0$ . In other words,  $B_{rs} = 0$  if  $r$  does not ship any intermediates to  $s$  either directly or indirectly via the third region.

## C Additional tables

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

Table 2: Sectoral aggregation

Code	Description
AGO	agriculture and raw materials
ENG	energy
LTM	low technology manufacturing
MLM	medium-low technology manufacturing
TRA	transport services
OCS	other commercial services
OSR	other (government) services
OBS	other business services
CRP	chemical, rubber and plastic products
MVH	motor vehicles and parts
OTN	other transport equipment
OME	other machinery and equipment
ELE	electronic equipment

Table 3: Bilateral trade gaps, gross trade in bln euro, 2007

	EU	OWE	OEE	CHN	IND	EAS	SEA	JPN	USA	ONA	RoW	TRA	surplus
EU		-7	-40	-125	-4	-29	-28	-20	78	14	8	67	-87
OWE	7		-10	-11	3	-3	-1	2	8	1	4	7	6
OEE	40	10		-11	1	-3	-1	-1	12	0	12	-4	58
CHN	125	11	11		7	-86	-27	-17	171	22	-2	0	215
IND	4	-3	-1	-7		-1	-10	-2	9	0	-29	-4	-42
EAS	29	3	3	86	1		8	-41	10	9	-47	11	71
SEA	28	1	1	27	10	-8		7	41	6	-5	5	112
JPN	20	-2	1	17	2	41	-7		43	9	-71	8	61
USA	-78	-8	-12	-171	-9	-10	-41	-43		-107	-85	-43	-607
ONA	-14	-1	0	-22	0	-9	-6	-9	107		-1	-17	27
RoW	-8	-4	-12	2	29	47	5	71	85	1		-30	187
TRA	-67	-7	4	0	4	-11	-5	-8	43	17	30		0
deficit	87	-6	-58	-215	42	-71	-112	-61	607	-27	-187	0	

Table 4: Bilateral trade gaps, value added trade in bln euro, 2007

	EU	OEU	RUS	CHN	IND	EAS	SEA	JAP	USA	ONA	RoW	TRA	surplus
EU		-7	-27	-93	-1	-30	-28	-25	90	7	-18	45	-87
OEU	7		-8	-8	1	-3	-2	-1	13	2	0	6	6
RUS	27	8		-8	2	-3	-1	-2	16	1	11	7	58
CHN	93	8	8		5	-27	-10	-6	131	15	-6	1	215
IND	1	-1	-2	-5		-2	-8	-3	8	0	-26	-3	-42
EAS	30	3	3	27	2		-2	-13	24	6	-15	4	71
SEA	28	2	1	10	8	2		12	40	4	4	3	113
JAP	25	1	2	6	3	13	-12		53	7	-44	5	61
USA	-90	-13	-16	-131	-8	-24	-40	-53		-85	-97	-48	-607
ONA	-7	-2	-1	-15	0	-6	-4	-7	85		-3	-12	27
RoW	18	0	-11	6	26	15	-4	44	97	3		-7	186
TRA	-45	-6	-7	-1	3	-4	-3	-5	48	12	7		0
deficit	87	-6	-58	-215	42	-71	-113	-61	607	-27	-186	0	

Table 5: Share of redirected domestic (SRDV) and foreign (SRFV) value added in bilateral intermediate value added trade for final output, 2007

	SRDV indicator			SRFV indicator		
	2001	2004	2007	2001	2004	2007
EU15	18.2	19.0	16.7	14.1	11.4	12.5
EU12	16.2	15.2	15.2	27.2	26.7	25.1
Other Western Europe	15.4	13.6	13.5	24.0	24.5	20.0
Other Eastern Europe	14.0	14.3	13.6	9.2	10.8	7.3
China	16.1	17.2	15.8	22.5	26.8	24.2
India	16.8	16.2	13.9	10.1	10.9	9.7
East Asia	20.3	21.9	21.0	34.6	34.7	28.7
South East Asia	15.6	17.1	16.4	44.4	39.5	34.7
Japan	23.6	23.9	21.7	10.0	11.8	13.5
USA	22.3	21.2	18.3	7.4	7.7	7.7
Other NAFTA	9.3	9.6	9.8	35.4	30.6	25.6
RoW	13.8	12.9	13.2	11.0	11.5	8.4
Total	17.6	17.4	15.8	17.6	17.4	15.8

Table 6: Share of redirected domestic (GSDRV) and foreign (GSFRV) value added in all globally redirected value added for final output, 2007

	GSDRV indicator			GSFRV indicator		
	2001	2004	2007	2001	2004	2007
EU15	23.3	24.4	21.9	16.6	13.7	16.0
EU12	2.2	2.5	2.9	6.2	6.6	7.7
Other Western Europe	4.0	3.7	3.9	4.5	5.6	5.3
Other Eastern Europe	2.5	3.5	4.8	0.6	1.0	1.1
China	6.1	7.4	9.0	10.4	16.4	17.5
India	1.2	1.2	1.8	0.9	1.4	1.9
East Asia	5.5	6.7	6.4	10.2	10.4	9.4
South East Asia	4.8	5.1	5.6	14.0	12.1	10.3
Japan	12.6	12.1	9.0	4.8	5.2	6.1
USA	21.9	16.6	13.3	9.6	9.5	9.9
Other NAFTA	3.7	3.2	3.5	14.7	11.3	9.0
RoW	12.1	13.4	17.9	7.4	6.7	6.0
Total	100.0	100.0	100.0	100.0	100.0	100.0