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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 use this analytical framework to develop indicators that identify production hubs and supply spokes in global supply chains. Using these indicators and the Global Trade Analysis Project (GTAP) database, we quantify the relative importance of redirected value-added trade and the hub and spoke relationships at the aggregate level and for specific highly integrated industries.

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1. Introduction

Growing trade in intermediate products reflects the rising complexity of producing goods and services. This not only entails a growing number of traded intermediate inputs, but also that these intermediates are commonly produced in 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 many locations all over the world.[1] Traditional trade statistics reporting the sales value do not measure spatial fragmentation well. The recent literature on trade in value added has overcome this by bringing together the literature on input–output (IO) accounting in interregional models and the recent literature on vertical specialization and trade in domestic value added.

The seminal paper of Hummels et al. (2001) was the first using the foreign intermediate content of exports as a measure of vertical specialization (VS).[2] However, the VS indicator

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[1] Theoretical explanations for increased international product fragmentation can be found in Grossman and Helpman (2005), Grossman and Rossi-Hansberg (2008), and Baldwin and Venables (2013). 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% of all tasks are off-shored: A way of producing an air-plane 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] VS is the share of intermediate imports in gross exports and together with DV, the share of domestic value added in gross exports, they add up to 1. A higher VS value is associated with higher amounts of imports in exports (i.e. more vertical specialization).

was not suitable to capture the complexities of extended international supply chains where intermediate inputs flow through multiple countries, sometimes several times.

Several recent papers on trade in value added have overcome these methodological shortcomings (Daudin et al., 2011; Koopman et al., 2010, 2014; Johnson and Noguera, 2012a, 2012b). These papers are based on a similar methodological framework that can account for trade in value added in the presence of multi-country and multi-stage production processes.[3]

The main contribution of our paper is to complement recently constructed indicators of vertical specialization by creating indicators that identify and quantify the relevance of production hubs and supply spokes in international supply chains. Until now hubs and spokes in the trading system were more informally addressed in the literature at the macro level (cf. Baldwin, 2007).[4] In addition, previous papers considered value-added trade from the perspective of the origin or final destination country, while we focus on the final producer country, just before the final destination.

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 final producer. Their value-added measure of exports does not distinguish between value added generated in the exporting country and the foreign value added generated in earlier stages which is essential for identifying producer hubs and spokes relations (Wang et al., 2013). Moreover, their methodology does not identify the industry–country pairs that are important in redirecting trade in value added. Koopman et al. (2014) emphasize mainly the productive use of all value-added imports by the final producer, while we focus on pass through of value-added trade via a specific final producer by analysing all value-added imports by the final producer in relation to all value-added exports of the same producer.

We define global supply production hubs as those industry–country pairs that use a relatively large share of imported value added in producing output for final use abroad.[5] In addition, we also identify global supply spokes, which are the regions that are important suppliers of the intermediate inputs to the production hubs – i.e. the incoming spokes.[6]

The key element in identifying both production hubs and supply spokes is redirected value added (pass through of value added), either as a share of outgoing intermediate value-added exports or as a share of incoming intermediate value-added imports. 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

[3] Some of the main results of these papers are relatively similar. They find that the average foreign content of domestic exports is between 20%DIFaddand 30% (the VS measure). Johnson and Noguera (2012a) construct the VAX-ratio (ratio of domestic value-added exports to gross exports) which is on average 73% in 2004.

[4] The network analysis of bilateral trade also uses the terms hubs and spokes, albeit in a different way, see De Benedictis and Tajoli (2011).

[5] In a recent paper Baldwin and Lopez-Gonzalez (2015) also identify the hubs in the global trading system, but mainly at the country level and only with sectoral disaggregation for China. They use the terms head-quarter and factory economies, while we label these as spokes and hubs, respectively.

[6] Our methodology is also well suited to identify the outgoing spokes: the final destinations that are important receivers of the value added that is redirected by the production hubs. However, in this paper we only analyze the supply or incoming spokes.

in another country and sent back to the home country) in an exhaustive and clear manner.

As a way to illustrate our methodology, we calculate our indicators from global input–output tables derived from the GTAP database.[7] Our results are consistent with other partial findings in the literature. Based on a global and consistent analytical framework, they confirm common priors: global production networks are mainly located in North America, Europe and the Asia-Pacific region (China, East Asia and Southeast Asia). More importantly, our estimations allow an in-depth industry analysis of hub and spoke relationships, and they can also identify and quantify the geographical importance of global supply chains at the sectoral level.

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 production hubs and supply spokes at the industry level in Section 3. We conclude in Section 4.

2. Methodological framework

We provide the background and details of the methodology used to identify the different components of value-added trade. To make the exposition easier, we follow the notational conventions from Miller and Blair (2009). Lower-case bold letters denote column vectors, as in $\mathbf{x}$; so $\mathbf{x}'$ is the corresponding row vector. Upper-case bold letters denote matrices (e.g. $\mathbf{Z}$), while $\mathbf{Z}'$ indicates the transpose of matrix $\mathbf{Z}$. The unit or summation vector is denoted by $\mathbf{i}$, and $\mathbf{i}_s$ is used as a selection vector (the sth entry of $\mathbf{i}_s$ being one and all other entries being zero). Scalars (including single elements of matrices of vectors) are denoted in italic lowercase. To represent diagonal matrices, we use the hat sign as in $\hat{\mathbf{z}}$, which denotes a matrix with $\mathbf{z}$ on its main diagonal and zeros elsewhere. The unit matrix is denoted by $\mathbf{I}$.

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 $M = \{1, 2, \ldots, m\}$, while sectors are indexed by i, j and k, which belong to the set $N = \{1, 2, \ldots, n\}$. Region-related matrices are denoted as superscripts ($\mathbf{Z}^{rs}$), where r refers to the region of origin and s to the region of destination. Sector-related entries of matrices or vectors are denoted as subscripts ($\mathbf{Z}_{ij}$), where i is the sector of origin and j the destination sector. Final destinations are always indicated with the superscript ρ. For instance, $\mathbf{Z}^{rs\rho}$ denotes the input from region r that region s needs to produce final output for region ρ. We use w as a superscript that defines a global total, obtained via summation of superscripted variables over the region set M. For example, $\mathbf{Z}^{rw} = \sum_{s\in M} \mathbf{Z}^{rs}$. Similarly, we use the subscript t to define the total economy, obtained via summation over the sector set N. Thus, $\mathbf{z}_t = \sum_{i\in N} \mathbf{z}_i$.

[7] As explained in the appendix, there are now several databases that can be used to analyze trade in value added, each with its advantages and disadvantages. We follow the recent literature and use the GTAP database, but it is important to note that the methodology that we develop to identify hubs and spokes can also be applied to alternative databases.

2.1. Trading schemes in global input–output analysis

We make use of global input–output matrices that have the following structure:[8]

$$\begin{bmatrix} \mathbf{S}^{11} & \mathbf{S}^{12} & \dots & \mathbf{S}^{1m} & \mathbf{f}^{11} & \mathbf{f}^{12} & \dots & \mathbf{f}^{1m} & \mathbf{x}^{1} \\ \mathbf{S}^{21} & \mathbf{S}^{22} & \dots & \mathbf{S}^{2m} & \mathbf{f}^{21} & \mathbf{f}^{22} & \dots & \mathbf{f}^{2m} & \mathbf{x}^{2} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \iddots & \vdots & \vdots \\ \mathbf{S}^{m1} & \mathbf{S}^{m2} & \dots & \mathbf{S}^{mm} & \mathbf{f}^{m1} & \mathbf{f}^{m2} & \dots & \mathbf{f}^{mm} & \mathbf{x}^{m} \\ \mathbf{p}'^{1} & \mathbf{p}'^{2} & \dots & \mathbf{p}'^{m} & & & & & \\ \mathbf{x}'^{1} & \mathbf{x}'^{2} & \dots & \mathbf{x}'^{m} & & & & & \end{bmatrix} \tag{1}$$

where $\mathbf{S}^{rs}$ denotes the $n \times n$ sectoral matrix of intermediate deliveries from region r to region s, $\mathbf{f}^{rs}$ is the n vector with final outputs produced in region r that are used in region s, $\mathbf{x}^{r}$ is the vector containing gross output values of region r, while $\mathbf{p}'^{s}$ 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, $\mathbf{x}'^{s}$ 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:

$$x_i^r = s_{it}^{rw} + f_i^{rw} \tag{2}$$

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

$$x_j^s = s_{tj}^{ws} + p_j^s \tag{3}$$

Summarizing Equation 1 as

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

we define matrices of input coefficients $\mathbf{A}$ and $\mathbf{V}$, where matrix element $a_{ij}^{rs} = s_{ij}^{rs}/x_j^s$ 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 $v_j^s = p_j^s/x_j^s$ represents the use of value added in sector j of region s per unit of gross input (of sector j in region s).

From Equation 2 and the definition of $\mathbf{A}$, we have

$$\mathbf{x} = \mathbf{Si} + \mathbf{Fi} = \mathbf{Ax} + \mathbf{f}^w = (\mathbf{I} - \mathbf{A})^{-1} f^w = \mathbf{Bf}^w, \tag{5}$$

which relates global final demands $\mathbf{f}^w$ to gross production. The elements of the global Leontief inverse matrix b_{ij}^{rs} 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 ρth column of $\mathbf{F}$ as: $\mathbf{f}^{\rho} = \mathbf{Fi}_{\rho}$, which represents the use of final output in region ρ. Multiplying the gross output requirements for $\mathbf{f}^{\rho}$ with value added per unit

[8] In fact, the GTAP dataset also includes specific entries for international transportation services. More specifically, intermediate supplies and intermediate and final demands for international transportation services. To keep our exposition as simple as possible, our treatment of these details are explained in the appendix.

of gross input yields the corresponding value-added requirements (Θ) of final demands in region ρ:

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

At the global-level value added exactly matches final demand. Hence, **v'B** equals the unit vector.[9] Then, it is easily verified that the column sum of $\Theta(\mathbf{f}^{\rho})$ equals final output use in region ρ:

$$i'\Theta(\mathbf{f}^{\rho}) = \mathbf{v}'\mathbf{B}\widehat{\mathbf{f}}^{\rho} = \mathbf{f}'^{\rho} \tag{7}$$

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

$$\Theta(\mathbf{f}^{\rho})\mathbf{i} = \hat{\mathbf{v}}\mathbf{B}\mathbf{f}^{\rho} = \hat{\mathbf{v}}\mathbf{x}(\mathbf{f}^{\rho}) = \mathbf{p}(\mathbf{f}^{\rho}), \tag{8}$$

where we expressed both gross output **x** and value added **p** as a function of the final demand vector $\mathbf{f}^{\rho}$.

Not all value added in $\Theta(\mathbf{f}^{\rho})$ is traded internationally. There is one block in this matrix where part of domestic value added remains at home: $\hat{\mathbf{v}}^{\rho}\mathbf{B}^{\rho\rho}\widehat{\mathbf{f}}^{\rho\rho}$, which represents domestic value added needed to produce domestic final output that is used at home. To obtain a matrix that contains only traded values, we first need to subtract, within this block, the non-traded component $(\hat{\mathbf{v}}^{\rho}(\Delta^{\rho\rho})^{-1}\widehat{\mathbf{f}}^{\rho\rho})$ to obtain the trade-only block[10]: $\hat{\mathbf{v}}^{\rho}(\mathbf{B}^{\rho\rho} - (\Delta^{\rho\rho})^{-1})\widehat{\mathbf{f}}^{\rho\rho}$, which represents value-added exports from ρ that are needed abroad to produce the intermediate imports required for the production of $\mathbf{f}^{\rho\rho}$.

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

$$\Gamma^{\rho} = \begin{bmatrix} \hat{\mathbf{v}}^{1}\mathbf{B}^{11}\widehat{\mathbf{f}}^{1\rho} & \hat{\mathbf{v}}^{1}\mathbf{B}^{12}\widehat{\mathbf{f}}^{2\rho} & \cdots & \hat{\mathbf{v}}^{1}\mathbf{B}^{1r}\widehat{\mathbf{f}}^{r\rho} & \cdots & \hat{\mathbf{v}}^{1}\mathbf{B}^{1\rho}\widehat{\mathbf{f}}^{\rho\rho} & \cdots & \hat{\mathbf{v}}^{1}\mathbf{B}^{1m}\widehat{\mathbf{f}}^{m\rho} \\ \hat{\mathbf{v}}^{2}\mathbf{B}^{21}\widehat{\mathbf{f}}^{1\rho} & \hat{\mathbf{v}}^{2}\mathbf{B}^{22}\widehat{\mathbf{f}}^{2\rho} & \cdots & \hat{\mathbf{v}}^{2}\mathbf{B}^{2r}\widehat{\mathbf{f}}^{r\rho} & \cdots & \hat{\mathbf{v}}^{2}\mathbf{B}^{2\rho}\widehat{\mathbf{f}}^{\rho\rho} & \cdots & \hat{\mathbf{v}}^{2}\mathbf{B}^{2m}\widehat{\mathbf{f}}^{m\rho} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & ⋰ & \vdots \\ \hat{\mathbf{v}}^{r}\mathbf{B}^{r1}\widehat{\mathbf{f}}^{1\rho} & \hat{\mathbf{v}}^{r}\mathbf{B}^{r2}\widehat{\mathbf{f}}^{2\rho} & \cdots & \hat{\mathbf{v}}^{r}\mathbf{B}^{rr}\widehat{\mathbf{f}}^{r\rho} & \cdots & \hat{\mathbf{v}}^{r}\mathbf{B}^{r\rho}\widehat{\mathbf{f}}^{\rho\rho} & \cdots & \hat{\mathbf{v}}^{r}\mathbf{B}^{rm}\widehat{\mathbf{f}}^{m\rho} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & ⋰ & \vdots \\ \hat{\mathbf{v}}^{\rho}\mathbf{B}^{\rho 1}\widehat{\mathbf{f}}^{1\rho} & \hat{\mathbf{v}}^{\rho}\mathbf{B}^{\rho 2}\widehat{\mathbf{f}}^{2\rho} & \cdots & \hat{\mathbf{v}}^{\rho}\mathbf{B}^{\rho r}\widehat{\mathbf{f}}^{r\rho} & \cdots & \hat{\mathbf{v}}^{\rho}(\mathbf{B}^{\rho\rho} - (\Delta^{\rho\rho})^{-1}\widehat{\mathbf{f}}^{\rho\rho} & \cdots & \hat{\mathbf{v}}^{\rho}\mathbf{B}^{\rho m}\widehat{\mathbf{f}}^{m\rho} \\ \vdots & \vdots & ⋰ & \vdots & ⋰ & \vdots & \ddots & \vdots \\ \hat{\mathbf{v}}^{m}\mathbf{B}^{m1}\widehat{\mathbf{f}}^{1\rho} & \hat{\mathbf{v}}^{m}\mathbf{B}^{m2}\widehat{\mathbf{f}}^{2\rho} & \cdots & \hat{\mathbf{v}}^{m}\mathbf{B}^{mr}\widehat{\mathbf{f}}^{r\rho} & \cdots & \hat{\mathbf{v}}^{m}\mathbf{B}^{m\rho}\widehat{\mathbf{f}}^{\rho\rho} & \cdots & \hat{\mathbf{v}}^{m}\mathbf{B}^{mm}\widehat{\mathbf{f}}^{m\rho} \end{bmatrix} \overbrace{\begin{bmatrix} \mathbf{p}^{1}(\mathbf{f}^{\rho}) \\ \mathbf{p}^{2}(\mathbf{f}^{\rho}) \\ \vdots \\ \mathbf{p}^{r}(\mathbf{f}^{\rho}) \\ \vdots \\ \mathbf{p}^{\rho}(\mathbf{f}^{\rho}) - \hat{\mathbf{v}}^{\rho}(\Delta^{\rho\rho})^{-1}\mathbf{f}^{\rho} \\ \mathbf{p}^{m}(\mathbf{f}^{\rho}) \end{bmatrix}}^{\text{Row sums}} \tag{9}$$

$$\underbrace{\begin{bmatrix} \mathbf{f}'^{1\rho} & \mathbf{f}'^{2\rho} & \cdots & \mathbf{f}'^{r\rho} & \cdots & \mathbf{f}'^{\rho\rho} - \mathbf{v}'^{\rho}(\Delta^{\rho\rho})^{-1}\widehat{\mathbf{f}}^{\rho} & \cdots & \mathbf{f}'^{m\rho} \end{bmatrix}}_{\text{Column sums}}.$$

The elements on the diagonal block denote domestic inputs and the elements on the off-diagonal blocks indicate foreign inputs. Along the rows of Γ^{ρ}, we find the value-added exports from a specific country into final output production for ρ in the different countries producing this output. Strictly, the matrix contains sector-specific entries, such that element $\gamma_{ij}^{r\sigma\rho}$ represents the internationally traded value added from sector i in region r that is needed by final producer σ for final j-output use in ρ. More loosely, we describe the entries of this matrix as bilateral value-added trade needed for final output use in ρ. For example, $\Gamma^{r\sigma\rho}$ provides the value added generated in r that is used by the final producer σ to supply the final destination ρ.

[9] The direct proof is by rewriting **v′= i′(I - A)** and then evaluating **v′B = i′(I - A)B = i′**.

[10] Here $(\Delta^{\rho\rho})^{-1}$ denotes the local Leontief inverse for region ρ, i.e. the Leontief inverse obtained from the national input–output table of ρ.

2.2. Decomposing bilateral trade in value added

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

First, we consider the blocks on the main diagonal except the one that gives the domestic requirements for the production of $\mathbf{f}^{\rho\rho}$:

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

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

Second, turning to the column with the requirements for $\mathbf{f}^{\rho\rho}$, we consider

$$\Gamma^{r\rho\rho} = \hat{\mathbf{v}}^r (\mathbf{B}^{r\rho} - \delta^{r\rho} (\Delta^{\rho\rho})^{-1}) \hat{\mathbf{f}}^{\rho\rho} \quad \forall (r, \rho) \in M, \tag{11}$$

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

Third, we consider the blocks:

$$\Gamma^{r\sigma\rho} = \hat{\mathbf{v}}^r \mathbf{B}^{r\sigma} \hat{\mathbf{f}}^{\sigma\rho} \quad \forall (r, \sigma, \rho) \in M : r \neq \rho, \;\; r \neq \sigma, \;\; \sigma \neq \rho. \tag{12}$$

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

Fourth, we inspect the blocks:

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

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

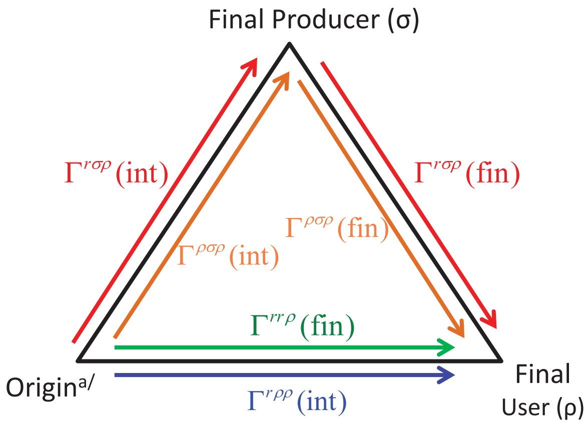
We conclude that four different types of value-added exports can be distinguished. The value-added requirements defined as $\Gamma^{rr\rho}$ (with $r \neq \rho$) are for direct final output exports. The requirements in $\Gamma^{r\rho\rho}$ are for intermediates converted to final use in the final destination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

2.3. Triangular trading scheme and links with other indicators

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

Figure 1 shows that we analyze bilateral trade in value added from different perspectives. For instance, we can focus on trade in value added from a particular origin to a specific final

Figure 1. Triangular trading scheme.



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

destination by taking the sum of all flows that pass through the final producers ($\Gamma^{rw\rho}$). 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 final producer by taking the sum of all flows that leave the final producer ($\Gamma^{r\sigma w}$). Looking at trade from this perspective emphasizes the productive use of value-added imports by the final producer. It is mainly from this perspective that Koopman et al. (2010, 2014) analyze trade in value added. A third perspective is to focus on the pass through of value-added trade via a specific final producer by taking the alternating sums over origins ($\Gamma^{w\sigma\rho}$) and final destinations ($\Gamma^{r\sigma w}$). The former provide us with the value-added exports by the final producer to specific destinations and the latter with its value-added imports from specific origins. It is from this 'pass-through' perspective that we analyze trade in value added in this paper.[11]

Our measures of value-added exports are closely related to the value-added export measures used by Johnson and Noguera (2012a), Koopman et al. (2010, 2014). But there are differences too. Most notably we aggregate value-added exports over sectors of origin (as also (Wang et al., 2013) are doing) whereas both Johnson and Noguera (2012a) and Koopman et al. (2010) aggregate over sectors of final use. As a concrete example, our methodology identifies the country of origin of the foreign value added embedded in the Boeing Dreamliner that is exported from the US (the redirector) to its final destinations – e.g. how much Japanese and Chinese value added is embedded in the exports of US airplanes. On the other hand, Johnson and Noguera (2012a) and Koopman et al. (2010) identify the final destination of value added created in a particular sector in the country of origin. For example, how much value added from the Dutch agricultural sector ends up being consumed in a specific country.

[11] 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. The advantage is that all hubs and spokes are compared to each other at the same position in the GVC, but the limitation is that it disregards the length and structure of the chains.

2.4. Production hubs and supply spokes indicators

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

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

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

and the bilateral exports *from* final producer σ (the outgoing spokes) can be derived as[12]

$$\gamma_{tj}^{w\sigma\rho} = \overbrace{\gamma_{tj}^{\sigma\sigma\rho} + \underbrace{\sum_{r\neq\sigma,\rho}\gamma_{tj}^{r\sigma\rho} + \gamma_{tj}^{\rho\sigma\rho}}_{\text{redirected by } \sigma}}^{\text{absorbed in } \rho} = f_j^{\sigma\rho} \quad \forall (\sigma,\rho)\in M : \sigma\neq\rho. \tag{15}$$

Equation 14 shows that the final producer imports intermediate value added for own final output production that is consumed domestically and intermediate value added for final output exports. Equation 15 shows that the final output exports of the final producer consist of a bundle of own value added and the foreign intermediate value added that it redirects.

The incoming spokes and outgoing spokes are shown in Figure 1, where $\Gamma^{r\sigma\rho}$(int) and $\Gamma^{\rho\sigma\rho}$(int) are the incoming spokes and $\Gamma^{r\sigma\rho}$(fin) and $\Gamma^{\rho\sigma\rho}$(fin) are the outgoing spokes. When the incoming value-added trade is large and the redirected foreign value-added trade is small, the final producer is mainly importing intermediates for own final use. However, if the redirected value-added trade is relatively large with respect to the incoming value-added trade, we define the final producer as a production hub. Thus, to check whether a

[12] The last equality in Equation 15 is based on $\Gamma'^{w\sigma\rho} = \sum_r \mathbf{v}'^r\mathbf{B}^{r\sigma}\hat{\mathbf{f}}^{\sigma\rho} = \mathbf{f}'^{\sigma\rho}$ because $\sum_r \mathbf{v}'^r\mathbf{B}^{r\sigma} = \mathbf{i}'\sum_r(\mathbf{I}-\sum_s \mathbf{A}^{sr})\mathbf{B}^{r\sigma} = \mathbf{i}'$.

region/country σ qualifies as a j-hub, we use the following indicator:

$$\mathrm{SF}_j^{\sigma} = \frac{\sum_{r\neq\sigma}\sum_{\rho\neq\sigma}\gamma_{tj}^{r\sigma\rho}}{\sum_{r\neq\sigma}\gamma_{tj}^{r\sigma w}}, \tag{16}$$

where SF measures foreign redirected value added as a share of total bilateral value-added imports that region σ needs to produce final j-output. This is an intensity measure showing the relative importance of region σ in assembling final j-output for the world market. Figure 2 illustrates the calculation of SF. For a specific final producer (σ), we determine the share of outgoing foreign intermediates in final output exports (the arrows from the final producer to the final users) as a percentage of total imports of foreign intermediates (the arrows from the origins to the final producer). The difference between the numerator and denominator is the amount of intermediates for final output used by the final producer. If this amount is negligible SF equals 1. The larger the size of the intermediates for own use is, the smaller the importance as a production hub of region σ becomes.

A large SF^{σ} indicates that this region is integrated into an international supply chain. We consider region σ to be a hub in the global supply chain of industry j if its SF_j^{σ} value is above the global value SF_j^{w}, which is a weighted average of all SF_j values. SF is our primary measure to identify production hubs in global supply chains.

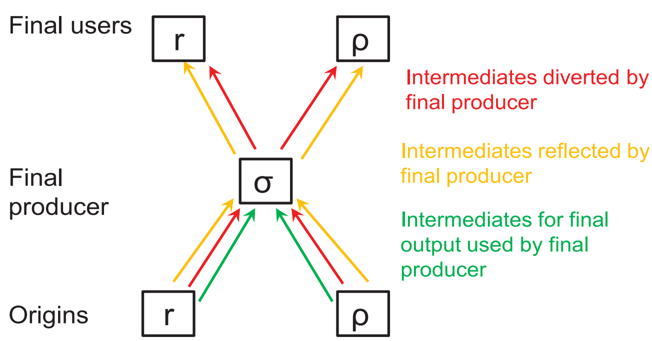
To indicate the size of the hub, we use the following GSF indicator:

$$\mathrm{GSF}_j^{\sigma} = \frac{\sum_{r\neq\sigma}\sum_{\rho\neq\sigma}\gamma_{tj}^{r\sigma\rho}}{\sum_{s}\sum_{r\neq s}\sum_{\rho\neq s}\gamma_{tj}^{rs\rho}}, \tag{17}$$

GSF_j^{σ} 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. In terms of Figure 2, the arrows from the final producer to the final users are compared to the arrows from all final producers to the final users.

A relative large value of GSF_j^{σ} shows that region σ redirects a large share of globally redirected value added. However, a region with a large GSF value is not, per se, a hub. The GSF measure does not relate the size of redirected value-added trade with incoming

Figure 2. Calculating the SF indicator.



value-added trade as the SF measure does. Note that regions with large internal markets (i.e. EU15, the USA, China) can have both large GSF and low SF values, reflecting that the foreign value added embedded in intermediate imported inputs is absorbed locally, and only a relative small share is redirected, even when in absolute terms the amount of redirected value added can be large. On the other hand, having both large SF and GSF values does show that the region is a large hub in global supply chains.

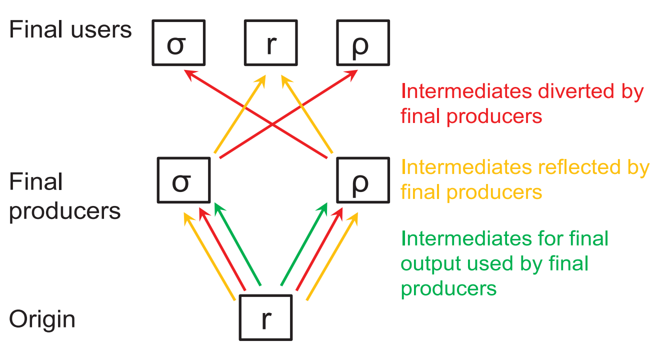
To analyze the regional or global nature of the production hub, we then decompose each GSF-measure into the different origins and final destinations of the value added involved to identify the incoming and outgoing spokes separately for each final producer. This last step allows us to analyze if the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

In addition, we use the information on the origin of the incoming spokes to detect the global supply spokes: the regions/countries that are important in supplying the j-hubs with intermediates. In particular, we define the j-spokes as those regions/countries for which the share of domestic value added that is redirected by other countries producing final j-output for foreign use is relatively large:

$$SD_j^r = \frac{\sum_{\sigma \neq r} \sum_{\rho \neq \sigma} \gamma_{tj}^{r\sigma\rho}}{\sum_{\sigma \neq r} \gamma_{tj}^{r\sigma w}}, \tag{18}$$

SD_j^r is an intensity measure showing the relative importance of region r as a spoke that supplies intermediates for assembly abroad of exports of final j-output. Figure 3 illustrates how SD is calculated. For a specific origin r, SD^r is the share of redirected intermediate value added by all final producers (the arrows from the final producers to the final destinations) as a percentage of intermediate value-added exports from the origin (the arrows from the origin to the final producers). Also the indicator is equal to its maximum value of one if the size of intermediates for final output used by final producers is negligible. In normal circumstances, the value of SD is smaller than one.

Figure 3. Calculating the SD indicator.



We also calculate GSD_j^r, which expresses the redirected domestic value added as a share of all globally redirected value added for final j-exports:

$$\mathrm{GSD}_j^r = \frac{\sum_{\sigma \neq r} \sum_{\rho \neq \sigma} \gamma_{tj}^{r\sigma\rho}}{\sum_s \sum_{r \neq s} \sum_{\rho \neq s} \gamma_{tj}^{rs\rho}}. \qquad (19)$$

This size measure indicates the importance of r's activity as a spoke that supplies intermediates for trade in final j-output at the global level. For this indicator all redirected value-added exports to the final users from the origin country are added while the GSF indicator measures this from the final producing region.

3. Identifying hubs and spokes using the GTAP data

Using our indicators based on redirected trade, we identify production hubs (using the indicator in Equation 16) and incoming supply spokes (using the indicator in Equation 18). In addition, we can also quantify the relative importance of each of these global supply chains. We use the GTAP database to illustrate the applicability of our indicators.[13] The GTAP database provides information on more than 100 regions and/or countries (depending on the database release) and 57 sectors. Our initial matrix calculations are done at the most disaggregated level, but for presentation reasons we aggregate the data into 12 regions.[14]

3.1. Hubs and spokes for aggregate total output

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

To obtain more information about the characteristics of these production hubs, we look at GSF – see Equation 17. First, from Figure 5 we can distinguish between regional and global hubs by looking at the final destination of the outgoing spokes. For instance, the ONA region has a predominant share of value-added trade being redirected to the aggregated NAFTA region (which is mainly the USA). This implies that ONA is a regional hub. Similarly, EU12 and OWE are also regional hubs that redirect mainly to the aggregated region EUplus (which is mainly EU15), while it also has a predominant share of intermediate inputs originated in EUplus (right-hand side graph in Figure 5). On the other hand, most of the East-Asian regions – China, EAS and SEA – can be defined as global hubs, since they redirect to many geographically different regions and are also supplied from many different regions.[15]

[13] As mentioned before, our methodology can also be applied to other global input–output tables, such as WIOD. In the appendix we analyze the main advantages and limitations in using the GTAP database.

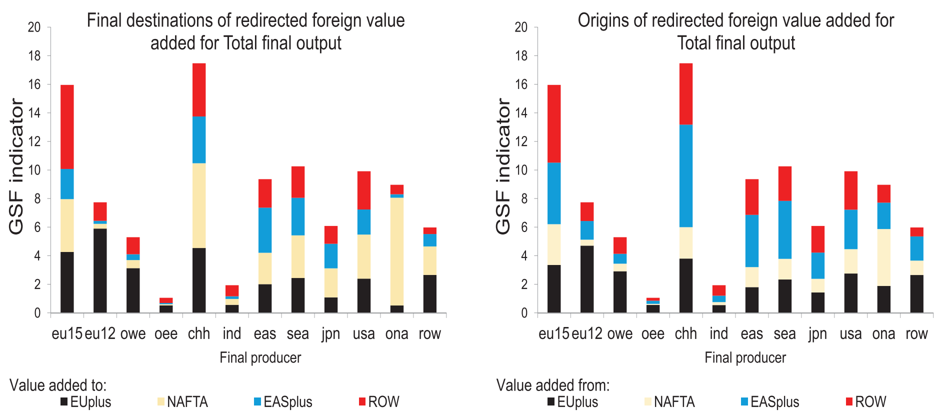
[14] The aggregation mapping into 12 regions is presented in the appendix. Note that the aggregation process will then ignore the 'internal' trade between the aggregated regions. In particular, this makes a difference for the indicators estimated for the EU27.

[15] We also assessed whether the nature of a hub was global or regional by calculating the average distance from the hub to the origins supplying the hub and the average distance from the hub to the final users supplied by the hub, making use

Figure 4. Identifying hubs using the SF indicator, 2007. Source: Own estimations using GTAP database.

Note: Region abbreviations are explained in the appendix.

Figure 5. Identifying the size and scope of hubs using the GSF indicator, 2007. Source: Own estimations using GTAP database.

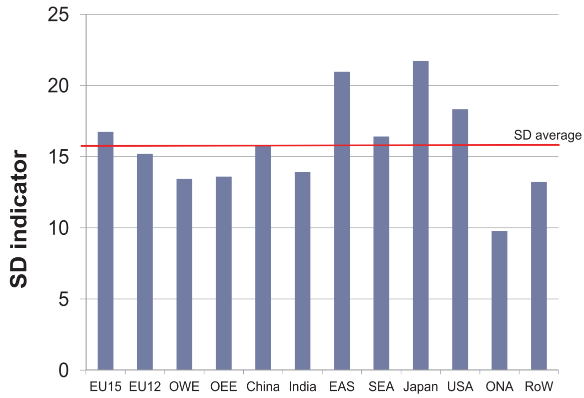


Note: The left-hand side graph presents the final destinations of GSF and the right-hand side of the origins. Region abbreviations are explained in the appendix.

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

of the distance measures from the CEPII-website (Mayer and Zignago, 2011). The distance measure assessments confirm our results using only hubs and spoke indicators (results available upon request).

Figure 6. Identifying spokes using the SD indicator, 2007. Source: Own estimations using GTAP database.



Note: Region abbreviations are explained in the appendix.

From the supply side, we can use the SD indicator to determine that the EU15, EAS, SEA, the USA, Japan and – to a lesser extent – China are the main incoming spokes in global supply chains (see Figure 6). In addition, using the GSD values we can determine relative sizes. We find that the EU15 is the main global incoming spoke (GSD = 22%), followed by the USA (GSD = 13%), Japan and China (both with GSD = 9%). In other words, these four regions supply more than half of the value added in the intermediates that are globally redirected by the hubs.

To sum up, at the aggregate-level global production networks are located mainly in the EASplus region, while regional networks – that supply the global economy – are located in North America (NAFTA) and Europe (EUplus). On the other hand, India and OEE (Other Eastern Europe, which is mainly Russia) cannot be considered as hubs nor spokes in global supply chains, since both regions have relatively low values for all indicators.

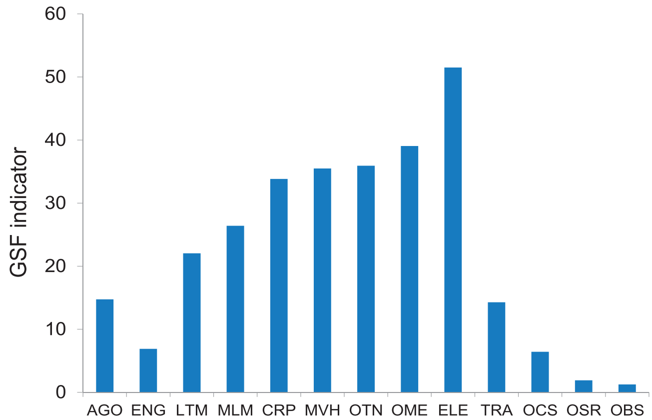
3.2. Relative importance of redirected trade by sector

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

The GTAP data that we use distinguish 57 economic sectors. Although technically feasible it is too cumbersome to present results for all sectors. Thus, we aggregate all 57 GTAP sectors into 13 sectors. (see the appendix for all the sectoral classifications.)

The importance of global production networks varies by sector. Figure 7 presents the global share of redirected value added in total value added of traded intermediates (GSF)

Figure 7. Global share of foreign redirected value-added trade in intermediate value-added trade (GSF) by economic sector, 2007. Source: Own estimations using GTAP database.



Note: Sector abbreviations are explained in the appendix.

for all aggregated sectors. The results suggest that global production networks matter mostly for manufacturing sectors.

For instance, GSF is above 20% for all manufacturing sectors, while lower than 15% for agriculture, energy and services sectors. In addition, our manufacturing sectors are classified by the technological level of each industry: from low-tech manufactures (LTM) to the electronic equipment (ELE), which has the highest technological level. Los et al. (2015) also show that the more high-tech manufacturing products are the ones with foreign value-added shares in final output and thus part of international production networks. From Figure 7 it is clear that the integration into global supply chains (represented by higher GSF values) increases by the technological content of the sector. The most globally integrated sector is electronic equipment, where more than half of global intermediate value-added trade is redirected.

Finally, in the appendix we present our hubs and spokes analysis for selected sectors. Here, we find that global production networks are specially important for a handful of sectors: electronic equipment, other machinery and equipment, other transport equipment, motor vehicles and parts, and chemical, rubber and plastic products.

4. Conclusions

The recent literature on trade in value added has advanced in deriving informative measures from national input–output tables and international trade statistics. These trade in value-added measures are used to compare bilateral trade gaps in value added and gross value terms and to derive indicators for vertical specialization. However, these papers do not track the value added generated in global supply chains, because they focus on the origins and final destinations of value added, and not on the final producer that redirects traded value added to the end-user. Our focus on the final producer is the main contribution of this paper. We measure the importance of final producers by incoming and outgoing value-added trade. By comparing the incoming and outgoing flows, we can derive the part of value-added trade that is redirected from a source country via the final producer to the end-using country.

Therefore, we have developed indicators for value-added trade and are able to identify the sources of redirected value added, the redirecting region and the final destinations by industry of end-use. Our proposed indicators for redirected value-added trade allow us to clearly identify the supply spokes, which are the relevant regions delivering value added to the redirecting regions, and the important redirecting regions, defined as production hubs, in global supply chains. Using these indicators we find several interesting results. Some of these results are consistent with other studies looking at global supply chains, while we can also analyze sector-specific results. First, using our indicators we clearly observe that global production networks are mainly located in North America, Europe and the Asia-Pacific region (China, East Asia and Southeast Asia). However, not all sub-regions in these highly integrated regions are equally important, or have the same function, in these supply chains. For instance, some regions act mainly as regional production hubs for a larger nearby region – i.e. other NAFTA serves as a production hub for the USA; while EU12 and other Western Europe serve as production hubs for EU15. These regions are more important as regional production networks than as global production networks. On the other hand, the Asia-Pacific region appears to have strong regional as well as global links with both EU15 and the USA.

Secondly, global production networks, at least the producer hubs for final products, matter mainly for manufacturing sectors. This is in particular the case for electronic equipment, other machinery and equipment, other transport equipment, motor vehicles and parts, and chemical, rubber and plastic products. However, there are significant differences between industries regarding the scope and nature of their global supply chains. A special case is electronic equipment, for which the major production hubs are located in the Asia-Pacific region. The spokes, the USA and EU15 still supply much of the value added for electronic equipment that is redirected by the Asia-Pacific region – in particular by China.

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