

Trade Redirection in Global Supply Chains

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Abstract

We define trade redirection in global supply chains as the reshipment of value added imports by the last but one country in the chain to their final destination. The redirector is either the final producer producing final output exports or the last exporter of intermediate output to the final producer producing for domestic use. We completely characterize trade redirection in terms of value added trade in global input-output models making use of the concept of intermediate value added exports up to the production gate of the final producer, factory gate exports for short. From the GTAP-datasets we obtain global input-output systems for the years 2001, 2004 and 2007. Empirical results for an aggregate system comprising twelve industries and twelve regions indicate that redirection for foreign final output use at home is slightly larger than redirection via final output exports. Redirection via final output exports (type I redirection) is most important in manufacturing while redirection for foreign final output use at home (type II redirection) is especially important for the services industries. Taking both types together, redirection amounted to almost one fifth of global value added exports in the period 2001-2007. We reveal recent developments in global supply chains via an analysis of the developments in trade redirection at the level of end-use industries, covering all redirection of intermediate imports by the last but one country in the chain. We conclude that factory gate exports are a useful concept to characterize the structure of international production networks (as revealed by their hub and spokes relationships), to assess whether a country's trade is relatively upstream or downstream and to measure the value added content of trade.

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

JEL Classification: F1, C67, D57

1 Introduction

The recent literature on trade in value added gives proof that developments in global supply chains can be fruitfully analyzed with global input-output tables. In particular, the work of Baldwin and Lopez-Gonzalez (2013), Daudin et al. (2011), Johnson and Noguera (2012a), Johnson and Noguera (2012b), Koopman et al. (2010), Koopman et al. (2012), Lejour et al. (2012) and Timmer et al. (2012) have raised attention of policy makers and trade analysts. In addition to the WIOD-database a trade in value added (TiVA) database has been established and recently launched at OECD. Yet, there still is quite some uncharted territory in the field of value added trade.

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In this paper we focus on trade redirection, which we define as the reshipment by the last but one country in the chain of value added imports to their final destination. The redirector is either the final producer who sends the imported intermediates as final output exports to the final user (type I redirection) or the country that sends as the last exporter intermediates to the final producer producing for domestic use (type II redirection). Lejour et al. (2012) addressed type I redirection and found that this type amounts to around 10% of global value added exports. This is about half the value of the VS measure of Hummels et al. (2001). In their seminal paper they proposed to use the foreign intermediate content of exports as a measure of vertical specialization. Typically, VS is 20-30% of global gross exports. It is unlikely that redirection of value added exports deviates as much from VS as reported by Lejour et al. (2012). This difference is the main motivation for also addressing type II redirection in this paper.

We completely characterize trade redirection in terms of value added trade in global input-output models making use of the concept of intermediate value added exports up to the production gate of the final producer, factory gate exports for short. Empirical results based on GTAP-data for 2001, 2004 and 2007 for an aggregate system comprising twelve industries and twelve regions indicate that redirection for foreign final output use at home is slightly larger than redirection via final output exports. Redirection via final output exports (type I redirection) is most important in manufacturing while redirection for foreign final output use at home (type II redirection) is especially important for the services industries. Taking both types together, redirection amounted to almost one fifth of global value added exports in the period 2001-2007. We reveal recent developments in global supply chains via an analysis of the developments in trade redirection at the level of end-use industries, covering all redirection of intermediate imports by the last but one country in the chain. The results for manufacturing sectors of end-use are quite in line with the results obtained by Lejour et al. (2012), yielding the same hub and spokes relationships they found. The major deviations are in the outcomes for services sectors of end-use. Type II redirection is especially important in these sectors as there is little trade in services while services industries dominate the domestic economy. Hence, type II redirection is most likely consisting of trade in intermediate goods for the domestic services industry producing for the home market and this trade may be large in view of the size of the services sector. Lejour et al. (2012) found that type I redirection by India for other business services was relatively high. However adding type II redirection for these services makes the position of India as a hub for other business services less prominent (because India is a relatively small exporter of manufactured intermediates to other business services abroad).

The paper is organized as follows. In Section 2 we start with the general concepts and relations needed to measure factory gate exports. We then define our indicators for detecting hubs and spokes in global supply chains. We present our results for redirected value added and our identification of hubs and spokes at the industry level in Section 3. We conclude in Section 4.

2 Extending the framework of analysis to measure factory gate exports

We start with a global input-output table for a world of m regions, indexed with $M = \{1, 2, \dots, m\}$, and n industries, indexed with $N = \{1, 2, \dots, n\}$.

$$\begin{bmatrix}
S_{11} & S_{12} & \cdots & S_{1m} & f_1^1 & f_1^2 & \cdots & f_1^m & x_1 \\
S_{21} & S_{22} & \cdots & S_{2m} & f_2^1 & f_2^2 & \cdots & f_2^m & x_2 \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
S_{m1} & S_{m2} & \cdots & S_{mm} & f_m^1 & f_m^2 & \cdots & f_m^m & x_m \\
p'_1 & p'_2 & \cdots & p'_m & & & & & \\
x'_1 & x'_2 & \cdots & x'_m & & & & &
\end{bmatrix} \quad (1)$$

In this table S_{rs} indicates the intermediate inputs produced in country r that are used in country s , f_r^ρ represents final outputs produced in country r and used in country ρ , p'_s indicates the sum total of primary inputs in production and represents values added in country s and x_r denotes gross output of country r .

We define input coefficients

$$A_{rs}(i, j) = S_{rs}(i, j) / x_s(j) \quad \forall (i, j) \in N; \forall (r, s) \in M \text{ and } v_r(j) = p_r(j) / x_r(j) \quad \forall j \in N; \forall r \in M.$$

and obtain the global Leontief-inverse in partitioned form as

$$\begin{bmatrix}
B_{11} & B_{12} & \cdots & B_{1m} \\
B_{21} & B_{22} & \cdots & B_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
B_{m1} & B_{m2} & \cdots & B_{mm}
\end{bmatrix} = \begin{bmatrix}
I - A_{11} & -A_{12} & \cdots & -A_{1m} \\
-A_{21} & I - A_{22} & \cdots & -A_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
-A_{m1} & -A_{m2} & \cdots & I - A_{mm}
\end{bmatrix}^{-1} = \begin{bmatrix}
\Delta_{11} & -\Delta_{12} & \cdots & -\Delta_{1m} \\
-A_{21} & \Delta_{22} & \cdots & -\Delta_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
-A_{m1} & -\Delta_{m2} & \cdots & \Delta_{mm}
\end{bmatrix}^{-1} \quad (2)$$

The entry $B_{rs}(i, j)$ denotes the gross output from (r, i) that is needed per unit of final output in (s, j) .

In the sequel we use Δ_{rr} to condense notation for $I - A_{rr}$ and we abundantly make use of toggles such as δ_{rs} which is one if $r = s$ and zero otherwise. Moreover, we use the hat-symbol to diagonalise a vector ($\hat{z}$ being a matrix with z on its main diagonal and zeroes elsewhere) and ι for the unit or summation vector.

Consider

$$X_{r\sigma}^\rho = B_{r\sigma} \hat{f}_\sigma^\rho \quad \forall (r, \sigma, \rho) \in M \quad (3)$$

$X_{r\sigma}^\rho(i, j)$ denotes all gross i -output needed from r for the production of final j -output in σ that is used in ρ . Because $\sum_s A_{rs} B_{s\sigma} = B_{r\sigma} - \delta_{r\sigma} I$ we can expand (3) as in

$$X_{r\sigma}^\rho = B_{r\sigma} \hat{f}_\sigma^\rho = \left[\sum_s A_{rs} B_{s\sigma} + \delta_{r\sigma} I \right] \hat{f}_\sigma^\rho = \sum_s [A_{rs} B_{s\sigma} + \delta_{r\sigma} \delta_{s\rho} I] \hat{f}_\sigma^\rho = \sum_s X_{rs\sigma}^\rho \quad \forall (r, \sigma, \rho) \in M \quad (4)$$

in which the component $X_{rs\sigma}^\rho(i, j)$ represents all gross i -output that is sent from r to the direct trading partner s for the production of final j -output in σ that is used in ρ . We look at trade here from a quadrangular perspective: a trading scheme in which we distinguish the origin r , the direct trading partner s , the final output producer σ and the final output user ρ . Alternatively, we may say that we take a look at the supply chain with four actors: the first and second country in the chain, and the last but one and last country in the chain. The longest possible export sequence in our quadrangular

system is $r \rightarrow (1 - \delta_{rs})s \rightarrow (1 - \delta_{s\sigma})\sigma \rightarrow (1 - \delta_{\sigma\rho})\rho$. Shorter sequences are obtained when a given country takes multiple roles at the same time.

We define gross exports as

$$\begin{aligned}\Pi_{rs\sigma}^\rho &= (1 - \delta_{rs})X_{rs\sigma}^\rho = (1 - \delta_{rs})(A_{rs}B_{s\sigma} + \delta_{r\sigma}\delta_{s\rho}I)\hat{f}_\sigma^\rho \\ &= (1 - \delta_{rs})(1 - \delta_{r\sigma})A_{rs}B_{s\sigma}\hat{f}_\sigma^\rho + \delta_{r\sigma}(1 - \delta_{rs})[A_{rs}B_{sr} + \delta_{s\rho}I]\hat{f}_r^\rho \quad \forall (r, s, \sigma, \rho) \in M\end{aligned}\quad (5)$$

According to this definition r exports intermediates to its direct trading partner s for the production of final output abroad when r itself is not the final producer. If r is the final producer it exports the intermediates needed in the partner countries for the production of intermediate imports for its own final output and in addition the final output itself to its direct trading partner ρ .

We note that the value added requirements for gross exports are

$$\nu_r' \Delta_{rr}^{-1} \Pi_{rs\sigma}^\rho = (1 - \delta_{rs})\nu_r' \Delta_{rr}^{-1} A_{rs} B_{s\sigma} \hat{f}_\sigma^\rho + \delta_{r\sigma} \delta_{s\rho} (1 - \delta_{rs}) \nu_r' \Delta_{rr}^{-1} \hat{f}_r^\rho \quad \forall (r, s, \sigma, \rho) \in M \quad (6)$$

These requirements can be interpreted as ‘earnings from exports’ or ‘earnings in exports’ or as ‘value added exports’, which we denote with $\Gamma_{rs\sigma}^\rho$:

$$\Gamma_{rs\sigma}^\rho = \hat{\nu}_r \Delta_{rr}^{-1} \Pi_{rs\sigma}^\rho \quad \forall (r, s, \sigma, \rho) \in M \quad (7)$$

We show in Annex A that (5) and (7) can indeed be interpreted as decompositions of gross and value added exports respectively. From (7) one may derive the well-known result that the value of a given vector of final output equals value added exports from all sources for this final output plus the untraded domestic value added requirements if the final output is both produced and used at home.

$$f_\sigma^\rho = t' \sum_r \sum_s \Gamma_{rs\sigma}^\rho + \delta_{\sigma\rho} \nu_\sigma' \Delta_{\sigma\sigma}^{-1} \hat{f}_\sigma^\rho \quad \forall (\sigma, \rho) \in M \quad (8)$$

One of the implications of this result is that differences in bilateral trade balances in gross trade and value added trade must be entirely due to differences in the balances of intermediate trade.

Turning to trade in intermediates, we define gross intermediate exports as $\tilde{\Pi}_{rs\sigma}^\rho = (1 - \delta_{rs})A_{rs}B_{s\sigma}\hat{f}_\sigma^\rho$ and the corresponding intermediate value added exports as $\tilde{\Gamma}_{rs\sigma}^\rho = \hat{\nu}_r \Delta_{rr}^{-1} \tilde{\Pi}_{rs\sigma}^\rho$. We collect ‘imports in exports’ as

$$t' \sum_s VS_{sr\sigma}^\rho = \underbrace{(1 - \delta_{r\sigma})t' \sum_s \tilde{\Pi}_{sr\sigma}^\rho}_{\text{Imports in exports for foreign final output}} + \underbrace{\delta_{r\sigma}t' \sum_{s \neq r} A_{sr}(B_{rr} - \Delta_{rr}^{-1})\hat{f}_r^\rho}_{\text{Imports in exports for domestic final output}} \quad \forall (r, \sigma, \rho) \in M \quad (9)$$

It can be shown that $t' \sum_s VS_{sr\sigma}^\rho$ is a decomposition of the VS-measure proposed in the seminal HIY

paper and it can be proved (as we show in Annex B) that

$$\begin{aligned}t' \sum_s \tilde{\Pi}_{rs\sigma}^\rho &= t' \sum_s VS_{sr\sigma}^\rho + t' \sum_s \tilde{\Gamma}_{rs\sigma}^\rho \\ t' \sum_s \tilde{\Pi}_{sr\sigma}^\rho &= t' \sum_s VS_{sr\sigma}^\rho + \delta_{r\sigma} \sum_\varphi \sum_s \tilde{\Gamma}_{\varphi sr}^\rho \quad \forall (r, \sigma, \rho) \in M\end{aligned}\quad (10)$$

or: a) the sales value of intermediate exports equals the purchase value of intermediate ‘imports in exports’ plus the earnings from intermediate exports, and b) intermediate imports consist of ‘imports

in exports' plus the value added imports needed for domestic final output production. The equations (10) are illuminating in three ways. First, they explain directly why the trade balance in gross trade equals the trade balance in value added trade: 'imports in exports' simply cancel when we take the difference of intermediate exports and intermediate imports. Second, they show that differences in the bilateral trade balances in gross terms and in value added terms can be fully attributed to differences in the amount of intermediate imports in intermediate exports. From (8) we know that any difference in bilateral trade balances must come from the balances of intermediate trade. Hence, the fact that the bilateral trade deficit of the US with China is substantially lower in value added terms than in gross terms, can be fully explained from the fact that the imports in Chinese intermediate exports to the US exceed the imports in US intermediate exports to China. Third, they illustrate that we are just taking a view here on a single frame of a movie. We see that on the import side we are at the end of the chain because all traded values added needed for final output production at home have been collected from the chain, while on the export side we are at the beginning of the chain sending intermediate exports into the chain.

Lejour et al. (2012) looked at redirection of foreign intermediate value added imports via final output exports by the last but one country of the chain. They ignored the redirection of foreign intermediate value added imports via the exports of intermediates by the last but one country of the chain to the last country in the chain producing final output for final use at home. To identify the latter redirection we must go 'into the chain'.

Recognizing that $(1 - \delta_{s\sigma})B_{s\sigma} = (1 - \delta_{s\sigma}) \sum_{\varphi} A_{s\varphi} B_{\varphi\sigma} = (1 - \delta_{s\sigma}) \Delta_{ss}^{-1} (\sum_{\varphi} (1 - \delta_{s\varphi}) A_{s\varphi} B_{\varphi\sigma})$ we can disaggregate intermediate value added exports going 'into the chain' $t' \sum_r \sum_s (1 - \delta_{s\sigma}) \tilde{\Gamma}_{rs\sigma}^{\rho}$ as follows:

$$\begin{aligned}
t' \sum_r \sum_s (1 - \delta_{s\sigma}) \tilde{\Gamma}_{rs\sigma}^{\rho} &= \underbrace{\sum_r \nu_r' \Delta_{rr}^{-1} \sum_s (1 - \delta_{s\sigma} - \delta_{rs}) A_{rs} \Delta_{ss}^{-1} A_{s\sigma} B_{\sigma\sigma} \hat{f}_{\sigma}^{\rho}}_{\text{To final producer from } s} + \\
&\underbrace{\sum_r \nu_r' \Delta_{rr}^{-1} \sum_s (1 - \delta_{s\sigma} - \delta_{rs}) A_{rs} \Delta_{ss}^{-1} \sum_{s_3} (1 - \delta_{s_3s} - \delta_{s_3\sigma}) A_{s_3s_3} \Delta_{s_3s_3}^{-1} A_{s_3\sigma} B_{\sigma\sigma} \hat{f}_{\sigma}^{\rho}}_{\text{To final producer from } s_3} + \\
&\underbrace{\sum_r \nu_r' \Delta_{rr}^{-1} \sum_s (1 - \delta_{s\sigma} - \delta_{rs}) A_{rs} \Delta_{ss}^{-1} \sum_{s_3} (1 - \delta_{s_3s} - \delta_{s_3\sigma}) A_{s_3s_3} \Delta_{s_3s_3}^{-1} \sum_{s_4} (1 - \delta_{s_4s_3} - \delta_{s_4\sigma}) A_{s_3s_4} \Delta_{s_4s_4}^{-1} A_{s_4\sigma} B_{\sigma\sigma} \hat{f}_{\sigma}^{\rho}}_{\text{To final producer from } s_4} + \\
&\underbrace{\sum_r \nu_r' \Delta_{rr}^{-1} \sum_s (1 - \delta_{s\sigma} - \delta_{rs}) A_{rs} \Delta_{ss}^{-1} \sum_{s_3} (1 - \delta_{s_3s} - \delta_{s_3\sigma}) A_{s_3s_3} \Delta_{s_3s_3}^{-1} \sum_{s_4} (1 - \delta_{s_4s_3} - \delta_{s_4\sigma}) A_{s_3s_4} \Delta_{s_4s_4}^{-1} \sum_{s_5} (1 - \delta_{s_5s_4} - \delta_{s_5\sigma}) A_{s_4s_5} B_{s_5\sigma} \hat{f}_{\sigma}^{\rho}}_{\text{Still in the chain after leaving } s_4} \\
&\forall (\sigma, \rho) \in M
\end{aligned} \tag{11}$$

where we use the subscript s_3 to indicate the third country in the chain, s_4 to indicate the fourth, and so on and so forth. This disaggregation is an infinite process and we stopped it in (11) at the cut-off s_4 where the cut-off is the position in the chain of the last country for which we identify the direct shipments of value added to the final producer.

Our next step is to collect the exports from the chain to the final producer by the last exporter,

say φ , in arrays $Z_{pr\varphi\sigma}^\rho$ where the subscript p indicates the position of φ in its role as the last exporter of intermediate value added. Thus $Z_{pr\varphi\sigma}^\rho$ represents intermediate value added exports from r , delivered by φ in its p^{th} position in the chain to final producer σ for final user ρ in industry of end-use j . We derive

$$Z_{1\varphi\sigma}^\rho = (1 - \delta_{\varphi\sigma}) \hat{v}_\varphi \Delta_{\varphi\varphi}^{-1} A_{\varphi\sigma} B_{\sigma\sigma} \hat{f}_\sigma^\rho$$

$$Z_{2r\varphi\sigma}^\rho = (1 - \delta_{\varphi\sigma}) \sum_r (1 - \delta_{r\varphi}) \hat{v}_r \Delta_{rr}^{-1} A_{r\varphi} \Delta_{\varphi\varphi}^{-1} A_{\varphi\sigma} B_{\sigma\sigma} \hat{f}_\sigma^\rho$$

$$Z_{3r\varphi\sigma}^\rho = (1 - \delta_{\varphi\sigma}) \sum_r \hat{v}_r \Delta_{rr}^{-1} \sum_s (1 - \delta_{s\sigma} - \delta_{s\varphi} - \delta_{rs}) A_{rs} \Delta_{ss}^{-1} A_{s\varphi} \Delta_{\varphi\varphi}^{-1} A_{\varphi\sigma} B_{\sigma\sigma} \hat{f}_\sigma^\rho$$

and

$$Z_{4r\varphi\sigma}^\rho = (1 - \delta_{\varphi\sigma}) \sum_r \hat{v}_r \Delta_{rr}^{-1} \sum_s (1 - \delta_{s\sigma} - \delta_{rs}) A_{rs} \Delta_{ss}^{-1} \sum_{s_3} (1 - \delta_{s_3s} - \delta_{s_3\sigma} - \delta_{s_3\varphi}) A_{s_3s} \Delta_{s_3s_3}^{-1} A_{s_3\varphi} \Delta_{\varphi\varphi}^{-1} A_{\varphi\sigma} B_{\sigma\sigma} \hat{f}_\sigma^\rho$$

and so on, etc., up to the cut-off position p_c . Thus we obtain factory gate exports as

$$Z_{r\varphi\sigma}^\rho = \sum_{p=1}^{p_c} Z_{pr\varphi\sigma}^\rho \quad (12)$$

In Figures 1 through 3 we show the structure of all $Z_{r\varphi\sigma}^\rho$ taken together in a world with three countries for total final output use (i.e. we sum each $Z_{r\varphi\sigma}^\rho$ over rows and columns and arrange them in a 4-dimensional array).

Figure 1 Factory gate exports for total final end-use

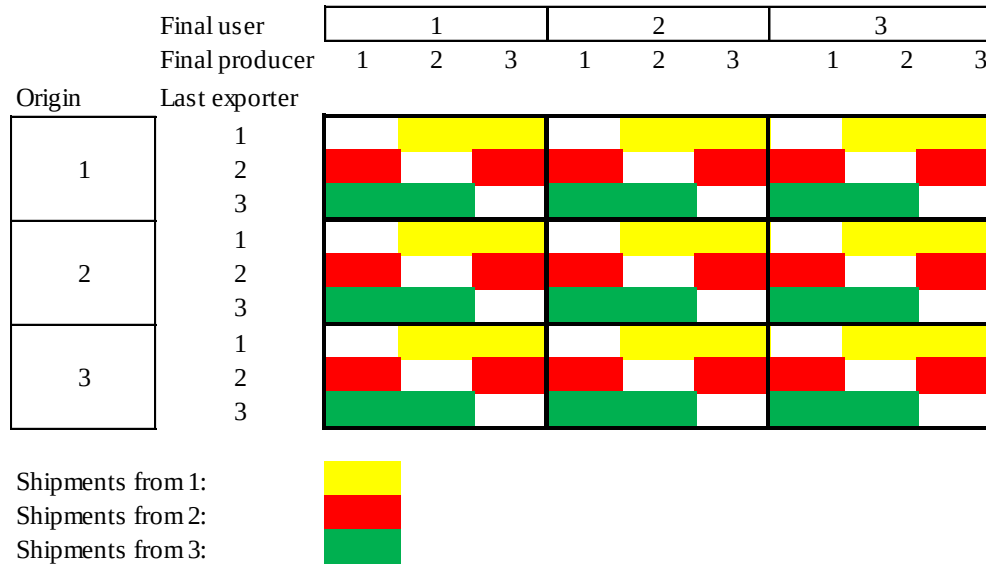
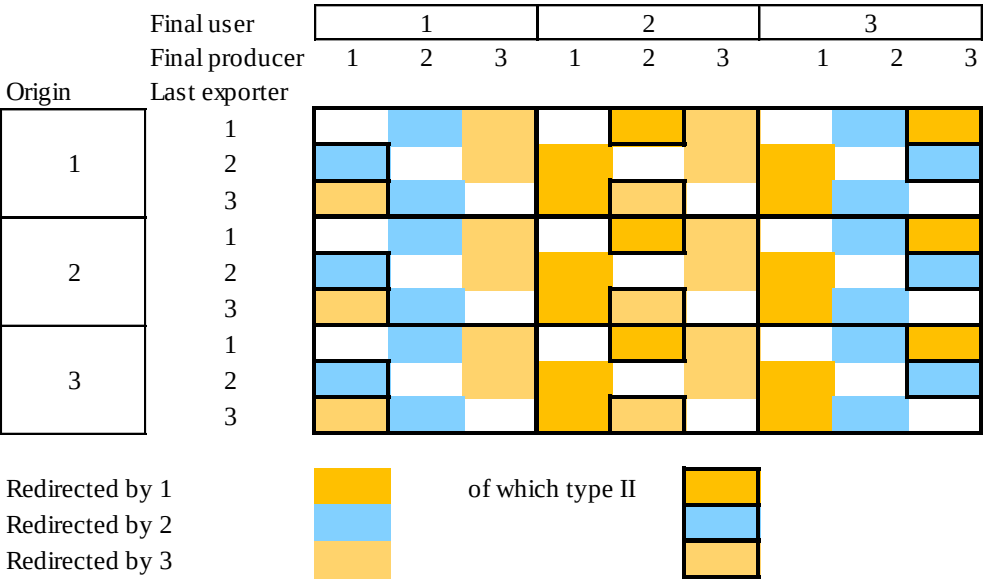


Figure 1 shows that a) the last exporter does not export own value added to itself as a final producer; b) as a final producer the last exporter does import own value added; this is the value added that was needed abroad to produce the intermediate imports of the final producer; c) the last exporter exports bundles of values added from all sources to foreign final producers. Figure 2 shows how we can derive redirected values added from the factory gate exports. Type I redirection is obtained as the sum

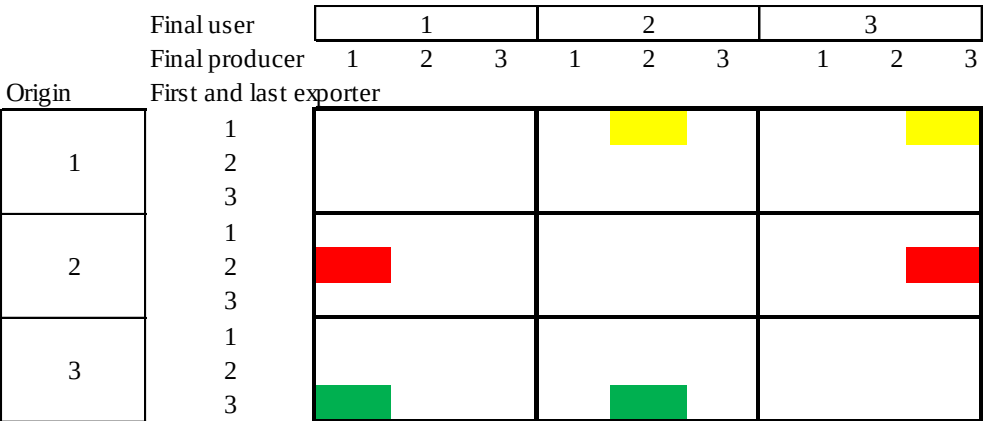
total of value added imports over all sources and last exporters into the final producer producing for foreign users. To determine Type 1 redirection we also need Figure 3 which shows the factory gate exports that are not redirected because they were sent by the last exporter directly to the final producer producing output for own use.

Figure 2 Redirection for total final end-use



Type II redirection is obtained as the sum total of value added exports by the last exporter over all sources and over all final producers producing for domestic use, except the exports that were sent directly to the final producer.

Figure 3 Factory gate exports that are not redirected



3 Hub and spokes indicators based on factory gate exports

Using type I redirection Lejour et al. proposed two pairs of indicators for the measurement of hub and spoke relationships. The first pair of indicators measures the intensity and market share of outgoing redirection. We redefine these in terms of Z as

$$\begin{aligned}
 SFRV_{\sigma}^I(j) &= \frac{t' \sum_r \sum_{\rho} \sum_{\varphi} (1 - \delta_{r\sigma} - \delta_{\sigma\rho}) Z_{r\varphi\sigma}^{\rho}}{t' \sum_r \sum_{\rho} \sum_{\varphi} Z_{r\varphi\sigma}^{\rho}} \\
 GSFRV_{\sigma}^I(j) &= \frac{t' \sum_r \sum_{\rho} \sum_{\varphi} (1 - \delta_{r\sigma} - \delta_{\sigma\rho}) Z_{r\varphi\sigma}^{\rho}}{t' \sum_r \sum_{\rho} \sum_{\varphi} \sum_{\sigma} (1 - \delta_{r\sigma} - \delta_{\sigma\rho}) Z_{r\varphi\sigma}^{\rho}} \quad \forall \sigma \in M, j \in N
 \end{aligned} \tag{13}$$

The second pair of indicators measures type I redirection intensity and market share of value added exports from the source:

$$\begin{aligned}
 SDRV_r^I(j) &= \frac{t' \sum_{\sigma} \sum_{\rho} \sum_{\varphi} (1 - \delta_{r\sigma} - \delta_{\sigma\rho}) Z_{r\varphi\sigma}^{\rho}}{t' \sum_{\sigma} \sum_{\rho} \sum_{\varphi} Z_{r\varphi\sigma}^{\rho}} \\
 GSDRV_r^I(j) &= \frac{t' \sum_{\sigma} \sum_{\rho} \sum_{\varphi} (1 - \delta_{r\sigma} - \delta_{\sigma\rho}) Z_{r\varphi\sigma}^{\rho}}{t' \sum_s \sum_{\rho} \sum_{\varphi} \sum_{\sigma} (1 - \delta_{s\sigma} - \delta_{\sigma\rho}) Z_{s\varphi\sigma}^{\rho}} \quad \forall \sigma \in M, j \in N
 \end{aligned} \tag{14}$$

Restricting factory gate exports to redirected factor gate exports with $\tilde{Z}_{r\varphi\sigma}^{\rho} = \sum_{p=2}^{p_c} \tilde{Z}_{pr\varphi\sigma}^{\rho}$, we can in essentially the same way define these pairs of indicators for type II redirection:

$$\begin{aligned}
 SFRV_{\varphi}^{II}(j) &= \frac{t' \sum_r \sum_{\sigma} (1 - \delta_{r\sigma}) \tilde{Z}_{r\varphi\sigma}^{\sigma}}{t' \sum_r \sum_{\rho} \sum_{\sigma} (1 - \delta_{r\sigma}) \tilde{Z}_{r\varphi\sigma}^{\rho}} \\
 GSFRV_{\varphi}^{II}(j) &= \frac{t' \sum_r \sum_{\sigma} (1 - \delta_{r\sigma}) \tilde{Z}_{r\varphi\sigma}^{\sigma}}{t' \sum_r \sum_{\sigma} \sum_s (1 - \delta_{r\sigma}) \tilde{Z}_{rs\sigma}^{\sigma}} \quad \forall \sigma \in M, j \in N
 \end{aligned} \tag{15}$$

and

$$\begin{aligned}
 SDRV_r^{II}(j) &= \frac{t' \sum_{\sigma} \sum_{\varphi} (1 - \delta_{r\sigma}) \tilde{Z}_{r\varphi\sigma}^{\sigma}}{t' \sum_{\sigma} \sum_{\rho} \sum_{\varphi} (1 - \delta_{r\sigma}) \tilde{Z}_{r\varphi\sigma}^{\rho}} \\
 GSDRV_r^{II}(j) &= \frac{t' \sum_{\sigma} \sum_{\varphi} (1 - \delta_{r\sigma}) \tilde{Z}_{r\varphi\sigma}^{\sigma}}{t' \sum_s \sum_{\sigma} \sum_{\varphi} (1 - \delta_{s\sigma}) \tilde{Z}_{s\varphi\sigma}^{\sigma}} \quad \forall \sigma \in M, j \in N
 \end{aligned} \tag{16}$$

Finally we note that we can use the concept of factory gate exports to define the value added composition of gross exports as in

$$vcx_{rs} = t' \sum_{\sigma} Z_{rs\sigma}^{\sigma} + t' \sum_{\sigma} \sum_{\rho} (1 - \delta_{s\rho}) Z_{r\rho s}^{\rho} + \delta_{rs} \sum_{\rho} (1 - \delta_{s\rho}) v_s' \Delta_{ss}^{-1} \hat{f}_s^{\rho} \quad (17)$$

4 Empirical results

The global input-output tables that we derived from the GTAP datasets for 2001, 2004 and 2007 show input-output linkages for 57 industries and 84 countries or regions common to all years. Because of the computational burden of calculating factory gate exports we aggregated them into a classification with 12 regions and 12 aggregate industries (see Annex C for their description). The rate of decay in the chain turned out to be around 6.7. We chose the fourth position in the chain as the cut-off after which only 0.1 percent of the input in the chain was on average still travelling in the chain.

Figure 4 Redirection as a % of value added exports, 2001-2007

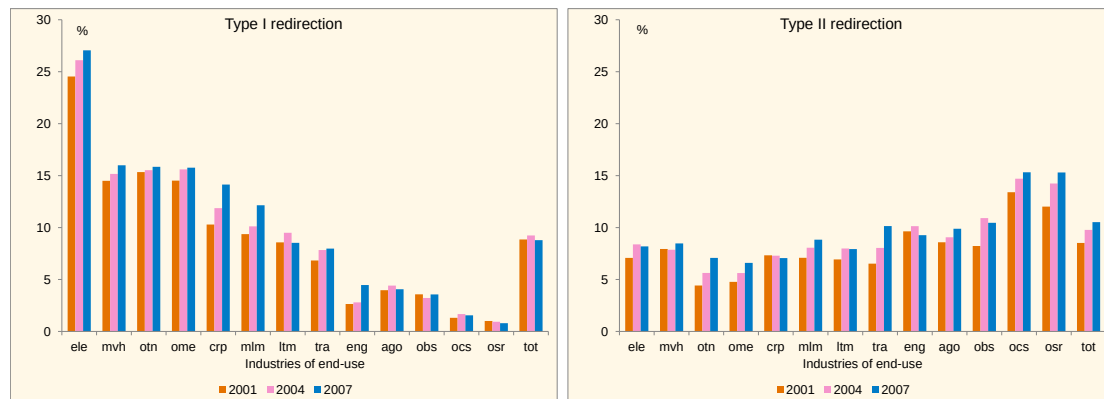


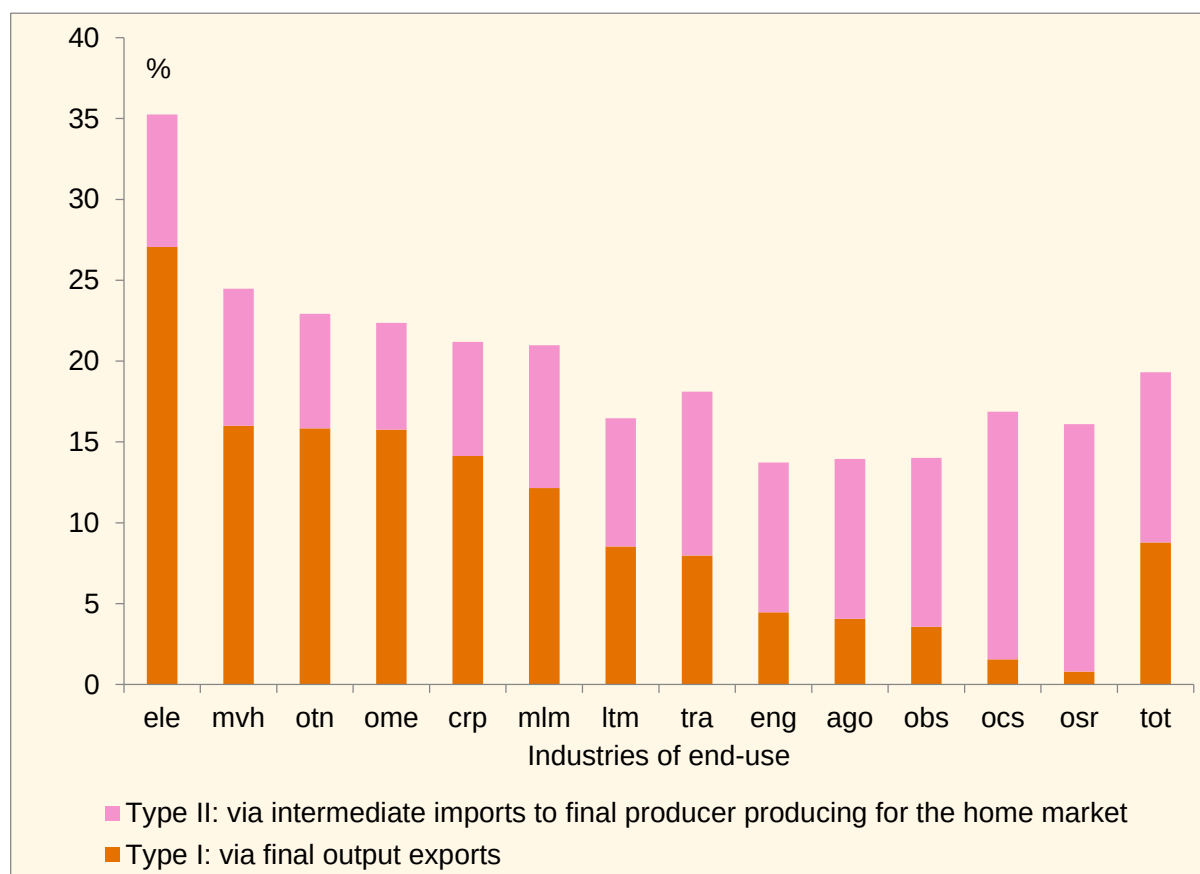
Table 1 shows that type I plus type redirection amounts to almost one fifth of global value added exports. Thus the addition of type II redirection brings relative redirection quite close to the VS-measure.

Table 1 Composition of global value added exports

	2001	2004	2007
Own value added in own final output exports	38	36	33
Factory gate exports	62	64	67
Direct for own final output use	45	45	48
Direct for final output exports (type I)	7	7	7
Redirected for own final output use (type II)	9	10	11
Redirected for final output exports (type I)	2	2	2
Total redirection	17	19	19
Total	100	100	100

At the industry level it is clear that type I redirection is relatively more important for manufacturing industries of end-use while type II redirection is most important for the services sectors of end-use and for agriculture and energy (figures 4 and 5).

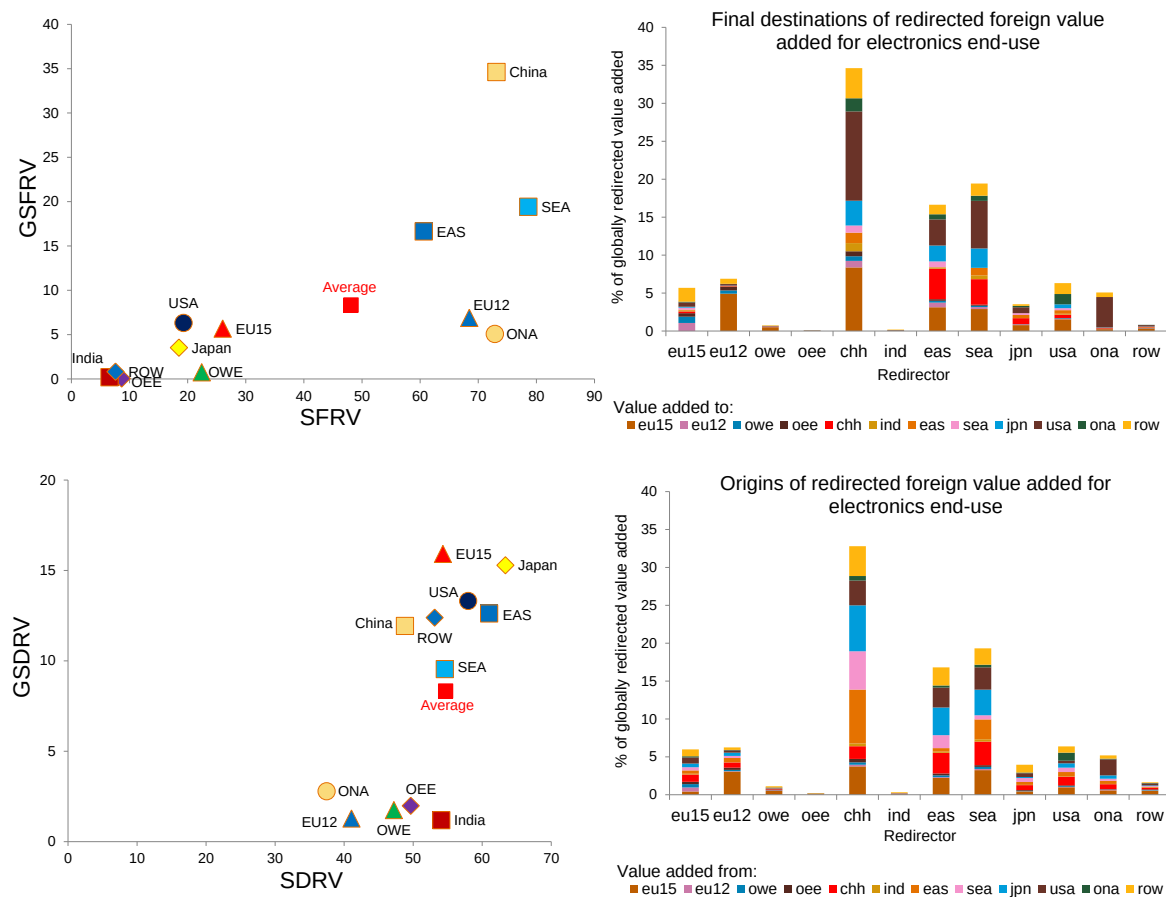
Figure 5 Type I and Type II redirection as a % of value added exports, 2007



Comparing the hubs and spokes relationships for particular industries of end-use with the ‘type I redirection only’ results of Lejour et al. (2012) we find quite similar patterns for total redirection (type I plus type II). In particular, for the electronic equipment industry (ELE) we find that China is the most important hub, with around a third of globally redirected value added and also with a large redirection intensity (with SFRV close to 75%). Then South-East Asia (SEA) and East-Asia (EAS) follow in order of importance. About 70 percent of all redirected value added in electronic equipment takes place in Asia. All three Asian hubs are global hubs, since their final destinations are more or less evenly spread over all regions of the world. However, the three Asian regions are using value added in intermediate inputs mainly from the other Asian regions. The new EU member states (EU12) and other NAFTA (ONA) are regional hubs, with their redirected trade going mainly to the old EU member states (EU15) plus and the USA, respectively. From the supply side, we find that EU15, Japan, USA and EAS are the main global spokes in this industry. These regions supply much of the value added which is redirected mainly by Asian countries –in particular China– but also by EU12 and ONA.

Also for other machinery and equipment (OME) the results are quite similar. From Figure 7 we observe that EU15 and China redirect much of the foreign value added in this sector, with each region redirecting between 15 and 20% of global redirected value added. Thus, we define both regions as the main global hubs in machinery and equipment. In addition, regions such as ONA, EU12, EAS, SEA, Other Western Europe (OWE) and Japan are also hubs in this sector. We find again that ONA and EU12 are regional hubs, strongly linked to the USA and EU15, respectively. In addition OWE is a regional hub as well, supplying to and sourcing from EU15 mainly. The Asian regions (EAS, SEA,

Figure 6 Total redirection for electronics end-use



Japan, China) are global hubs. On the other hand, India and Other Eastern Europe (OEE; mainly Russia) are not integrated into the global supply chain of OME, but Rest of World (ROW) does show up as an important supply spoke for intermediate inputs. The USA is important both as a supply spoke and as a final destination.

The major differences in results from this paper and from Lejour et al. (2012) are in the services industries. In other business services (OBS) for instance, Lejour et al (2012) identified India and SEA as the most important hubs. However, if we add type II redirection most regions gain in importance relative to India (Figure 8). The reason for this is that India is not an important provider of type II redirection here. This redirection presumably involves mainly the supply of manufactured goods to the domestic OBS sector and India is not an importer exporter of manufactured goods.

In Figure 9 we use the composition of factory gate exports to identify the relative up- or downstream-ness of these exports. The figure shows that total factory gate exports are relatively upstream for China, Japan, EU15, EU12 and the USA and relatively downstream for OEE and ROW.

Finally, in Figure 10 we present the value added composition of gross exports (according to equation (17)). The dominance of the share of domestic value added is striking for all regions. In particular, OEE and India show up again as being almost unconnected.

Figure 7 Total redirection for other machinery equipment end-use

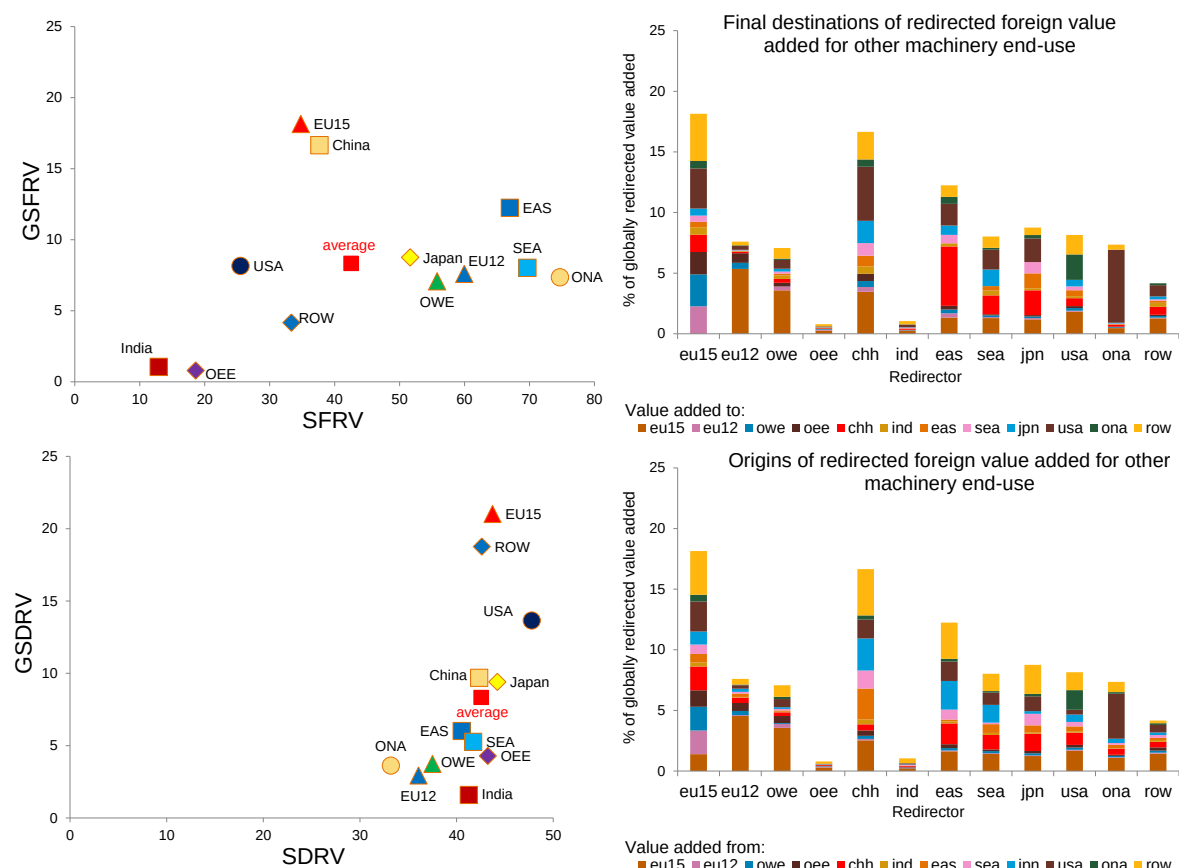


Figure 8 Type I and type I+II redirection for other business services

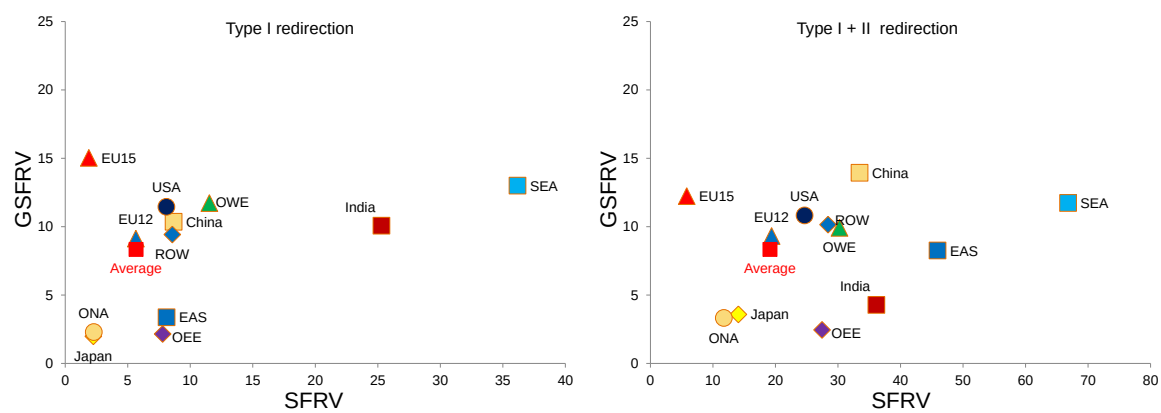


Figure 9 Downstream and upstream decomposition of factory gate exports, 2007

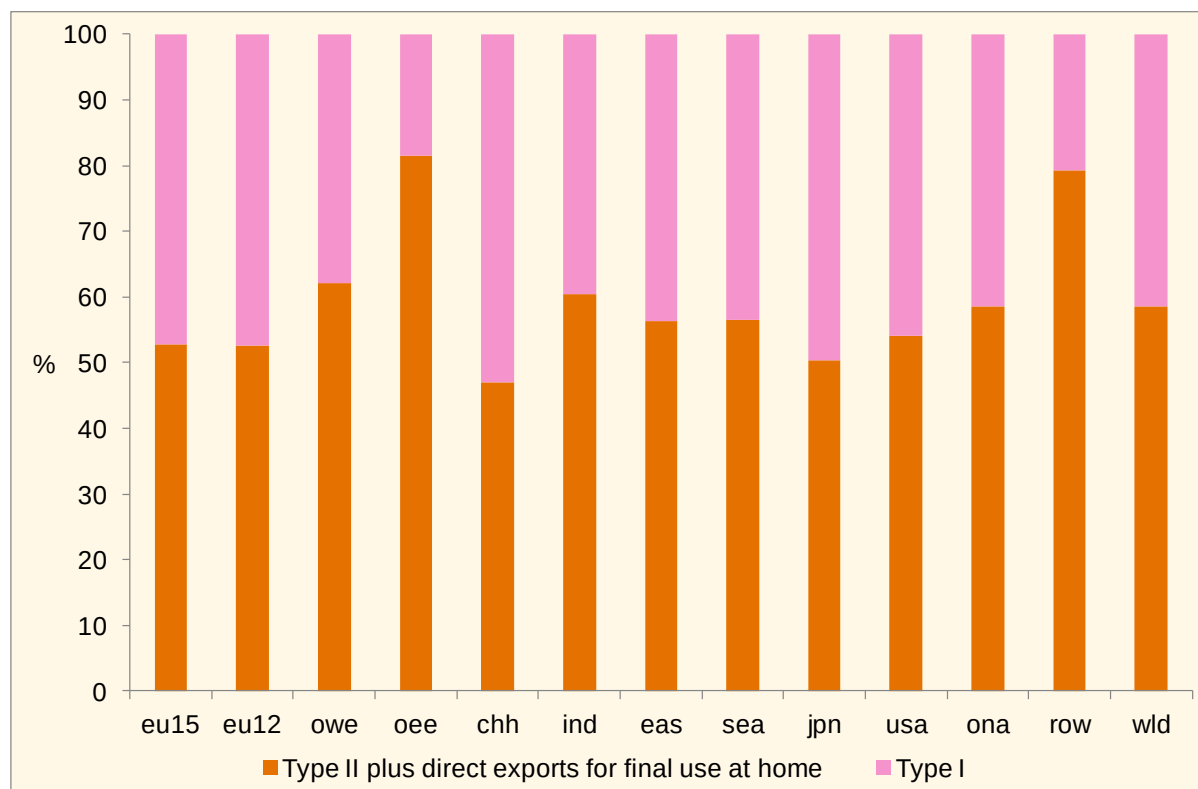
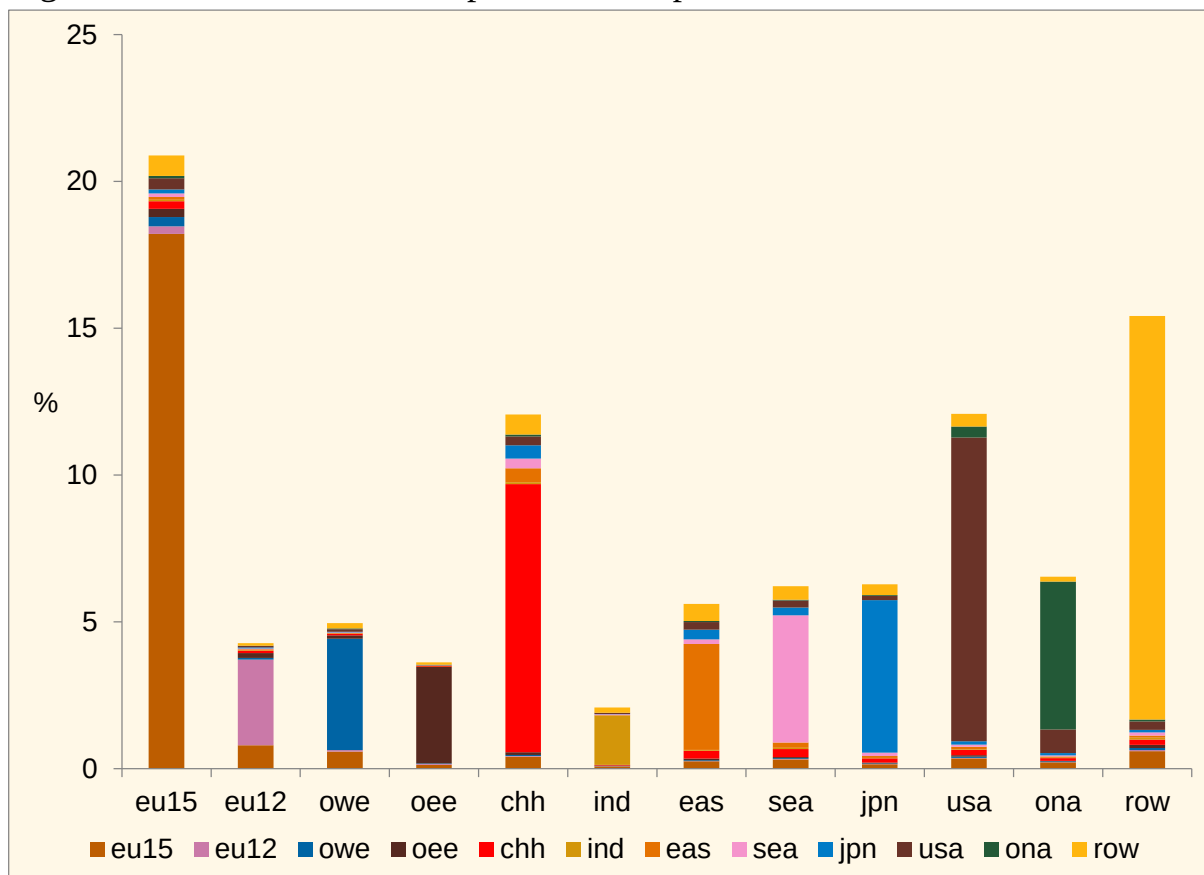


Figure 10 Value added composition of exports



5 Conclusions

This paper extends the analysis of Lejour et al. (2012) by also covering trade redirection by the last but one country in the chain to final producers producing for the home market (type II redirection). This addition more than doubles redirected exports as a percentage of value added exports and brings the sum total close to 20%. The results on hubs and spokes relationships are not very different though: it is the volume that increases rather than the relationships. The introduction of type II redirection improves the hubs and spokes relationships for the services sectors, and especially for these sectors the changes compared to Lejour et al (2012) are largest.

In order to measure type II redirection we introduced the concept of factory gate exports. We conclude that this turns out to be useful concept a) to characterize the structure of international production networks (as revealed by their hubs and spokes relationships), b) to assess whether a country's trade is relatively upstream or downstream and c) to measure the value added content of trade.

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Annex A Verifying gross and value added exports

That (5) is indeed a proper decomposition of total gross exports follows from:

$$\sum_s \sum_\sigma \sum_\rho \Pi_{rs\sigma}^\rho t = \sum_{s \neq r} (S_{rs} t + f_r^s) \quad \forall r \in M \quad (18)$$

From (7) we obtain for total value added exports

$$\begin{aligned} \sum_\rho \sum_\sigma \sum_s \Gamma_{rs\sigma}^\rho t &= \sum_\rho \sum_\sigma \sum_s \hat{v}_r \Delta_{rr}^{-1} \Pi_{rs\sigma}^\rho t = \sum_\rho \sum_\sigma \hat{v}_r \{ (B_{r\sigma} - \delta_{r\sigma} \Delta_{rr}^{-1}) f_\sigma^\rho + \delta_{r\sigma} (1 - \delta_{r\rho}) \Delta_{rr}^{-1} f_r^\rho \} \\ &= \sum_\rho \sum_\sigma \hat{v}_r B_{r\sigma} f_\sigma^\rho - \hat{v}_r \Delta_{rr}^{-1} f_r^r \quad \forall r \in M \end{aligned} \quad (19)$$

This total exceeds the amount of value added exports that are usually obtained within a triangular framework consisting of the first and the last but one and last country of the chain. Within such a framework it is often assumed that value added exports $\sum_s \Gamma_{rsr}^r$ are zero and hence that total value

added exports amount to $\sum_\rho \sum_\sigma \hat{v}_r B_{r\sigma} f_\sigma^\rho - v_r' B_{rr} f_r^r$. Thus the excess of (19) equals

$$v_r' (B_{rr} - \Delta_{rr}^{-1}) f_r^r = v_r' \Delta_{rr}^{-1} \sum_{s \neq r} A_{rs} B_{sr} f_r^r \quad (20)$$

which is the sum total of the value added exports from r for its own use of domestic final output. Thus we conclude that (7) is indeed a proper decomposition of total value added exports (and actually an improvement of the value added exports that is often obtained within a triangular framework).

Annex B Gross intermediate trade and intermediate value added trade

Let us define gross intermediate exports as $\tilde{\Pi}_{rs\sigma}^\rho = (1 - \delta_{rs})A_{rs}B_{s\sigma}\hat{f}_\sigma^\rho$ and the corresponding intermediate value added exports as $\tilde{\Gamma}_{rs\sigma}^\rho = \hat{v}_r\Delta_{rr}^{-1}\tilde{\Pi}_{rs\sigma}^\rho$.

We consider two cases for intermediate exports:

$$\begin{aligned}
 (1 - \delta_{r\sigma})t' \sum_s \Pi_{rs\sigma}^\rho &= (1 - \delta_{r\sigma})t' \sum_s (1 - \delta_{rs})A_{rs}B_{s\sigma}\hat{f}_\sigma^\rho \\
 &= (1 - \delta_{r\sigma})t' \Delta_{rr} B_{r\sigma} \hat{f}_\sigma^\rho = (1 - \delta_{r\sigma})t' \left(\sum_{\varphi \neq r} A_{\varphi r} + \hat{v}_r \right) B_{r\sigma} \hat{f}_\sigma^\rho \\
 &= (1 - \delta_{r\sigma})t' \sum_{\varphi} \Pi_{\varphi r\sigma}^\rho + (1 - \delta_{r\sigma})\hat{v}_r' \Delta_{rr}^{-1} \sum_{\varphi \neq r} A_{r\varphi} B_{\varphi\sigma} \hat{f}_\sigma^\rho \\
 &= (1 - \delta_{r\sigma})t' \sum_{\varphi} \Pi_{\varphi r\sigma}^\rho + (1 - \delta_{r\sigma})t' \sum_s \tilde{\Gamma}_{rs\sigma}^\rho \quad \forall (r, \sigma, \rho) \in M : r \neq \sigma
 \end{aligned} \tag{21}$$

and

$$\begin{aligned}
 \delta_{r\sigma}t' \sum_s \tilde{\Pi}_{rsr}^\rho &= \delta_{r\sigma}t' \sum_s (1 - \delta_{rs})A_{rs}B_{sr}\hat{f}_r^\rho \\
 &= \delta_{r\sigma}t' (\Delta_{rr} B_{rr} - I) \hat{f}_r^\rho = \delta_{r\sigma}t' \left(\sum_{\varphi \neq r} A_{\varphi r} + \hat{v}_r \right) (B_{rr} - \Delta_{rr}^{-1}) \hat{f}_r^\rho \\
 &= \delta_{r\sigma}t' \sum_{\varphi \neq r} A_{\varphi r} (B_{rr} - \Delta_{rr}^{-1}) \hat{f}_r^\rho + \delta_{r\sigma}\hat{v}_r' (\Delta_{rr}^{-1} \left(\sum_{\varphi \neq r} A_{r\varphi} B_{\varphi r} + I \right) - \Delta_{rr}^{-1}) \hat{f}_r^\rho \\
 &= \delta_{r\sigma}t' \sum_{\varphi \neq r} A_{\varphi r} (B_{rr} - \Delta_{rr}^{-1}) \hat{f}_r^\rho + \delta_{r\sigma}\hat{v}_r' \Delta_{rr}^{-1} \sum_{\varphi \neq r} A_{r\varphi} B_{\varphi r} \hat{f}_r^\rho \\
 &= \delta_{r\sigma}t' \sum_{\varphi \neq r} A_{\varphi r} (B_{rr} - \Delta_{rr}^{-1}) \hat{f}_r^\rho + \delta_{r\sigma}t' \sum_s \tilde{\Gamma}_{rsr}^\rho \quad \forall (r, \rho) \in M
 \end{aligned} \tag{22}$$

Collecting ‘imports in exports’ as

$$t' \sum_s VS_{sr\sigma}^\rho = \underbrace{(1 - \delta_{r\sigma})t' \sum_s \tilde{\Pi}_{sr\sigma}^\rho}_{\text{Imports in exports for foreign final output}} + \underbrace{\delta_{r\sigma}t' \sum_{s \neq r} A_{sr} (B_{rr} - \Delta_{rr}^{-1}) \hat{f}_r^\rho}_{\text{Imports in exports for domestic final output}} \quad \forall (r, \sigma, \rho) \in M \tag{23}$$

we obtain

$$t' \sum_s \tilde{\Pi}_{rs\sigma}^\rho = t' \sum_s VS_{sr\sigma}^\rho + t' \sum_s \tilde{\Gamma}_{rs\sigma}^\rho \quad \forall (r, \sigma, \rho) \in M \tag{24}$$

For the imports we consider again two cases:

$$(1 - \delta_{r\sigma})t' \sum_s \tilde{\Pi}_{sr\sigma}^\rho = (1 - \delta_{r\sigma})t' \sum_{s \neq r} A_{sr} B_{r\sigma} \hat{f}_\sigma^\rho = (1 - \delta_{r\sigma})t' \sum_s VS_{sr\sigma}^\rho \quad \forall (r, \sigma, \rho) \in M : r \neq \sigma \tag{25}$$

and

$$\begin{aligned}
\delta_{r\sigma} \iota' \sum_s \tilde{\Pi}_{srr}^\rho &= \delta_{r\sigma} \iota' \sum_{s \neq r} A_{sr} B_{rr} \hat{f}_r^\rho \\
&= \delta_{r\sigma} \iota' \sum_{s \neq r} A_{sr} (B_{rr} - \Delta_{rr}^{-1}) \hat{f}_r^\rho + \delta_{r\sigma} \iota' \sum_{s \neq r} A_{sr} \Delta_{rr}^{-1} \hat{f}_r^\rho \\
&= \delta_{r\sigma} \iota' \sum_s V S_{srr}^\rho + \delta_{r\sigma} \iota' (\Delta_{rr} - \hat{\nu}_r) \Delta_{rr}^{-1} \hat{f}_r^\rho \quad (26) \\
&= \delta_{r\sigma} \iota' \sum_s V S_{srr}^\rho + \delta_{r\sigma} f_r'^\rho - \delta_{r\sigma} \nu_r' \Delta_{rr}^{-1} \hat{f}_r^\rho \\
&= \delta_{r\sigma} \iota' \sum_s V S_{srr}^\rho + \delta_{r\sigma} \iota' \sum_\varphi \sum_s \tilde{\Gamma}_{\varphi sr}^\rho \quad \forall (r, \rho) \in M
\end{aligned}$$

Thus we obtain for the import equation:

$$\iota' \sum_s \tilde{\Pi}_{sr\sigma}^\rho = \iota' \sum_s V S_{sr\sigma}^\rho + \delta_{r\sigma} \sum_\varphi \sum_s \tilde{\Gamma}_{\varphi sr}^\rho \quad \forall (r, \sigma, \rho) \in M \quad (27)$$

Annex C Industry and country classifications

Regional aggregates

Code:	Description:	Countries or 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

Sectoral aggregates

Code: Description:

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