Trade Redirection in Global Supply Chains

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Abstract

In global input-output models the global Leontief inverse links value added from a given source to the final sinks (where both sources and sinks are country-industry pairs). Rising globalization has raised the complexity of cross-border linkages between sources and sinks. In the literature on trade in value added the processes operating beyond the global Leontief inverse are either not described at all or decomposed in a way that is not very illuminating. The paper tries to clarify how value added embodied in gross trade reaches its final destination by decomposing gross trade into imports in exports and value added trade. The process of value added accumulation from the source towards the sink can be considered to consist of three different stages: from the source to the final output factory gate (via trade in intermediates), at the final output factory (in final output production) and at the sale of final output to foreign customers (via international transport). Redirected trade in value added is defined as the re-export of imported value added by the country that is the last exporter in all chains that lead to the final sink. For each specific industry of final output the importance of trade redirection can be established for both the sources, the last exporters in all chains and the sinks of final output from the industry at hand. Thus I aim to show that the concept of redirected trade is a useful indicator for globalization patterns.

The framework developed in the paper has useful applications. I include as an example: the identification of the major hubs, their major suppliers and their major customers in the global supply chains for final output of electronics, using the global input-output tables from the WIOD-database for the period 1995-2011.

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

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1 Introduction

The recent literature on trade in value added gives proof that developments in global supply chains can be fruitfully analysed with global input-output tables. In particular, the work of Baldwin and Lopez-Gonzalez (2013), Daudin et al. (2011), Johnson (2014), Johnson and Noguera (2012a), Johnson and Noguera (2012b), Koopman *et al.* (2010), Koopman *et al.* (2014), Lejour *et al.* (2014) , Timmer *et al.* (2013) and Timmer *et al.* (2014) 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 launched at OECD. Yet, there still is quite some uncharted territory in the field of value added trade.

In this paper I focus on redirection of trade in value added, which is defined as the re-export of imported value added by the country that is the last exporter in all chains that lead to the final sink. The redirector is either the final producer who sends the value added in imported intermediates as final output exports to the final user or the producer of intermediates who is the last exporter in all chains supplying value added to final producers producing for domestic use. Lejour *et al.* (2014) addressed redirection via final output exports and found that around 10% of global value added exports are thus redirected. 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.* (2014). This difference is the main motivation to add in this paper the redirection of value added imports to final output producers producing for the home market.

I completely characterize the relationship between gross and value added trade in global input-output models making use of the concept of intermediate exports up to the production gate of the final producer, ‘factory gate imports’ for short. Thus I clarify how value added embodied in gross trade reaches its final destination. The process of value added accumulation from the source towards the sink can be considered to occur in three different stages: from the source to the final output factory gate (via trade in intermediates), at the final output factory (in final output production) and at the sale of final output to foreign customers (via international transport). This accounting framework provides a firm background for the precise definition of trade redirection and for comments on some of the early, pioneering studies in the field of trade in value added. I analyse trade redirection for the global supply chains for electronics final output, using global input-output tables from the WIOD-database for the period 1995-2011.

The paper is organized as follows. In Section 2 I explain the relationships between gross and value added trade add define the role of trade direction. In Section 3 I briefly comment on some of the early, pioneering studies on trade in value added. Results from the trade redirection analysis are presented for the electronics industry in Section 4. Section 5 concludes.

2 Value added accumulation from the source to the sink and the role of trade redirection

Global input-output arithmetic

Starting point for the analysis is a global input-output table for a world of m regions, indexed by $M=\{1,2,\cdots,m\}$, producing output in n industries, indexed with $N=\{1,2,\cdots n\}$. In addition to the producing regions an international trading services market is distinguished and denoted with subscript int . Producers of these services export to this market and users of these services import from this market. This set-up reflects the fact that in general it is unknown who is taking care of international trading margins: the exporter, the importer or a third party. In global input-output tables trade flows are recorded against fob prices. The international trading services market provides the cif margin[2].

The structure of the global input-output table is as follows:

$$\begin{bmatrix} Z & F & x \\ w' & & \\ x' & & \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1m} & Z_{1\text{int}} & f_1^1 & f_1^2 & \cdots & f_1^m & x_1 \\ Z_{21} & Z_{22} & \cdots & Z_{2m} & Z_{2\text{int}} & f_2^1 & f_2^2 & \cdots & f_2^m & x_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ Z_{m1} & Z_{m2} & \cdots & Z_{mm} & Z_{m\text{int}} & f_m^1 & f_m^2 & \cdots & f_m^m & x_m \\ Z_{\text{int}1} & Z_{\text{int}2} & \cdots & Z_{\text{int}m} & 0 & f_{\text{int}}^1 & f_{\text{int}}^2 & \cdots & f_{\text{int}}^m & x_{\text{int}} \\ w_1' & w_2' & \cdots & w_m' & 0' & & & & & \\ x_1' & x_2' & \cdots & x_m' & x_{\text{int}}' & & & & & \end{bmatrix} \tag{2.1}$$

Z is an $(m+1)n\times(m+1)n$ matrix of intermediate input deliveries, F an $(m+1)n\times m$ matrix of final output deliveries, x a vector of length $(m+1)n$ with total gross output deliveries (the sum total of intermediate and final output deliveries), w' an $(m+1)n$ row vector with value added inputs of the producing regions and zeroes for the international trading services market, x' the row vector of length $(m+1)n$ with gross input deliveries (the sum total of intermediate input and value added input deliveries). It is convenient to decompose these huge arrays on a regional basis. I first explain the meaning of the entries in the table of the producing regions, assuming $r,s\in M$. Then $z_{rs}(i,j)$, which is an entry in Z_{rs}, denotes the intermediate input delivery from the country-industry pair (r,i) to the country-industry pair (s,j)). Similarly, $f_r^s(i)$ indicates final output produced in (r,i) that is finally used in region s, $x_r(i)$ gives total output from (r,i), $w_s(j)$ denotes the value added input that is used by (s,j) and $x_s(j)$ shows the sum total of all inputs used by (s,j). Next, I turn to the entries in the table when r or s refer to the market for international trading services int . Then $z_{r\,\text{int}}(i,i)$ denotes the intermediate input supply from (r,i) to the same industry in the international trading services market and $z_{s\,\text{int}}(i,j)$ indicates the import demand (s,j) for these services (that is, it covers the cif-margin for the international trading services from industry i on all the intermediate imports of (s,j)).

[2] This market can be constructed from the GTAP-datasets. Hence, the primary inputs that are present in the GTAP global input-output tables add-up to value added, which makes these tables most appropriate for an analysis of the relationships between gross and value added trade. In the WIOD-tables international trading margins appear – somewhat inappropriately – as a primary input. Hence, in the WIOD-tables not all primary inputs add-up to value added and international trade margins remain a separate input.

Similarly, $f_{\text{int}}^{s}(i)$ indicates this margin on the imports by region s of final output produced in industries i, $x_{\text{int}}(i)$ gives total import margin demands for services from industries i, $w_{\text{int}}(j)$ is zero $\forall j \in N$ and $x_{\text{int}}(j)$ shows the sum total of supplies of international trading services from industries j.

The global input-output table is characterized by two adding up conditions: for gross output deliveries

$$x_r(i) = \sum_s \sum_j z_{rs}(i,j) + \sum_s f_r^s(i) \tag{2.2}$$

and for gross input deliveries

$$x_s(j) = \sum_r \sum_i z_{rs}(i,j) + w_s(j) \tag{2.3}$$

From these adding up conditions the powerful concepts of Leontief-inverses have been derived. Before turning to these it is convenient to introduce some extra notation and to indicate the parts of Z and F that are not traded internationally but remain at home with $\underline{Z}$ and $\underline{F}$ respectively:

$$\underline{Z} = \begin{bmatrix} Z_{11} & 0 & \cdots & 0 & 0 \\ 0 & Z_{22} & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & Z_{mm} & 0 \\ 0 & 0 & \cdots & 0 & 0 \end{bmatrix} \text{ and } \underline{F} = \begin{bmatrix} f_1^1 & 0 & \cdots & 0 \\ 0 & f_2^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & f_m^m \\ 0 & 0 & \cdots & 0 \end{bmatrix}$$

Gross output trade can then be denoted with the matrices $\overline{Z} = Z - \underline{Z}$ and $\overline{F} = F - \underline{F}$. Using ι as a unit or summation vector of appropriate length I will use in the sequel

- $\underline{z} = \underline{Z}\iota$ for domestically produced intermediates used at home
- $\overline{z} = \overline{Z}\iota$ for intermediate exports (or the supply of trading services for intermediate imports if the source is int)
- $z = \underline{z} + \overline{z}$ for total deliveries of intermediates
- $\underline{f} = \underline{F}\iota$ for domestically produced final output used at home
- $\overline{f} = \overline{F}\iota$ for final output exports (or the supply of trading services for final output imports if the source is int)
- $f = \underline{f} + \overline{f}$ for total deliveries of final output

To derive the Leontief-inverses, input coefficients A and v' are needed. These are obtained by dividing the entries of Z and w' respectively by the column totals x' (that is $\overline{a}_{rs}(i,j) = \overline{z}_{rs}(i,j)/x_s(j)$, $\underline{a}_{rr}(i,j) = \underline{z}_{rr}(i,j)/x_r(j)$ and $v_s(j) = w_s(j)/x_s(j)$ whenever $x_s(j)$ is positive; the input coefficients are assumed to be zero when total inputs are zero). The row vector v' with value added input coefficients will also appear in the sequel as a diagonal matrix $\hat{v}$.

Indicating gross exports as $e = \overline{z} + \overline{f}$ one can rewrite the adding-up conditions (2.2) and (2.3) as follows

$$x = \underline{z} + \underline{f} + e = \underline{A}x + \underline{f} + e \text{ or } (I - \underline{A})x = \underline{f} + e \text{ or } x = (I - \underline{A})^{-1}(\underline{f} + e) \text{ or } x = L(\underline{f} + e) \qquad (2.4)$$

and

$$\iota'\underline{A} + \iota'(\overline{A} + \hat{v}) = \iota' \text{ or } \iota'(I - \underline{A}) = \iota'(\overline{A} + \hat{v}) \text{ or } \iota'(\overline{A} + \hat{v})(I - \underline{A})^{-1} = \iota'(\overline{A} + \hat{v})L = \iota' \qquad (2.5)$$

In these equations the local Leontief inverse L is a block-diagonal matrix where the blocks contain the regional local inverses and the last block for the international market is a unit matrix. Equation (2.4) shows that its typical element $l_{rr}(i, j) \ \forall r \in M$ indicates the domestic intermediates that are needed from (r, i) to produce in (r, j) one unit of final output used at home or one unit of gross exports. For the international trading services market $L_{\text{int int}} = I$. Hence, equation (2.4) just says for this market that total import margin demands consist of the sum total of the value of international trading services on imported intermediates and those on imported final output. At the regional level (2.5) implies that $\iota'(\sum_r \overline{A}_{rs} + \hat{v}_s)L_{ss}\hat{e}_s = e'_s \ \ \forall s \in M$ or that regional exports can be decomposed in 'imports in exports (VS)' and 'domestic value added in exports (DV)'. This property of local input-output analysis was prominently brought forward in the seminal paper on vertical specialization by Hummels, Ishii and Yi (2001). Equation (2.5) simply recalls for the international market that for each service the sum total of input coefficients into this market is unity ($\iota'\sum_r \overline{A}_{r\,\text{int}} = \iota'$).

Making use of the *global* coverage of the input output table the adding up conditions can be rewritten as

$$x = z + f = Ax + f \text{ or } (I - A)x = f \text{ or } x = (I - A)^{-1} f = Bf \qquad (2.6)$$

and

$$\iota'(A + \hat{v}) = \iota' \text{ or } \iota'(I - A) = v' \text{ or } v'(I - A)^{-1} = v'B = \iota' \qquad (2.7)$$

In these equations B denotes the so-called global Leontief inverse. Equation (2.6) shows that its typical element $b_{rs}(i, j) \ \ \forall r, s \in M$ indicates the gross output that is needed from (r, i) to produce one unit of final output in (s, j), including the final output from (s, j) itself . For the international trading services market $b_{\text{int}\,s}(i, j) \ \ \forall s \in M$ shows the costs for trading service i per unit of final output produced in (s, j) while $b_{r\,\text{int}}(i, i) \ \ \forall r \in M$ represents the gross output needed from (r, i) per unit of trading service i on final output imports. From (2.7) I derive that $\sum_r v'_r B_{rs}\hat{f}_s = f'_s \ \ \forall s \in M$ or that the production value of each final output equals a 'global bundle' of value added. This property of global input-output analysis began to be used empirically in the pioneering studies of trade in value added by Daudin, Rifflart and Schweisguth (2011), Johnson and Noguera (2012) and Koopman, Wang and Wei (2014).

From source to final output factory gate

It is the ultimate destiny of all intermediate exports, $\overline{z}_r \ \forall r \in M$, to be consumed in the production process of final outputs[3]. A decomposition of intermediate exports that directly reflects this is the following:

$$\begin{aligned} \iota' e_r &= \sum_s \sum_\sigma \iota' \overline{A}_{rs} B_{s\sigma} f_\sigma^w \\ &= \sum_s \sum_\sigma \iota' \overline{A}_{rs} (B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_\sigma^w + \sum_\sigma \iota' \overline{A}_{r\sigma} L_{\sigma\sigma} f_\sigma^w \\ &= \underbrace{\sum_s \sum_\sigma \iota' \overline{A}_{rs} L_{ss} \sum_t \overline{A}_{st} B_{t\sigma} f_\sigma^w}_{\text{Exports in other countries' exports, } VS1_r} + \underbrace{\sum_\sigma \iota' \overline{A}_{r\sigma} L_{\sigma\sigma} f_\sigma^w}_{\text{Final output factory gate imports, } FG_r} \qquad \forall r \in M \end{aligned} \tag{2.8}$$

In equation (2.8) I introduced the superscript w for summation over all destinations of final output (thus $f_\sigma^w = \sum_\rho f_\sigma^\rho$) and the toggle $\delta_{s\sigma}$ that takes the value one if $s = \sigma$ and is zero otherwise. The expression after the third equality in equation (2.8) follows from the identity[4] $B - L = L\overline{A}B$. Equation (2.8) shows that intermediate exports can be split in two components: the first of these, $VS1_r$ shows the exports being carried further in other countries' intermediate exports. These exports are often denoted by VS1, referring to the measure which was introduced by Hummels, Ishii and Yi (2001) and used more extensively by Yi (2003)[5]. The second component, FG_r, shows the exports that arrive at the final output factory gate. I call these 'factory gate imports' rather than 'factory gate exports' to prevent the misunderstanding that they refer to final output exports. To my knowledge the concept of factory gate imports has not been used in the literature before. It is important not to misinterpret factory gate imports as the exports that arrive directly at the factory gate. In fact, the process of arrivals at the gate is a complicated, indirect one. A first indication of this is obtained from another decomposition of intermediate exports:

$$\iota' e_r = \underbrace{\sum_q \iota' \overline{A}_{qr} L_{rr} \sum_s \sum_\sigma \overline{A}_{rs} B_{s\sigma} f_\sigma^w}_{\text{Imports in intermediate exports, } VS_r} + \underbrace{v_r' L_{rr} \sum_s \sum_\sigma \overline{A}_{rs} B_{s\sigma} f_\sigma^w}_{\text{Domestic value added in intermediate exports, } DV_r} \qquad \forall r \in M \tag{2.9}$$

Equation (2.9) shows the classical *VS-DV* split of intermediate exports, which is also due to Hummels, Ishii and Yi (2001)[6]. The first component, VS_r, shows the imports in intermediate exports and the second component, DV_r, indicates domestic value added in intermediate exports. Decomposing the latter as

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[3] The same applies for a considerable part of the international trading services $\overline{z}_{\text{int}}$ (the remaining part being needed for international trade margins on final output imports).

[4] This identity can be derived as follows. B can be rewritten as $B = [I - \underline{A} - \overline{A}]^{-1} = [(I - \underline{A})(I - L\overline{A})]^{-1} = (I - L\overline{A})^{-1} L$. Pre-multiplication with $(I - L\overline{A})$ yields $(I - L\overline{A})B = L$ or $B - L = L\overline{A}B$.

[5] It should be noted that $VS1$ may also refer to exports in final output exports; hence, equation (2.8) only shows the 'exports in intermediate exports' part of it.

[6] Again, both VS and DV may also refer to imports or domestic value added in final output exports; equation (2.9) only shows imports or domestic value added in intermediate exports.

$$\underbrace{v_r' L_{rr} \sum_s \sum_\sigma \bar{A}_{rs} B_{s\sigma} f_\sigma^w}_{\text{Domestic value added in intermediate exports, } DV_r} = \underbrace{v_r' L_{rr} \sum_s \sum_\sigma \bar{A}_{rs} (B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_\sigma^w}_{\text{Domestic value added in } VS1_r} + \underbrace{v_r' L_{rr} \sum_\sigma \bar{A}_{r\sigma} L_{\sigma\sigma} f_\sigma^w}_{\text{Domestic value added in } FG_r} \quad \forall r \in M$$

suggests the interpretation that the last term (domestic value added in FG_r) represents the direct shipment of domestic value added from r to the factory gates. Its complement, $\sum_q \iota' \bar{A}_{qr} L_{rr} \sum_\sigma \bar{A}_{r\sigma} L_{\sigma\sigma} f_\sigma^w \quad \forall r \in M$, would then indicate the indirect shipments of other countries' exports via r.

By a simple relabeling of indices in equations (2.8) and (2.9) the intermediate imports of r may be obtained as:

$$\begin{aligned} m_r' \iota &= \sum_q \iota' \bar{A}_{qr} L_{rr} \sum_s \sum_\sigma \bar{A}_{rs} B_{s\sigma} f_\sigma^w + \sum_q \iota' \bar{A}_{qr} L_{rr} f_r^w \\ &= \sum_q \iota' \bar{A}_{qr} L_{rr} \sum_s \sum_\sigma \bar{A}_{rs} B_{s\sigma} f_\sigma^w + \sum_q v_q' L_{qq} \sum_s \bar{A}_{qs} B_{sr} f_r^w \qquad (2.10) \\ &= \underbrace{\sum_q \iota' \bar{A}_{qr} L_{rr} \sum_s \sum_\sigma \bar{A}_{rs} B_{s\sigma} f_\sigma^w}_{\text{Imports in intermediate exports, } VS_r} + \underbrace{\sum_q v_q' (B_{qr} - \delta_{qr} L_{rr}) f_r^w}_{\text{Factory gate value added imports, } VG_r} \quad \forall r \in M \end{aligned}$$

After the third equality sign in equation (2.10) use was made of the identity[7] $B - L = B\bar{A}L$. Equation (2.10) shows that intermediate imports can be decomposed in two components: imports in exports, VS_r, and factory gate imports that can be either expressed in gross terms, FG_r, or in value added terms, VG_r. It can be noted that the equality $\sum_q \iota' \bar{A}_{qr} L_{rr} f_r^w = \sum_q v_q' (B_{qr} - \delta_{qr} L_{rr}) f_r^w$ also follows directly from the combination of equation (2.5) with equation (2.7). The process of value added accumulation at the factory gate can be further clarified, making use of the power expansion[8] $B - L = L\bar{A}L + L\bar{A}L\bar{A}L + L\bar{A}L\bar{A}L\bar{A}L + \cdots$ which shows the alternative supply chains via which inputs from the source arrive at the factory gate. Using the three different representations of $B - L$ factory gate imports have the following equivalent appearances

$$\begin{aligned} \sum_q \iota' \bar{A}_{qr} L_{rr} f_r^w &= \sum_q v_q' (B_{qr} - \delta_{qr} L_{rr}) f_r^w \\ &= \sum_q v_q' L_{qq} \sum_s \bar{A}_{qs} B_{sr} f_r^w \qquad (B - L = L\bar{A}B: \text{forward looking from the source}) \\ &= \sum_q v_q' \sum_s B_{qs} \bar{A}_{sr} L_{rr} f_r^w \qquad (B - L = B\bar{A}L: \text{backward looking from the gate}) \\ &= \sum_q v_q' (L_{qq} \bar{A}_{qr} L_{rr} + L_{qq} \sum_s \bar{A}_{qs} L_{ss} \bar{A}_{sr} L_{rr} + L_{qq} \sum_s \bar{A}_{qs} L_{ss} \sum_t \bar{A}_{st} L_{tt} \bar{A}_{tr} L_{rr} + \cdots) f_r^w \quad \forall r \in M \\ & \qquad (B - L = LAL + LALAL + \ldots: \text{looking at the chain from source to sink}) \end{aligned}$$

(2.11)

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[7] This second representation can be derived as follows. $B = [I - \underline{A} - \bar{A}]^{-1} = [(I - \bar{A}L)(I - \underline{A})]^{-1} = L(I - \bar{A}L)^{-1}$. Post-multiplication with $(I - \bar{A}L)$ yields $B(I - \bar{A}L) = L$ or $B - L = B\bar{A}L$.

[8] The expansion is derived via

$$B - L = L(I - \bar{A}L)^{-1} - L = (I - L\bar{A})^{-1} L - L = L \sum_{k=1}^{\infty} (\bar{A}L)^k = [\sum_{k=1}^{\infty} (L\bar{A})^k] L = L\bar{A}L + L\bar{A}L\bar{A}L + L\bar{A}L\bar{A}L\bar{A}L + \cdots$$

Making use of the first expansion, $B - L = L\bar{A}B$, one basically looks forward from the source to see where domestic value added exports are finally converted into final output. With the second expansion, $B - L = B\bar{A}L$, one is looking backward from the final output factory gate, to see where the factory gate inputs came from. Using the third expansion $B - L = L\bar{A}L + L\bar{A}L\bar{A}L + L\bar{A}L\bar{A}L\bar{A}L + \cdots$ one looks at the supply chains via which inputs from the source actually arrive at the factory gate.

From the final output factory to the final sink

The final producer just adds domestic value added to factory gate imports (or to the value added in factory gate imports) to complete the final output:

$$\sum_q \iota' \bar{A}_{qr} L_{rr} f_r^w + v_r' L_{rr} f_r^w = \sum_q v_q' (B_{qr} - \delta_{qr} L_{rr}) f_r^w + v_r' L_{rr} f_r^w = \sum_q v_q' B_{qr} f_r^w = \iota' f_r^w \tag{2.12}$$

Letting $\iota' \bar{f}_w^\rho = \sum_{\sigma \in M} \iota' \bar{f}_\sigma^\rho + \iota' \bar{f}_{\text{int}}^\rho$ denote the cif value of total final output imports by the sink ρ its value added composition can be given as:

$$\iota' \bar{f}_w^\rho = \sum_q \sum_{\sigma \in M} v_q' B_{q\sigma} \bar{f}_\sigma^\rho + \sum_q v_q' B_{q\text{int}} \bar{f}_{\text{int}}^\rho \tag{2.13}$$

Double counting in imports and exports: decomposition from the '*from source to final sink*' perspective

Wrapping up, total exports $\iota'\overline{e}_r$ from source r can be decomposed as

$$\iota'\overline{e}_r = \sum_\sigma \sum_q \iota'\overline{A}_{qr} L_{rr} \sum_s \overline{A}_{rs} (B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_\sigma^w \quad \text{(Imports in redirected intermediate exports)}$$

$$+ \sum_\sigma \sum_q \iota'\overline{A}_{qr} L_{rr} \overline{A}_{r\sigma} L_{\sigma\sigma} f_\sigma^w \quad \text{(Imports in outbound factory gate imports)}$$

$$+ \sum_q \iota'\overline{A}_{qr} L_{rr} \overline{f}_r^w \quad \text{(Imports in final output exports)}$$

$$+ \sum_\sigma v_r' L_{rr} \sum_s \overline{A}_{rs} (B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_\sigma^w \quad \text{(Domestic value added in redirected intermediate exports)}$$

$$+ \sum_\sigma v_r' L_{rr} \overline{A}_{r\sigma} L_{\sigma\sigma} f_\sigma^w \quad \text{(Domestic value added in outbound factory gate imports)}$$

$$+ v_r' L_{rr} \overline{f}_r^w \quad \text{(Domestic value added in final output exports)}$$

and total imports of r as

$$\overline{m}_r'\iota = \sum_\sigma \sum_q \iota'\overline{A}_{qr} L_{rr} \sum_s \overline{A}_{rs} (B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_\sigma^w \quad \text{(Imports for redirected intermediate exports)}$$

$$+ \sum_\sigma \sum_q \iota'\overline{A}_{qr} L_{rr} \overline{A}_{r\sigma} L_{\sigma\sigma} f_\sigma^w \quad \text{(Imports for outbound factory gate imports)}$$

$$+ \sum_q \iota'\overline{A}_{qr} L_{rr} \overline{f}_r^w \quad \text{(Imports for final output exports))}$$

$$+ \sum_q \sum_\sigma v_q' (B_{q\sigma} - \delta_{q\sigma} L_{\sigma\sigma}) \overline{f}_\sigma^r \quad \text{(Redirected value added in final output imports)}$$

$$+ \sum_\sigma v_\sigma' L_{\sigma\sigma} \overline{f}_\sigma^r \quad \text{(Value added in final output imports)}$$

$$+ \sum_q v_q' \sum_s (B_{qs} - \delta_{qs} L_{ss}) \overline{A}_{sr} L_{rr} \underline{f}_r^r \quad \text{(Value added in redirected intermediate imports for final output used at home)}$$

$$+ \sum_q v_q' L_{qq} \overline{A}_{qr} L_{rr} \underline{f}_r^r \quad \text{(Value added in inbound factory gate imports for final output used at home)} \quad \forall r \in M$$

(from source to sink perspective)

(2.14)

It is to be noted that the value added terms in these decompositions exactly appear twice: they are recorded as domestic value added exports and as imports at the final sink. Hence, internationally, there is no double counting in terms of value added flows.

Because imports in exports are present in imports as well as exports the trade balance is the same in terms of gross trade as in terms of value added trade. In other words limiting trade analysis to trade in value added from the '*from source to final sink*' perspective removes the double counting of imports in exports. There are however double counted items in trade in value added at the country level. These cancel too in the balance. They are:

- $v_r'(B_{rr} - L_{rr})\underline{f}_r^r$, the domestic value added in intermediate exports needed abroad to produce factory gate imports for the production of final output used at home which is exported as DV_r and imported as VG_r

- $\sum_\sigma v_r' B_{r\sigma} \overline{f}_\sigma^r$, the domestic value added in intermediate exports needed abroad to produce final output imports for r which is exported as DV_r and returning in final output imports

Decomposition (2.14) can be seen as a decomposition from the *source to the final sink perspective*, showing domestic value added in exports at the export side and their final destinations at the import side. This is to be understood as an allocation of all value added in trade to the outgoing carriers and the decomposition shows that these will in the end be absorbed by the final sinks. The allocation implies that the value added in the gross trade components in decomposition (2.14) is ignored.

Trade redirection: decomposition from the '*last exporter*' perspective

An alternative decomposition can be derived from the '*from source to sink*' decomposition. I call this a decomposition from the '*last exporter*' perspective. The decomposition shows the value added flows on their last journey to the final sinks. Again the value added components are only recorded twice: when they enter the country of the last exporter and when they leave this country on their last journey, or, in the case of direct flows in which the last trip is also the first: when they leave the exporting country and arrive at the final sink. Hence, again, in terms of value added flows there is no international double counting. Moreover, globally, the value added in trade in this decomposition exactly equals the value added in trade of the '*from source to sink*' decomposition.

This decomposition is as follows:

$$\iota'\bar{e}_r = \sum_s \sum_\sigma \bar{A}_{rs}(B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_\sigma^w \quad \text{(Redirected intermediate exports)}$$

$$+ \sum_\sigma \sum_q \iota' \bar{A}_{qr} L_{rr} \bar{A}_{r\sigma} L_{\sigma\sigma} \bar{f}_\sigma^w \quad \text{(Imports in outbound factory gate imports for final output exports)}$$

$$+ \sum_q v_q'(B_{qr} - \delta_{qr} L_{rr}) \bar{f}_r^w \quad \text{(Redirected value added via final output exports)}$$

$$+ \sum_q v_q'(B_{qr} - \delta_{qr} L_{rr}) \sum_\sigma \bar{A}_{r\sigma} L_{\sigma\sigma} \underline{f}_\sigma^\sigma \quad \text{(Redirected value added in 'end of chain' outbound factory gate imports)}$$

$$+ v_r' L_{rr} \bar{f}_r^w \quad \text{(Direct value added in final output exports)}$$

$$+ v_r' L_{rr} \sum_\sigma \bar{A}_{r\sigma} L_{\sigma\sigma} \underline{f}_\sigma^\sigma \quad \text{(Direct value added in outbound factory gate imports)}$$

and

$$\bar{m}_r'\iota = \sum_q \iota' \bar{A}_{qr} L_{rr} \sum_s \sum_\sigma \bar{A}_{rs}(B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_\sigma^w \quad \text{(Imports for redirected intermediate exports)}$$

$$+ \sum_q \iota' \bar{A}_{qr} L_{rr} \sum_\sigma \bar{A}_{r\sigma} L_{\sigma\sigma} \bar{f}_\sigma^w \quad \text{(Imports for outbound factory gate imports for final output exports)}$$

$$+ \sum_q \sum_\sigma \iota' \bar{A}_{q\sigma} L_{\sigma\sigma} \bar{A}_{\sigma r} L_{rr} \underline{f}_r^r \quad \text{(Imports in factory gate imports for final output used at home)}$$

$$+ \sum_q \sum_\sigma \iota' \bar{A}_{q\sigma} L_{\sigma\sigma} \bar{f}_\sigma^r \quad \text{(Factory gate imports in final output imports)}$$

$$+ \sum_q v_q'(B_{qr} - \delta_{qr} L_{rr}) \bar{f}_r^w \quad \text{(Redirected value added via final output exports)}$$

$$+ \sum_q v_q'(B_{qr} - \delta_{qr} L_{rr}) \sum_\sigma \bar{A}_{r\sigma} L_{\sigma\sigma} \underline{f}_\sigma^\sigma \quad \text{(Redirected value added in 'end of chain' outbound factory gate imports)}$$

$$+ \sum_\sigma v_\sigma' L_{\sigma\sigma} \bar{f}_\sigma^r \quad \text{(Direct value added in final output imports)}$$

$$+ \sum_q v_q' L_{qq} \bar{A}_{qr} L_{rr} \underline{f}_r^r \quad \text{(Direct value added in factory gate imports for final output used at home)}$$

(Last exporter perspective)

(2.15)

The derivation of equation (2.15) from equation (2.14) is straightforward and fully explained in the extensive footnote[9]. Total domestic double counting in gross and value added terms is the same in both decompositions. However, the domestic double counting in terms of value added is quite different. For the decomposition from the perspective of the '*last exporter*' the double counted value added items are:

- trade redirection via final output exports $\sum_{q \neq r} \sum_{\sigma} v_q' (B_{q\sigma} - \delta_{q\sigma} L_{\sigma\sigma}) \bar{f}_{\sigma}^{r}$
- and trade redirection via 'end of chain' exports to factory gates producing final output for domestic use $\sum_{q} v_q' (B_{qr} - \delta_{qr} L_{rr}) \sum_{\sigma} \bar{A}_{r\sigma} L_{\sigma\sigma} \underline{f}_{\sigma}^{\sigma}$

This does not mean that the value added double counting of the '*from source to sink*' decomposition is absent in the '*last exporter*' decomposition, but rather that this double counting is just ignored in the '*last exporter*' decomposition because – globally – all trade in value added is already covered.

Redirection indicators for the last exporter, the source and the sink

Based on the '*last exporter*' decomposition I propose – for each country - indicators for the intensity of redirection for final output of a certain industry, the level of specialization in this redirection and the relative size of redirection.

Let Δ_i denote a selection matrix of dimension $n \times n$ consisting of zeroes with the exception of the i^{th} diagonal element which is one. Then $\Delta_i f$ represents a vector with zeroes except for the i^{th} element which is $f(i)$. The intensity of redirection is measured as the share of redirected value added imports in total value added imports, or as

$$I_r^{\exp}(i) = \frac{\sum_{q} v_q' (B_{qr} - \delta_{qr} L_{rr}) (\Delta_i \bar{f}_r^{w} + \sum_{\sigma} \bar{A}_{r\sigma} L_{\sigma\sigma} \Delta_i \underline{f}_{\sigma}^{\sigma})}{\sum_{q} v_q' B_{qr} (\Delta_i \bar{f}_r^{w} + \sum_{\sigma} \bar{A}_{r\sigma} L_{\sigma\sigma} \Delta_i \underline{f}_{\sigma}^{\sigma})} \quad \forall r \in M, i \in N \tag{2.16}$$

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[9] On the export side: $\sum_{s} \sum_{\sigma} \bar{A}_{rs} (B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_{\sigma}^{w}$ is obtained as the sum of $\sum_{\sigma} \sum_{q} \iota' \bar{A}_{qr} L_{rr} \sum_{s} \bar{A}_{rs} (B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_{\sigma}^{w}$ and $\sum_{\sigma} v_r' L_{rr} \sum_{s} \bar{A}_{rs} (B_{s\sigma} - \delta_{s\sigma} L_{\sigma\sigma}) f_{\sigma}^{w}$; $\sum_{q} v_q' (B_{qr} - \delta_{qr} L_{rr}) \bar{f}_r^{w}$ is the value added conversion of $\sum_{q} \iota' \bar{A}_{qr} L_{rr} \bar{f}_r^{w}$ and $\sum_{q} v_q' (B_{qr} - \delta_{qr} L_{rr}) \sum_{\sigma} \bar{A}_{r\sigma} L_{\sigma\sigma} \underline{f}_{\sigma}^{\sigma}$ is the value added conversion of $\sum_{\sigma} \sum_{q} \iota' \bar{A}_{qr} L_{rr} \bar{A}_{r\sigma} L_{\sigma\sigma} \underline{f}_{\sigma}^{\sigma}$. On the import side: $\sum_{q} \sum_{\sigma} \iota' \bar{A}_{q\sigma} L_{\sigma\sigma} \bar{A}_{\sigma r} L_{rr} \underline{f}_r^{r}$ is the gross trade conversion of $\sum_{q} v_q' \sum_{\sigma} (B_{q\sigma} - \delta_{q\sigma} L_{\sigma\sigma}) \bar{A}_{\sigma r} L_{rr} \underline{f}_r^{r}$ and $\sum_{q} \sum_{\sigma} \iota' \bar{A}_{q\sigma} L_{\sigma\sigma} \bar{f}_{\sigma}^{r}$ is the gross trade conversion of $\sum_{q} \sum_{\sigma} v_q' (B_{q\sigma} - \delta_{q\sigma} L_{\sigma\sigma}) \bar{f}_{\sigma}^{r}$; $\sum_{q} v_q' (B_{qr} - \delta_{qr} L_{rr}) \bar{f}_r^{w}$ is the value added conversion of $\sum_{q} \iota' \bar{A}_{qr} L_{rr} \bar{f}_r^{w}$ and $\sum_{q} v_q' (B_{qr} - \delta_{qr} L_{rr}) \sum_{\sigma} \bar{A}_{r\sigma} L_{\sigma\sigma} \underline{f}_{\sigma}^{\sigma}$ is the value added conversion of $\sum_{\sigma} \sum_{q} \iota' \bar{A}_{qr} L_{rr} \bar{A}_{r\sigma} L_{\sigma\sigma} \underline{f}_{\sigma}^{\sigma}$.

The specialization measure indicates whether the exporter is relatively specialized in trade redirection for industry i compared to other exporters and other industries

$$R_r^{\exp}(i) = \frac{I_r^{\exp}(i) \Big/ \sum_{j \in N} I_r^{\exp}(j)}{\sum_{\substack{s \in M \\ s \neq r}} I_s^{\exp}(i) \Big/ \sum_{\substack{s \in M \\ s \neq r}} \sum_{j \in N} I_s^{\exp}(j)} \quad \forall r \in M, i \in N \tag{2.17}$$

where a value larger than one indicates specialization. Finally the size measure is calculated as the exporters' share in global trade redirection for the industry of end-use.

$$S_r^{\exp}(i) = \frac{\sum_q v_q'(B_{qr} - \delta_{qr} L_{rr})(\Delta_i \overline{f}_r^{\,w} + \sum_\sigma \overline{A}_{r\sigma} L_{\sigma\sigma} \Delta_i \underline{f}_\sigma^{\,\sigma})}{\sum_q \sum_s v_q'(B_{qs} - \delta_{qs} L_{ss})(\Delta_i \overline{f}_s^{\,w} + \sum_\sigma \overline{A}_{s\sigma} L_{\sigma\sigma} \Delta_i \underline{f}_\sigma^{\,\sigma})} \quad \forall r \in M, i \in N \tag{2.18}$$

For the sources intensity is measured as the share of domestic value added exports that is being redirected, or

$$I_r^{\text{src}}(i) = 1 - \frac{v_r' L_{rr}(\Delta_i \overline{f}_r + \sum_\sigma \overline{A}_{r\sigma} L_{\sigma\sigma} \Delta_i \underline{f}_\sigma)}{\sum_\sigma \sum_\rho v_r'(B_{r\sigma} - \delta_{r\sigma} \delta_{r\rho} L_{\sigma\sigma}) \Delta_i f_\sigma^\rho} \quad \forall r \in M, i \in N \tag{2.19}$$

and for the sinks intensity is measured as the share of redirected value added imports in final output use, or

$$I_r^{\text{sink}}(i) = 1 - \frac{\sum_\sigma v_\sigma' L_{\sigma\sigma} \Delta_i \overline{f}_\sigma^{\,r} + \sum_q v_q' L_{qq} \overline{A}_{qr} L_{rr} \Delta_i \underline{f}_r}{\sum_q \sum_\sigma v_q' B_{q\sigma} \Delta_i \overline{f}_\sigma^{\,r} + \sum_q v_q'(B_{qr} - \delta_{qr} L_{rr}) \Delta_i \underline{f}_r} \quad \forall r \in M, i \in N \tag{2.20}$$

The specialization and size indicators for sources and sinks are defined similarly to the definitions (2.17) and (2.18).

3 Comparison with early, pioneering studies on trade in value added

This section still has to be developed further. The basic message is the following. Several conclusions emerge when the findings are confronted with those from the pioneering and some of the more recent studies on trade in value added. First, the gross trade decomposition of Koopman, Wang and Wei (2014) is not useful because it distinguishes value added trade as a component of gross trade in many different corners at the same time. Thus they double-count value added trade several times internationally which makes it hard to understand what one is looking at. Moreover, their starting point is to convert all gross trade into value added trade using the value added contained in the global Leontief inverse. This is erroneous and allocates more value added to gross trade than actually is available. Second, Johnson and Noguera (2012b and 2012c) and Johnson (2014) found econometric evidence that value added trade travels further than gross trade. This cannot be true because the value added in trade is carried by gross trade and both trade types must thus travel the same distance. The result is due to a misalignment of the gross and value added trade indicators in their estimations. Third, Lejour, Rojas-Romagosa and Veenendaal (2014) underestimate redirected trade by almost 50% because their redirected trade measure does not include redirection to the final output factory gates producing final output for domestic use.

4 Trade redirection for final use of electronics

As an illustration of the usefulness of the indicator analysis I present preliminary results of redirection for the end-use of electronic equipment. In general[10] only those countries are presented that have a share of at least one percent in total redirected value added trade for the electronics industry. To improve legibility of the figures countries from Asia are depicted in red, those from Europe in green, NAFTA-members in purple and other countries in blue.

In Figure 4.0.1 through Figure 4.0.3 the intensity of redirection by the last exporter is shown together with its level of redirection specialisation and its size for the years 1995, 2003 and 2011. It turns out that CHN, KOR, TWN, MEX and IRL are important redirectors both in terms of intensity and in terms of specialisation. The rise of CHN over time is remarkable as well as the persistent, high intensity of IRL (as shown in Figure 4.0.0.4). Over the years CHN has grown in importance but its redirection intensity is declining since 2007. IRL remains a redirector of high intensity but its specialisation and relative size seem to steadily decline over time.

The redirection characteristics of the sources are shown in Figure 4.0.5 through Figure 4.0.7 for the years 1995, 2003 and 2011. Initially, USA was an important source with a relatively high redirection intensity. By 2011 CHN has become the largest source for redirected trade in electronics but its intensity is relatively modest (which means that direct shipments into CHN are relatively important). It is a remarkable fact that most sources of some weight (covering more than one percent of total redirected value added trade for the electronics industry) have an intensity of redirection that is below the median intensity and that they do not seem to specialise.

Typical redirection characteristics of the final users of electronic equipment are shown in the last figure, that refers to 2003. The largest users are all clustered together around the median intensity and differences in specialisation are modest. Apparently the global market for electronic products serves final users more or less similarly and no development pattern is emerging from the figures over time.

[10] The exception is the inclusion of countries with a smaller share if their RCA is larger than 1 in the first three figures.

Figure 4.0.1 Intensity of redirection of exporters for final use of electronics, 1995

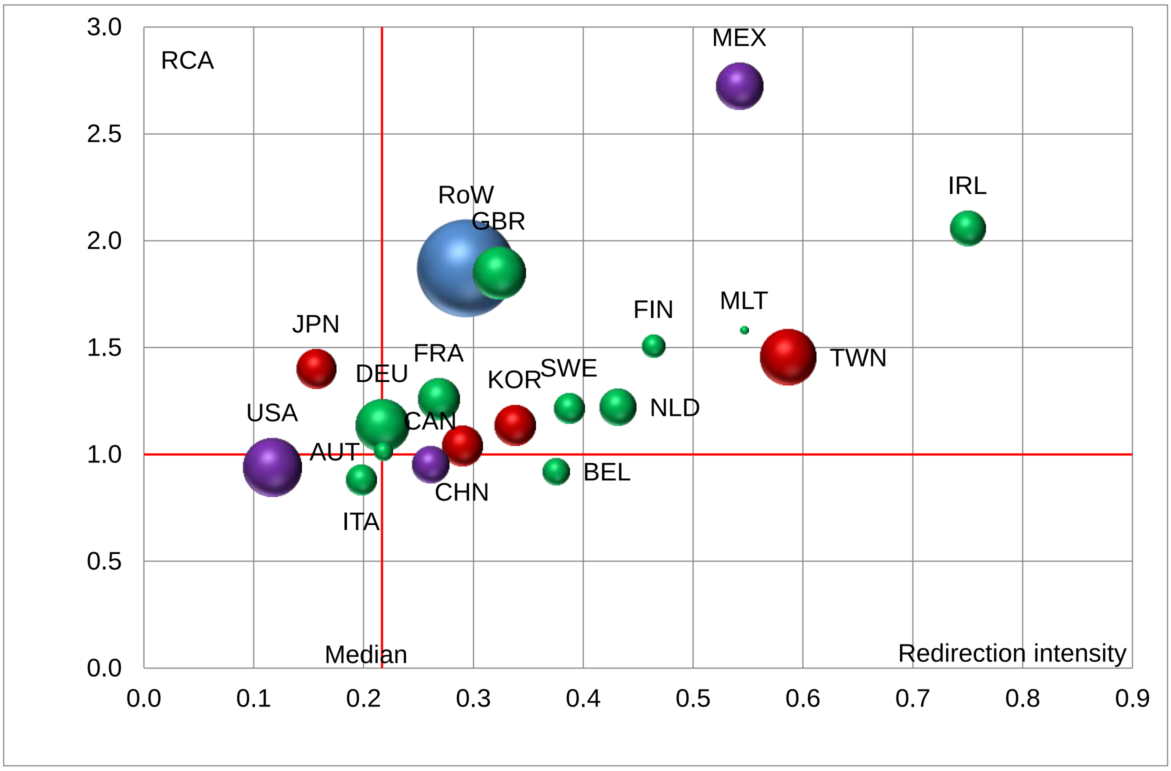


Figure 4.0.2 Intensity of redirection of exporters for final use of electronics, 2003

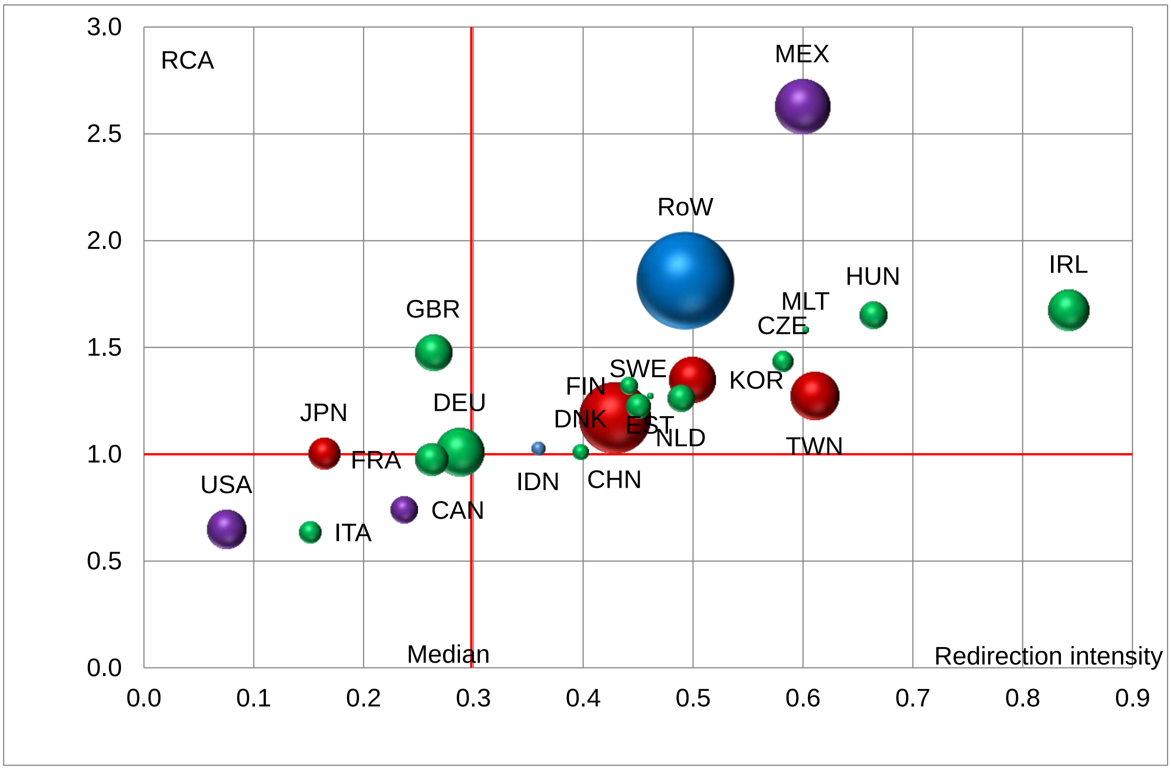


Figure 4.0.3 Intensity of redirection of exporters for final use of electronics, 2011

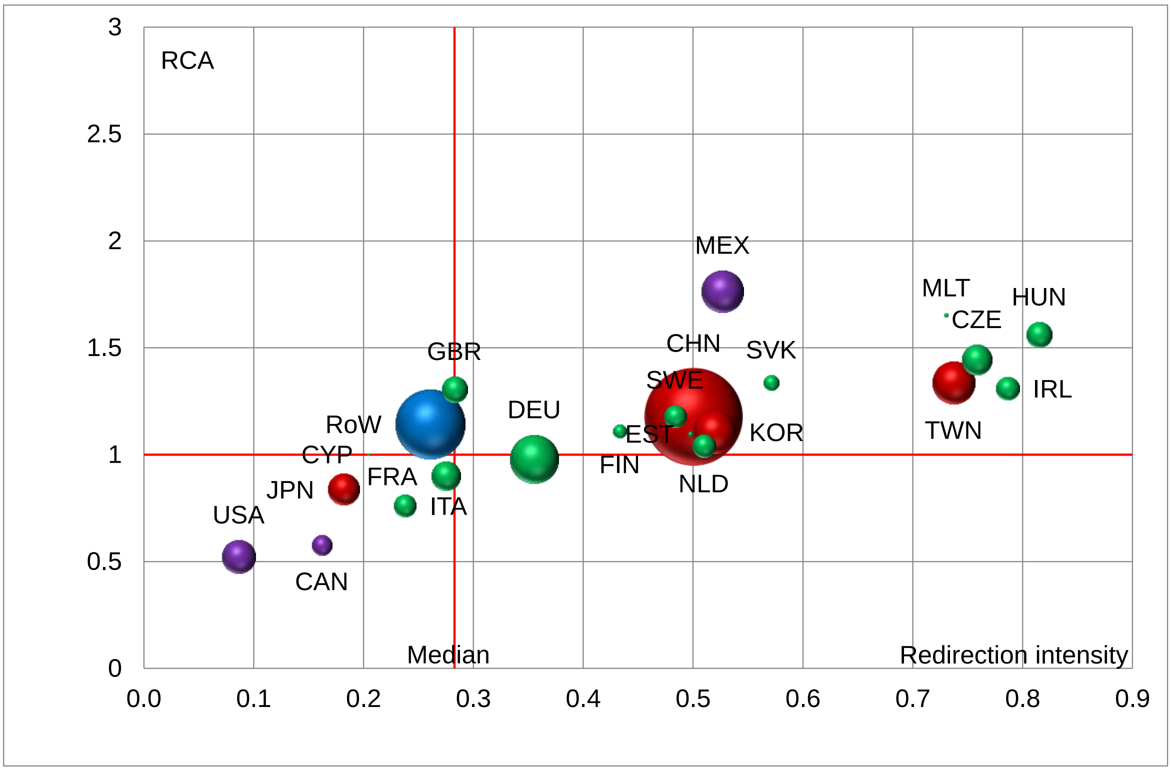


Figure 4.0.0.4 Intensity of redirection of exporters China (red) and Ireland (blue) for final use of electronics, 1995-2011

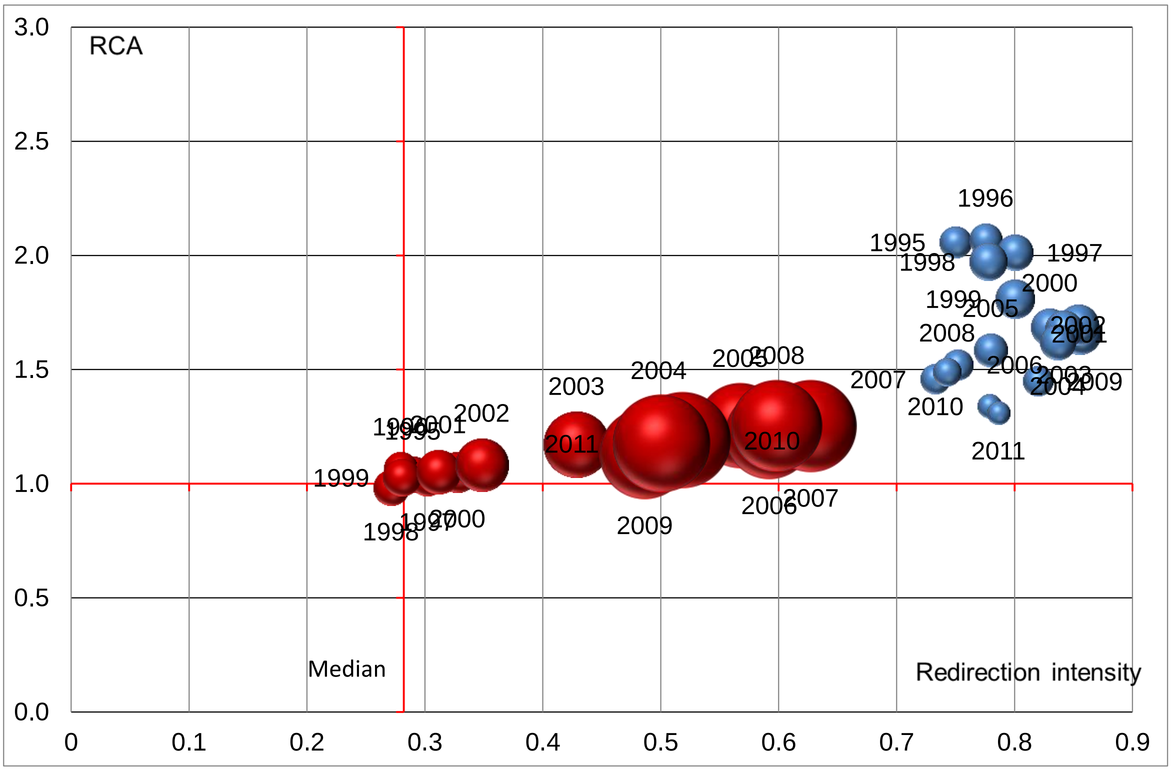


Figure 4.0.5 Intensity of redirection from sources for final use of electronics, 1995

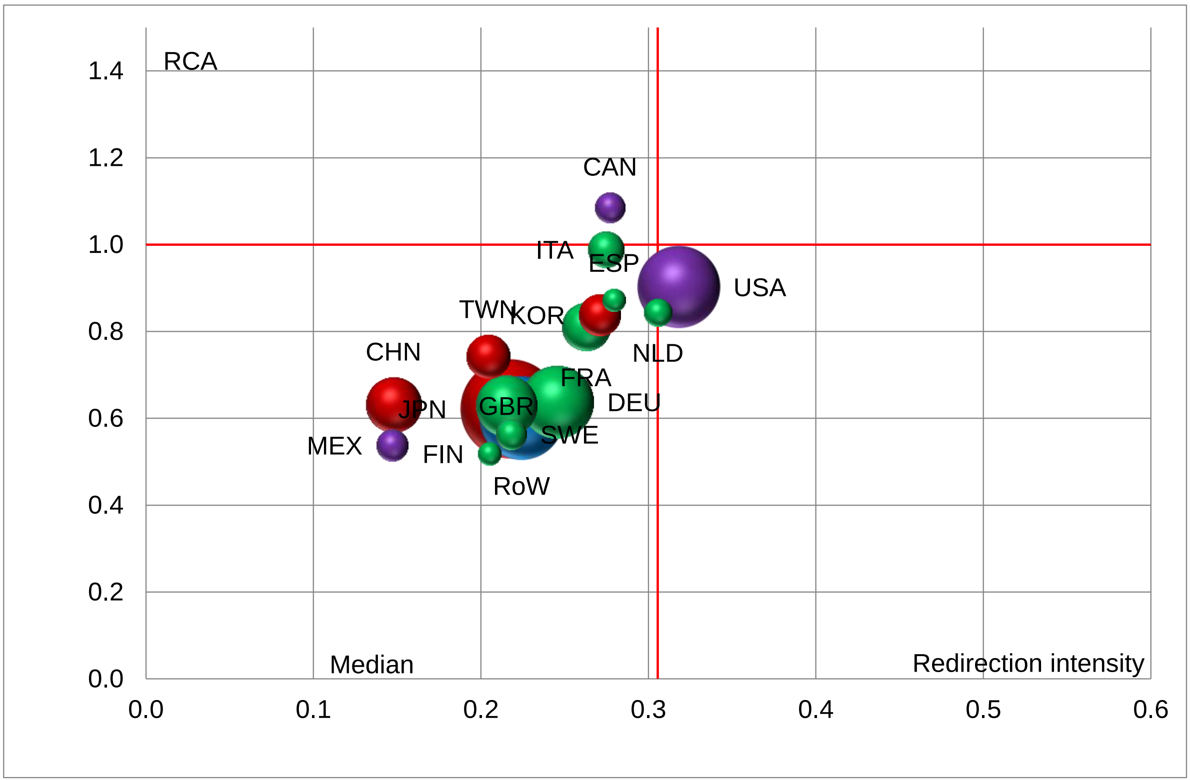


Figure 4.0.6 Intensity of redirection from sources for final use of electronics, 2003

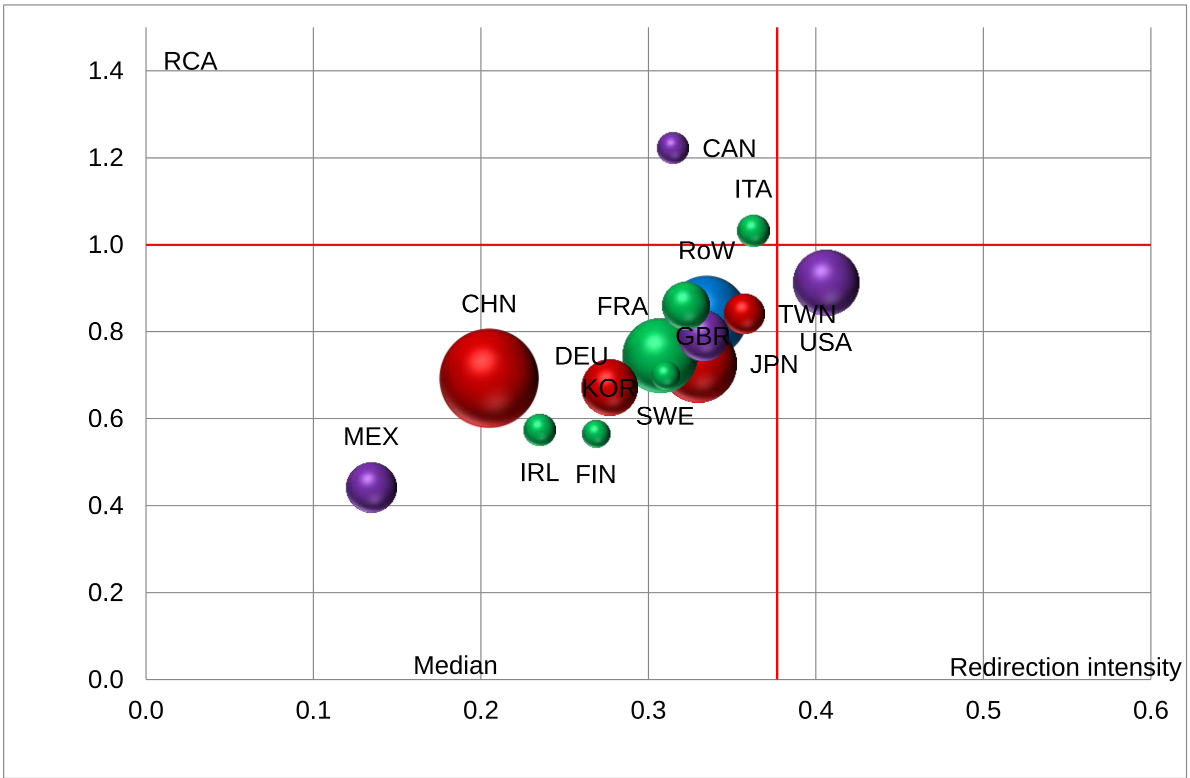


Figure 4.0.7 Intensity of redirection from sources for final use of electronics, 2011

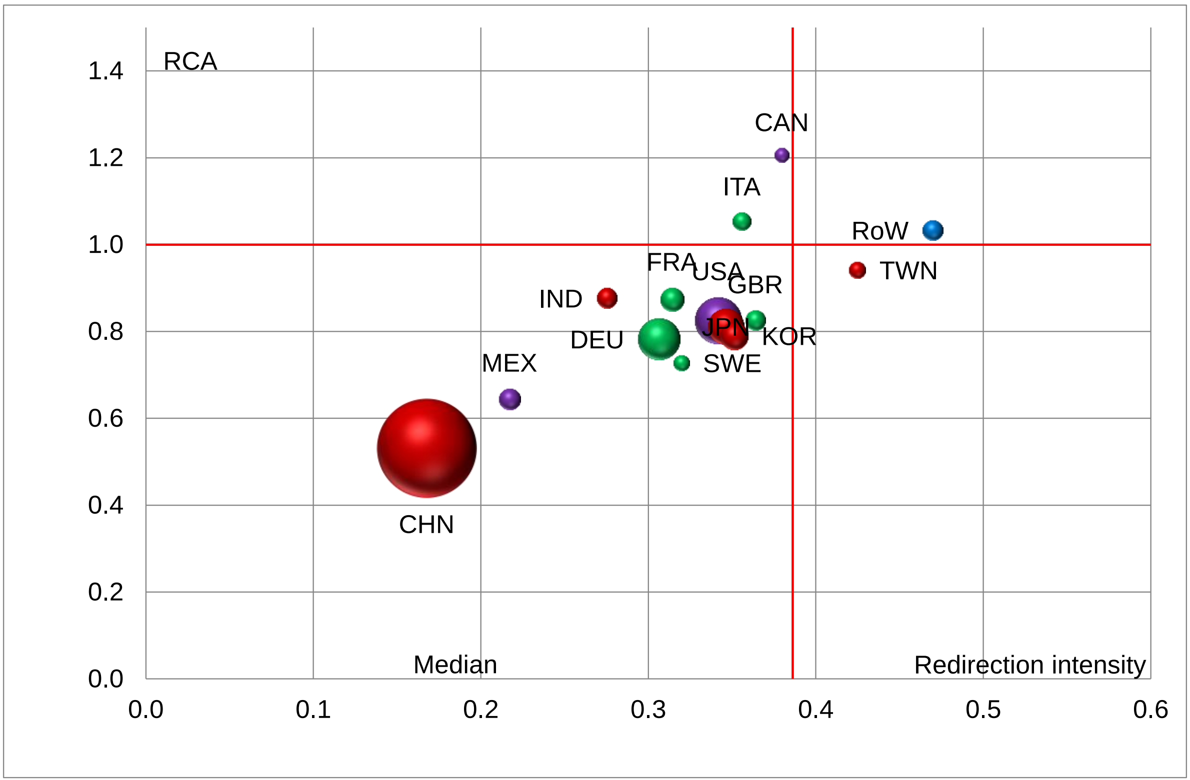
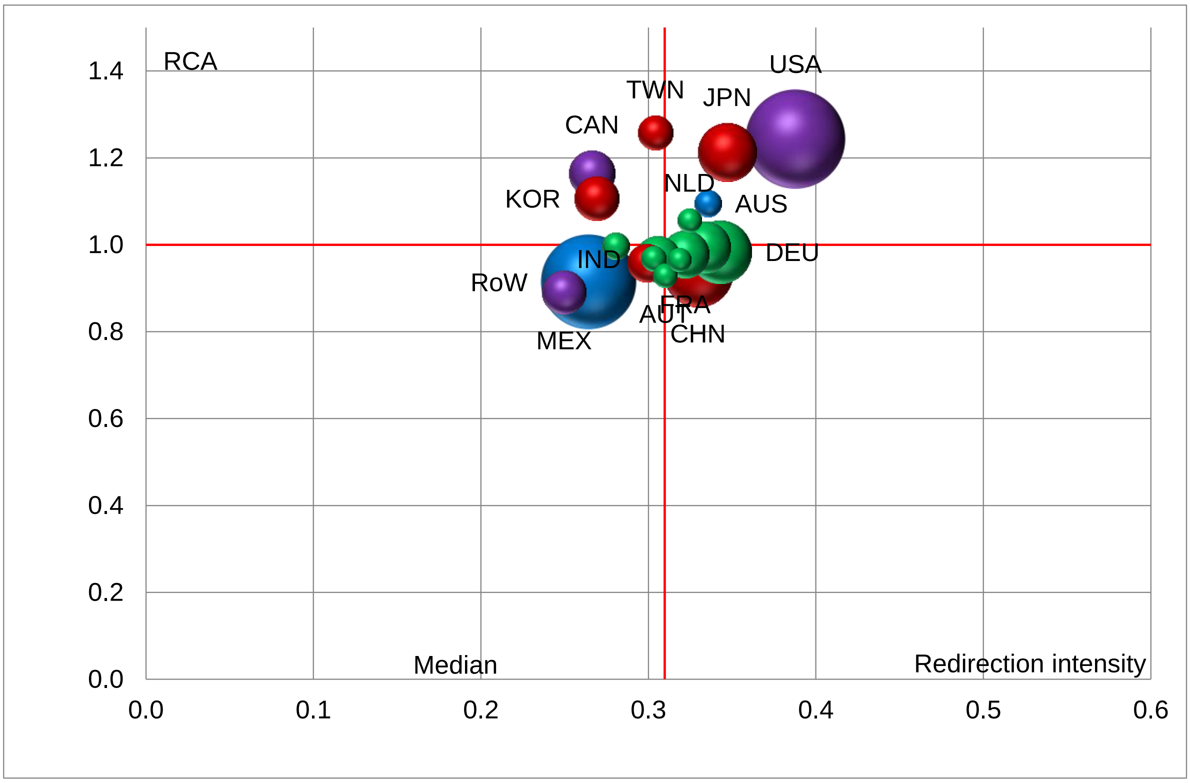


Figure 4.0.8 Intensity of redirection to sinks of final use of electronics, typical year 2003



5 Conclusion

I developed two alternative decompositions of gross trade. The decomposition of gross trade from the '*source to sink*' perspective exactly covers global trade in value added and counts the value added flows only twice: when they leave the source and when they arrive at the sink. The only double counting of value added trade in this decomposition is at the national level, when domestic value added exports for intermediate production abroad return home, embodied in final output imports or in factory gate imports for the production of final output used at home. The decomposition of gross trade from the '*last exporter*' perspective exactly covers global trade in value added too, but allocates the value added flows differently: to the last exporter of all chains leading to the final sink. Again, double counting of value added trade occurs only at the national level, when imported value added is redirected by the last exporter to the final sink. The decomposition enables to define indicators that reflect the intensity of redirection, the degree of redirection specialisation and the relative size of the redirector.

Preliminary results from the WIOD-tables show that the concept of redirected trade is a useful indicator for globalization patterns. Redirected trade highlights especially the importance of the last exporter in the chains for a specific industry of end-use and indicates the major shifts in the relative importance of the sources of value added for that industry over time. Thusfar, redirected trade did not reveal discriminating patterns of supply-chain reliance of the final users.

Future research will be directed at further exploring the trade redirection concept empirically (making use too of the tables that can be derived from the GTAP-datasets for 2001,2004, 2007 and 2011) and at addressing some awkward results in the recent trade in value added literature.

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