Made in the world? New evidence on the internationalization of supply chains

Olle Grünewald (National Board of Trade), Sébastien Miroudot (OECD) and Håkan Nordström (National Board of Trade)

Preliminary and incomplete draft – Please do not quote

May 9, 2014

1. Introduction

In the past five years, the concept of "global value chain" (GVC) has become popular to describe the way firms vertically fragment their production into different stages located in different economies. The concept was first introduced by Gereffi *et al.* (2001) to analyse governance structures in sectors producing for global markets and is now widely used by policymakers. For example, at the Saint Petersburg Summit in September 2013, leaders from the G20, a group of the largest world economies, noted "the importance of better understanding the rapid expansion of global value chains (GVCs) and impacts of participation in GVCs for growth, industrial structure, development and job creation" (Saint Petersburg G20 leaders Declaration).

The "made in the world" narrative suggest that production today is truly global with inputs coming from all parts of the world before being assembled into final products also shipped all over the world. The idea that GVCs are global has however been questioned. For example, Baldwin and Lopez-Gonzalez (2013) argue that GVCs "is a great buzzword" but "is inaccurate in aggregate". "Supply chain trade is not global – it's regional" and that "the global production network is marked by regional blocs, what could be called Factory Asia, Factory North America, and Factory Europe".

Because trade costs and the time to market increase with distance, there must be other costs savings to make it worthwhile to source from distant markets. If two inputs have the same characteristics and the same cost when produced in two countries, the company will prefer to source from the closest economy to save on transport costs and time for delivery. But if an input is only available in a remote place or if transport costs are easily offset by the difference in the price of the input, sourcing locations can be found at higher distances. Falling trade barriers is another factor that allow companies to source more regionally if not (yet) globally.

How global are global value chains? Several indicators based on international input-output tables are now available to provide an empirical answer to this question (Johnson and Noguera, 2012; Koopman *et al.*, 2014; Los *et al.*, 2014). In this paper, we further discuss this new literature on the mapping of global value chains and provide additional measures to characterize the depth of vertical specialization in GVCs and the involvement of different economies. In particular, we look at the average distance travelled by inputs along value chains. We also try to distinguish between the 'international' part of value chains (where there is an international border crossing) and the 'domestic part' (where the stages are within the same country). Part 2 provides a short literature review of different approaches used to measure the length and internationalization of GVCs. Part 3 introduces how value chains are measured, the data we use and look at the recent evolution of international trade in value added terms. Part 4 introduces how to measure the internationalization of supply chains. Part 5 and 6 describes our empirical approach and the new measures we suggest and then discusses our results. Part 7 presents our concluding remarks.

2. Literature review

While the concept of GVC was first introduced to describe very concrete value chains at the industry level, input-output techniques have enabled researchers to look at aggregate results in order to assess the extent of the internationalization of production. Using national input-output tables, one can evaluate the extent to which domestic companies rely on foreign inputs. For example, Feenstra and Hanson (1999) calculate outsourcing indices and document the increase in US offshoring. Hummels *et al.* (2001) measure the import content of exports and discuss the increase in 'vertical trade', i.e. trade flows of intermediate inputs used to produce exports.

While such measures already provide evidence on the rise of GVCs, they do not allow for the identification of countries participating in the value chain and whether they are close or far. More recently, researchers have relied on inter-country input-output tables to trace value added across countries and decompose gross exports according to the sourcing industry and country (Koopman *et al.*, 2014). With newly available international input-output tables, such as the World Input-Output Database (WIOD) or the Trade in Value Added (TiVA) database compiled by OECD and WTO, one can directly compare the contribution of different types of countries to exports in value added terms.

Los *et al.* (2014) extend the Feenstra and Hanson (1999) outsourcing index to a multicountry setting and look at whether global value chains are regional or global. Using the WIOD input-output tables, they find that in almost all industries the share of value added coming from outside the region has increased as opposed to within region value added. GVCs remain regional but become more and more global. The Feenstra and Hanson measure is however limited to the sourcing of inputs. In particular, it does not capture outsourcing of the final assembly of products.

Once the contribution of each country and industry to global output is known, one can combine this information with the geographic distance between countries to evaluate the average distance travelled by products. Such analysis is proposed by Los and Temurshoev (2012) who calculate an "Expected Distance to Final Destination" (EDFD)[1]. Their results confirm that this EDFD indicator has increased over time.

This methodology draws on traditional input-output analysis of backward and forward linkages in the context of an interregional input-output table (Chenery, 1953; Leontief and Strout, 1963). When looking at global value chains, these linkages have been interpreted as proxies for the number of production stages (Fally, 2012) or the upstreamness of countries in such value chains (Antràs *et al.*, 2012). The distance in GVCs has also been previously estimated through the concept of "average propagation length" (Dieztzenbacher and Romero, 2007), which can be understood as the average number of steps it takes a stimulus in one industry in one country to propagate and affect other industries.

[…. This section is incomplete …]

[1] Los and Temurshoev (2012) prefer to call the average distance an 'expected distance', interpreting as probabilities the shares of output used as inputs or final products in each country. But this does not fundamentally change the analysis.

3. Measuring supply chains

For simplicity we begin the exposition by considering value chains in a closed economy setting. We will then introduce a multi-country model in order to study the internationalization of supply chains using the WIOD dataset (November 2013 release).

3.1 Closed economy benchmark

Consider a closed economy described by the following input-output table:

Table 1. Input-Output table

Using sector *j = 1, 2, …, n*

		Intermediate demand				Final demand	Total Use
		Sector 1	**Sector 2**	**…**	**Sector n**		
Supplying Sector *i =1, 2 ,… , n*	**Sector 1**	Z_{11}	Z_{12}	…	Z_{1n}	F_1	D_1
	Sector 2	z_{21}	z_{22}	…	Z_{2n}	F_2	D_2
	…	…	…	…	…	…	…
	Sector n	Z_{n1}	Z_{n2}	…	Z_{nn}	F_n	D_n
	Value Added	V_1	V_2	…	V_n	$GDP = \sum V_j$	
	Total supply	Y_1	Y_2	…	Y_n		

The first $n \times n$ elements of the IO-table record transactions of intermediate goods and services between the sectors (industries) of the economy, where purchases of industry $j=1,2 \ldots,n$ are recorded vertically and sales of industry $i=1,2,\ldots,n$ horizontally. The $n+1$ column ("Final demand") records sales to final consumers and the $n+1$ row ("Value added") outlays on labour and capital that process raw materials and manufactured inputs into more valuable outputs. The value-added activities could be a processing stage or a service activity such as transportation, financial services or retail services.

Following Wassily Leontief (1936) seminal work on input-output analysis, we adopt a linear model with fixed input coefficients. Mathematically, the Leontief production function is given by

$$Y_j = \min\left(\frac{Z_{1j}}{a_{1j}}, \frac{Z_{2j}}{a_{2j}}, \ldots, \frac{Z_{nj}}{a_{nj}}, \frac{V_j}{1-\sum a_{ij}}\right),$$

where Y_j denotes the output of sector j, Z_{ij} inputs from sector i and V_j inputs of primary production factors. The a_{ij} coefficients in the denominator of the production function shows the *minimum input requirements* from sector i to produce one unit of output in sector j. Assuming that firms maximize profits, they will employ just the minimum requirement of each input to produce the desired output,

$$Z_{ij} = a_{ij} Y_j.$$

Note that there are no substitution possibilities in the Leontief model; i.e., firms are not helped by additional inputs of one type (say, car tires) if they face binding constraints on other inputs that must be combined in fixed proportions (car engines) to produce a finished product (car). Note also that the production technology exhibits (by assumption) constant returns to scale; i.e., the input coefficients sum to one including the value-added coefficient.

The output of each sector is used both as inputs and final goods. The *dual use* assumption is partly an artifact of the high aggregation level of real world IO-tables. For example, the IO-table produced by *Statistics Sweden* identifies about 50 sectors, where each sector is made up of hundreds of firms that produce a variety of intermediate and final goods, of which some may serve both purposes. A case in point is passenger cars that may either be a consumption good or an intermediate input for, say, a taxi company.

As far as final demand is concerned the Leontief model is silent on the microeconomic foundation, but we may think of a representative household that maximize utility subject to a budget constraint. Specifically, final demand is treated as an exogenous vector $(F_1, F_2, \ldots, F_n)$ in the Leontief model, and the issue is to calculate the intermediate inputs requirements of all sectors to produce this vector of final demand.

Putting everything together, we get a linear equation system that – in general equilibrium – equalizes supply and demand in all sectors of the economy, including intermediate demands:

$$\begin{aligned} Y_1 &= a_{11} Y_1 + a_{12} Y_2 + \cdots + a_{1n} Y_n + F_1 \\ Y_2 &= a_{21} Y_1 + a_{22} Y_2 + \cdots + a_{2n} Y_n + F_2 \\ &\vdots \\ Y_n &= a_{n1} Y_1 + a_{n2} Y_2 + \cdots + a_{nn} Y_n + F_n \end{aligned}$$

Expressed in matrix algebra the equation system boils down to,

$$\underbrace{\boldsymbol{Y}}_{\substack{\textit{production}}} = \underbrace{\boldsymbol{AY}}_{\substack{\textit{intermediate}\\ \textit{demand}}} + \underbrace{\boldsymbol{F}}_{\substack{\textit{final}\\ \textit{demand}}}$$

where

$$\underset{(n\times 1)}{\boldsymbol{Y} = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix}}, \quad \underset{(n\times n)}{\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}} \quad \text{and} \quad \underset{(n\times 1)}{\boldsymbol{F} = \begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_n \end{bmatrix}}.$$

This equation system has a simple solution (the general equilibrium of the economy),

$$\boldsymbol{Y} = [\boldsymbol{I} - \boldsymbol{A}]^{-1}\boldsymbol{F},$$

where ***I*** is the "identity matrix" with *ones* on the diagonal and *zeros* on the off-diagonal terms

$$\underset{(n\times n)}{\boldsymbol{I} = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}}.$$

The $n\times n$ matrix $[\boldsymbol{I} - \boldsymbol{A}]^{-1}$ is known as the "Leontief inverse" or "total requirement matrix". As shown by Miller and Blair (2008, p. 33), provided that $a_{ij} \geq 0$ for all *i* and *j* and $\sum_{i=1}^{n} a_{ij} < 1$ for all *j*, the Leontief inverse is the solution to an infinite geometric series of **A**,

$$[\boldsymbol{I} - \boldsymbol{A}]^{-1} = \boldsymbol{I} + \boldsymbol{A} + \boldsymbol{A}^2 + \boldsymbol{A}^3 + \cdots .$$

This is the matrix analogue to a geometric series in standard algebra where $[1-a]^{-1} = 1 + a + a^2 + a^3 + \cdots$ for |a| < 1. If we multiply the geometric analogue of the Leontief inverse with the final demand vector it becomes clear why it is referred to as the "total requirement matrix":

$$\begin{aligned}\boldsymbol{Y} &= [\boldsymbol{I}-\boldsymbol{A}]^{-\mathbf{1}}\boldsymbol{F}\\ &= \boldsymbol{F} + \boldsymbol{AF} + \boldsymbol{A^2F} + \boldsymbol{A^3F} + \cdots = \underbrace{\boldsymbol{A}[\boldsymbol{I}-\boldsymbol{A}]^{-\mathbf{1}}\boldsymbol{F}}_{\substack{\textit{intermediate}\\ \textit{use}}} + \underbrace{\boldsymbol{F}}_{\substack{\textit{final}\\ \textit{con.}}}\end{aligned}$$

In market equilibrium, the production of each industry must satisfy both the final demand $\boldsymbol{F}$ and the derived demand for intermediary inputs to produce the final demand vector $\boldsymbol{A}[\boldsymbol{I}-\boldsymbol{A}]^{-\mathbf{1}}\boldsymbol{F}$. The reason why the final demand vector is multiplied both with $\boldsymbol{A}$ and higher powers of $\boldsymbol{A}$ is that the suppliers of inputs use inputs themselves, which in turn are produced with yet other inputs, all the way back to the initial production stage that only uses primary production factors (by assumption).

Consider now the columns of the IO-table (turned horizontally):

$$\begin{aligned}Y_1 &= a_{11}Y_1 + a_{21}\,Y_1 + \cdots + a_{n1}\,Y_1 + V_1\\ Y_2 &= a_{12}Y_2 + a_{22}\,Y_2 + \cdots + a_{n2}\,Y_2 + V_2\\ &\vdots\\ Y_n &= a_{1n}Y_n + a_{2n}Y_n + \cdots + a_{nn}\,Y_n + V_n\end{aligned}$$

The columns of the IO-table record the input requirements of each industry to produce a certain amount of output. For instance, to produce Y_1 units of output in industry 1, industry 1 needs $a_{11}Y_1$ units of inputs from (other firms) in the same industry; $a_{21}\,Y_1$ units of inputs from firms in industry 2; $a_{31}\,Y_1$ units of inputs from industry 3; etcetera. The industry must also employ primary production factors (labor and capital) in order to process inputs into more valuable outputs (i.e. "add value" to the inputs). Putting the valued-added vector on the left hand side, using matrix notation, we have:

$$\underbrace{\boldsymbol{V}}_{n\times 1} = \underbrace{[\boldsymbol{i}-\boldsymbol{A}'\boldsymbol{i}]}_{n\times 1} \cdot \underbrace{\boldsymbol{Y}}_{\boldsymbol{n\times 1}}$$

where

$$\underset{(n\times 1)}{\boldsymbol{V} = \begin{bmatrix}V_1\\V_2\\\vdots\\V_n\end{bmatrix}},\quad \underset{(n\times n)}{\boldsymbol{A}' = \begin{bmatrix}a_{11} & a_{21} & \cdots & a_{n1}\\ a_{12} & a_{22} & \cdots & a_{n2}\\ \vdots & \vdots & \ddots & \vdots\\ a_{1n} & a_{2n} & \cdots & a_{nn}\end{bmatrix}}\ \text{and}\quad \underset{(n\times 1)}{\boldsymbol{i} = \begin{bmatrix}1\\1\\\vdots\\1\end{bmatrix}}.$$

$\boldsymbol{A}'$ is the "transpose" of the $\boldsymbol{A}$-matrix, which is constructed by turning the $\boldsymbol{A}$-matrix horizontally (the 1:st column become the 1:st row; the 2:nd column the 2:ond row, etcetera). The unit vector $\boldsymbol{i}$ serves the role of a "summation vector" in matrix algebra. Post-multiplication of a matrix by $\boldsymbol{i}$ creates a column vector whose elements are the row sums of the matrix, while pre-multiplication with $\boldsymbol{i}'$ creates row vector whose elements are the column sums of the matrix. $[\boldsymbol{i}-\boldsymbol{A}'\boldsymbol{i}]$ is the value-added vector per unit of output, which is constant because of the constant returns to scale assumption of the Leontief model. The symbol $\cdot$ in V= $[\boldsymbol{i}-\boldsymbol{A}'\boldsymbol{i}]\ \cdot\boldsymbol{Y}$ denotes element-by-element multiplication (also known as the "dot product" or "scalar product") and is only defined for equally sized vectors.

Instead of carrying around $[\boldsymbol{i}-\boldsymbol{A}'\boldsymbol{i}]$ in the equations we are about to derive, we introduce the shorthand notation $\boldsymbol{v} = [\boldsymbol{i}-\boldsymbol{A}'\boldsymbol{i}]$ for the value added per unit of output:

$$\underbrace{\boldsymbol{V}}_{n\times 1} = \underbrace{\boldsymbol{v}}_{n\times 1} \cdot \underbrace{\boldsymbol{Y}}_{\boldsymbol{n}\times\boldsymbol{1}} = \begin{bmatrix} v_1 \cdot Y_1 \\ v_2 \cdot Y_2 \\ \vdots \\ v_n \cdot Y_n \end{bmatrix}; \qquad \boldsymbol{v} = [\boldsymbol{i} - \boldsymbol{A}'\boldsymbol{i}].$$

An equivalent way of writing the above formula used by some authors in the GVC-literature is:

$$\underbrace{\boldsymbol{V}}_{n\times 1} = \underbrace{\underbrace{\boldsymbol{v}}_{n\times 1} \cdot \underbrace{\boldsymbol{Y}}_{n\times 1}}_{\substack{element- \\ by-element \\ multiplication}} = \underbrace{\underbrace{diag(\boldsymbol{v})}_{n\times n} \; \underbrace{\boldsymbol{Y}}_{n\times 1}}_{\substack{matrix \\ multiplication}} \; ; \quad diag(\boldsymbol{v}) = \underbrace{\begin{bmatrix} v_1 & 0 & \cdots & 0 \\ 0 & v_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & v_n \end{bmatrix}}_{n\times n}$$

where $diag(\boldsymbol{v})$ is a square matrix with value-added coefficients on the diagonal and zeros on the off-diagonal terms, sometimes abbreviated $\widehat{\boldsymbol{v}} = diag(\boldsymbol{v})$. If we substitute $\boldsymbol{Y} = [\boldsymbol{I} - \boldsymbol{A}]^{-1}\boldsymbol{F}$ for $\boldsymbol{Y}$ in $\boldsymbol{V} = \boldsymbol{v} \cdot \boldsymbol{Y}$ we get the value-added content of each sector in the final demand vector

$$\boldsymbol{V^F} = \boldsymbol{v} \cdot [\boldsymbol{I} - \boldsymbol{A}]^{-1}\boldsymbol{F},$$

where superscript "F" distinguishes value-added in final demand from value-added in production.

1.1. Multi-country Leontief model

We will now scale up the closed economy Leontief model to a multi-country framework in order to study the internationalization of supply chains using the WIOD dataset. We express the model in block matrix notation.

Let $\boldsymbol{A}$ denote the inter-country input-output (ICIO) table,

$$\boldsymbol{A} = \underbrace{\begin{bmatrix} \boldsymbol{A_{11}} & \boldsymbol{A_{12}} & \cdots & \boldsymbol{A_{1m}} \\ \boldsymbol{A_{21}} & \boldsymbol{A_{22}} & \dots & \boldsymbol{A_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A_{m1}} & \boldsymbol{A_{m2}} & \cdots & \boldsymbol{A_{mm}} \end{bmatrix}}_{\substack{m \times m\ countries \\ n \times n\ sectors\ in\ each\ block}}$$

with $m{\times}m$ country blocks and $n{\times}n$ sectors in each block. Divide $\boldsymbol{A}$ into a block-diagonal matrix $\boldsymbol{A^D}$ containing *domestic* IO-tables and an off-diagonal matrix $\boldsymbol{A^X}$ containing *international* IO-relations:

$$\boldsymbol{A^D} = \begin{bmatrix} \boldsymbol{A_{11}} & \boldsymbol{0} & \cdots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{A_{22}} & \dots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{A_{mm}} \end{bmatrix}, \quad \boldsymbol{A^X} = \begin{bmatrix} \boldsymbol{0} & \boldsymbol{A_{12}} & \cdots & \boldsymbol{A_{1m}} \\ \boldsymbol{A_{21}} & \boldsymbol{0} & \dots & \boldsymbol{A_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A_{m1}} & \boldsymbol{A_{m2}} & \cdots & \boldsymbol{0} \end{bmatrix}.$$

The final demand matrix is given by

$$\boldsymbol{F} = \underbrace{\begin{bmatrix} \boldsymbol{F_{11}} & \boldsymbol{F_{12}} & \cdots & \boldsymbol{F_{1m}} \\ \boldsymbol{F_{21}} & \boldsymbol{F_{22}} & \dots & \boldsymbol{F_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{F_{m1}} & \boldsymbol{F_{m2}} & \cdots & \boldsymbol{F_{mm}} \end{bmatrix}}_{\substack{m \times m\ countries \\ n\ \times 1\ sectors\ in\ each\ block}}$$

which can divided into a block-diagonal matrix $\boldsymbol{F^D}$ containing final demand for domestic products and an off-diagonal matrix $\boldsymbol{F^X}$ containing final demand for foreign products.

$$\boldsymbol{F^D} = \begin{bmatrix} \boldsymbol{F}_{11} & \boldsymbol{0} & \cdots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{F}_{22} & \dots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{F}_{mm} \end{bmatrix}, \quad \boldsymbol{F^X} = \begin{bmatrix} \boldsymbol{0} & \boldsymbol{F}_{12} & \cdots & \boldsymbol{F}_{1m} \\ \boldsymbol{F}_{21} & \boldsymbol{0} & \dots & \boldsymbol{F}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{F}_{m1} & \boldsymbol{F}_{m2} & \cdots & \boldsymbol{0} \end{bmatrix}.$$

Summing over the columns in $\boldsymbol{F}$ (post-multiplication with the summation vector $\boldsymbol{i}$) we get the global demand vector $\boldsymbol{Fi}$, the demand vector for domestic goods $\boldsymbol{F^D i}$ and demand vector for foreign goods $\boldsymbol{F^X i}$ viewed from each country in the model.

$$\boldsymbol{Fi} = \begin{bmatrix} \sum_p \boldsymbol{F}_{1p} \\ \sum_p \boldsymbol{F}_{2p} \\ \vdots \\ \sum_p \boldsymbol{F}_{mp} \end{bmatrix}, \quad \boldsymbol{F^D i} = \begin{bmatrix} \boldsymbol{F}_{11} \\ \boldsymbol{F}_{22} \\ \vdots \\ \boldsymbol{F}_{mm} \end{bmatrix}, \quad \boldsymbol{F^X i} = \begin{bmatrix} \sum_{p\neq 1} \boldsymbol{F}_{1p} \\ \sum_{p\neq 2} \boldsymbol{F}_{2p} \\ \vdots \\ \sum_{p\neq m} \boldsymbol{F}_{mp} \end{bmatrix}$$

Using the above notation we can express the global equation system either as,

$$\underbrace{\begin{bmatrix} \boldsymbol{Y}_1 \\ \boldsymbol{Y}_2 \\ \vdots \\ \boldsymbol{Y}_m \end{bmatrix}}_{\boldsymbol{Y}} = \underbrace{\begin{bmatrix} \boldsymbol{A}_{11} & \boldsymbol{A}_{12} & \cdots & \boldsymbol{A}_{1m} \\ \boldsymbol{A}_{21} & \boldsymbol{A}_{22} & \dots & \boldsymbol{A}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A}_{m1} & \boldsymbol{A}_{m2} & \cdots & \boldsymbol{A}_{mm} \end{bmatrix}}_{\boldsymbol{A}} \underbrace{\begin{bmatrix} \boldsymbol{Y}_1 \\ \boldsymbol{Y}_2 \\ \vdots \\ \boldsymbol{Y}_m \end{bmatrix}}_{\boldsymbol{Y}} + \underbrace{\begin{bmatrix} \sum_p \boldsymbol{F}_{1p} \\ \sum_p \boldsymbol{F}_{2p} \\ \vdots \\ \sum_p \boldsymbol{F}_{mp} \end{bmatrix}}_{\boldsymbol{Fi}}$$

or as

$$\underbrace{\begin{bmatrix} \boldsymbol{Y}_1 \\ \boldsymbol{Y}_2 \\ \vdots \\ \boldsymbol{Y}_m \end{bmatrix}}_{\boldsymbol{Y}} = \underbrace{\begin{bmatrix} \boldsymbol{A}_{11} & \boldsymbol{0} & \cdots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{A}_{22} & \dots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{A}_{mm} \end{bmatrix}}_{\boldsymbol{A^D}} \underbrace{\begin{bmatrix} \boldsymbol{Y}_1 \\ \boldsymbol{Y}_2 \\ \vdots \\ \boldsymbol{Y}_m \end{bmatrix}}_{\boldsymbol{Y}} + \underbrace{\begin{bmatrix} \boldsymbol{0} & \boldsymbol{A}_{12} & \cdots & \boldsymbol{A}_{1m} \\ \boldsymbol{A}_{21} & \boldsymbol{0} & \dots & \boldsymbol{A}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A}_{m1} & \boldsymbol{A}_{m2} & \cdots & \boldsymbol{0} \end{bmatrix}}_{\boldsymbol{A^X}} \underbrace{\begin{bmatrix} \boldsymbol{Y}_1 \\ \boldsymbol{Y}_2 \\ \vdots \\ \boldsymbol{Y}_m \end{bmatrix}}_{\boldsymbol{Y}} + \underbrace{\begin{bmatrix} \boldsymbol{F}_{11} \\ \boldsymbol{F}_{22} \\ \vdots \\ \boldsymbol{F}_{mm} \end{bmatrix}}_{\boldsymbol{F^D i}} + \underbrace{\begin{bmatrix} \sum_{p\neq 1} \boldsymbol{F}_{1p} \\ \sum_{p\neq 2} \boldsymbol{F}_{2p} \\ \vdots \\ \sum_{p\neq m} \boldsymbol{F}_{2p} \end{bmatrix}}_{\boldsymbol{F^X i}}$$

if we need to make a distinction between domestic and foreign goods as. Using matrix notation, the global equation system can thus be written as:

$$\begin{aligned} \boldsymbol{Y} &= \boldsymbol{AY} + \boldsymbol{Fi} \\ &= \boldsymbol{A^D Y} + \boldsymbol{A^X Y} + \boldsymbol{F^D i} + \boldsymbol{F^X i} \end{aligned}$$

The individual elements of the global model could either be identified by two separate indices for country and sector *or* a combined *supplier-cum-sector* index *i* (rows) and a *user-cum-sector* index *j* (columns). We will follow the latter convention to avoid a clutter of four indices (source country, source sector; partner country, partner sector):

$$i,j = \underbrace{1,2,\dots,n}_{\substack{country\ 1 \\ sector\ 1,2,..,n}} \ ; \ \underbrace{n+1, n+2, \ \dots, 2n}_{\substack{country\ 2 \\ sector\ 1,2,\dots,n}} ; \ \dots \ ; \ \underbrace{(m-1)n+1, \ (m-1)n+2, \dots, mn}_{\substack{country\ m \\ sector\ 1,2,\dots,n}}$$

The WIOD database (December 2013 release) identifies 40 countries plus a Rest of World aggregate with 35 sectors in each economy. The dimension of vector $\boldsymbol{Y}$ is thus 1435×1, the dimension of matrix $\boldsymbol{A}$ is 1435×1435 and the dimension of $\boldsymbol{F}$ is 1435×41.

4. The internationalization of supply chains

In this section, we derive a set of indicators of the internationalization of supply chains, applied to the WIOD dataset over the period 1995 to 2011.[2] The WIOD dataset identifies 40 countries, of which 27 belong to the European Union, plus a rest of the world aggregate. Each country is divided into 35 sectors, about half of which are services sectors.

4.1 Import content of export

As a point of departure, consider first the measure of vertical specialization in world trade derived by Hummels, Ishii and Yi (2001), which in turn draws on an earlier study by Feenstra and Hanson (1999). At the time of HIY-study there were no inter-country IO-tables available, so the authors had to define vertical specialization on basis of national IO-tables with ancillary information on imports of intermediate goods by sector. This is what their model looks like in our notation:

$$\boldsymbol{Y} = \boldsymbol{A^D Y} + \boldsymbol{F^D} + \boldsymbol{X}$$
$$\boldsymbol{M} = \boldsymbol{A^M Y} + \boldsymbol{F^M}$$

The first equation says that the domestic supply ($\boldsymbol{Y}$) equals domestic intermediate ($\boldsymbol{A^D Y}$) and final demand ($\boldsymbol{F^D}$) plus export ($\boldsymbol{X}$). The second equation breaks down the demand for imports ($\boldsymbol{M}$) into intermediate ($\boldsymbol{A^M Y}$) and final demand ($\boldsymbol{F^M}$). The equation system is block-recursive; i.e., once we have solved for the domestic supply in the first block of equations (as a function of final domestic demand and export demand),

$$\boldsymbol{Y} = [\boldsymbol{I} - \boldsymbol{A^D}]^{-1}(\boldsymbol{F^D} + \boldsymbol{X}),$$

we can also calculate the equilibrium demand for imports:

$$\boldsymbol{M} = \boldsymbol{A^M}[\boldsymbol{I} - \boldsymbol{A^D}]^{-1}(\boldsymbol{F^D} + \boldsymbol{X}) + \boldsymbol{F^M}$$

Note that imports are used for three purposes. *Firstly*, to satisfy final demand for imported goods and services $(\boldsymbol{M_1} = \boldsymbol{F^M})$; *secondly*, to satisfy demand for imported inputs for the production for the domestic market $(\boldsymbol{M_2} = \boldsymbol{A^M}[\boldsymbol{I} - \boldsymbol{A^D}]^{-1}\boldsymbol{F^D})$; and *thirdly*, to satisfy demand for imported inputs for the production for the export market $(\boldsymbol{M_3} = \boldsymbol{A^M}[\boldsymbol{I} - \boldsymbol{A^D}]^{-1}\boldsymbol{X})$. Summing the third element over all sectors ($\boldsymbol{i'M_3}$) and dividing with the aggregate export ($\boldsymbol{i'X}$) we get the HIY-measure (2001) of vertical specialization,

$$\boldsymbol{VS} = \frac{\boldsymbol{i'A^M}[\boldsymbol{I} - \boldsymbol{A^D}]^{-1}\boldsymbol{X}}{\boldsymbol{i'X}},$$

which measures the average import content of the export vector. Since the latter may include some re-imported ("returning") domestic value after processing abroad, the HIY-measure is an imperfect proxy for the foreign content of the export vector.

4.2 Share of foreign value-added in export

Due to the progress in constructing inter-country input-output tables (TiVA, WIOD, UNCTAD-EORA GVC Database), the foreign value-added shares can now be calculated more precisely by deducting the domestic value-added that returns home after processing abroad. Los, Timmer and de Vries (2014) provide a formula for doing just that. Using the WIOD dataset they show that the foreign

[2] See Timmer *et al.*(2012) and Dietzenbacher *et al.* (2013) for more information on the WIOD dataset and its construction.

value-added share in 14 manufacturing product groups has increased significantly between 1995 and 2011, with only a temporary dip in the trend in conjunction with the financial crises in 2008-2009.

The Los, Timmer and de Vries (2014) indicator of foreign value-added is derived from the formula

$$\boldsymbol{V^F} = \boldsymbol{v} \cdot [\boldsymbol{I} - \boldsymbol{A}]^{-1}\boldsymbol{F}\,,$$

which calculates the value-added in final demand. We will offer an alternative definition based on the value added content in production, derived by tracing the supply chain backward (upstream) instead of forward (downstream).

Let us start by showing that the value-added created by a sector plus the value-added embodied in the inputs sum to gross production value, or expressed in per unit of output to one. To prove this perhaps self-evident proposition we have to work backward through the supply chain and sum the value-added at each stage:

$$V_j = \underbrace{v_j}_{\substack{VA\ by\\ sector\\ j\ per\\ unit\ of\\ output}} + \underbrace{\sum_i a_{ij} v_i}_{\substack{input\\ weighted\\ VA\ of\ 1{:}st\ tier\\ suppliers\\ to\ sector\ j}} + \underbrace{\sum_i \sum_k a_{ij} a_{ki}\, v_k}_{\substack{input\\ weighted\\ VA\ of\ 2{:}nd\ tier\\ suppliers\ to\ sector\ j\\ (the\ suppliers\ of\\ the\ 1{:}st\ tier\\ suppliers)}} + \underbrace{\sum_i \sum_k \sum_l a_{ij} a_{ki}\, a_{lk} v_l}_{\substack{input\\ weighted\\ VA\ of\ 3{:}rd\ tier\\ suppliers\ to\ sector\ j\\ (the\ suppliers\ of\\ the\ 2{:}nd\ tier\\ suppliers)}} + \cdots \quad .$$

Stacking all sectors vertically using matrix notation we have:

$$\begin{aligned}\boldsymbol{V} &= \boldsymbol{v} + \boldsymbol{A}'\boldsymbol{v} + \boldsymbol{A}'^2\boldsymbol{v} + \boldsymbol{A}'^3\boldsymbol{v} + \cdots \\ &= \underbrace{\boldsymbol{v}}_{\substack{direct\\ VA}} + \underbrace{\boldsymbol{A}'[\boldsymbol{I} - \boldsymbol{A}']^{-1}\,\boldsymbol{v}}_{\substack{VA\ embodied\\ in\ inputs\ bought\\ from\ other\ sectors}} = [\boldsymbol{I} - \boldsymbol{A}']^{-1}\boldsymbol{v}\end{aligned}$$

Finally, substituting in the definition of $\boldsymbol{v}$ in the above formula, we get

$$\begin{aligned}\boldsymbol{V} &= [\boldsymbol{I} - \boldsymbol{A}']^{-1}\,\boldsymbol{v} \\ &= \underbrace{[\boldsymbol{I} - \boldsymbol{A}']^{-1}\,[\boldsymbol{I} - \boldsymbol{A}']}_{\equiv \boldsymbol{I}}\ \boldsymbol{i} = \boldsymbol{i}\end{aligned}$$

Thus, recalling that $\boldsymbol{i} = [1,\ 1, \ldots, 1]$ is the unit vector, the value added created by a sector plus the value added embodied in the inputs used by the sector add to 100 percent (QED).

Now, in order to derive the foreign value-added share in production we begin by asking how much value-added *per unit of output* that country ***p = 1, 2, …, m*** contributes to any given supply chain in the world. This can be calculated by tracing the contribution of country ***p*** in the supply chain,

$$\underbrace{\boldsymbol{V_p}}_{mn\times 1} = \boldsymbol{v_p} + \boldsymbol{A}'\boldsymbol{v_p} + \boldsymbol{A}'\boldsymbol{A}'\boldsymbol{v_p} + \boldsymbol{A}'\boldsymbol{A}'\boldsymbol{A}'\boldsymbol{v_p} + \cdots = \underbrace{[\boldsymbol{I} - \boldsymbol{A}']^{-1}}_{mn\times mn}\ \underbrace{\boldsymbol{v_p}}_{mn\times 1} \quad ; \qquad \boldsymbol{v_p} = \begin{bmatrix}\boldsymbol{0}\\ \vdots\\ \boldsymbol{v_p}\\ \vdots\\ \boldsymbol{0}\end{bmatrix}$$

where $\boldsymbol{v_p}$ is the global value-added vector with zeroes in all positions but for country ***p*** (35 sectors in the WIOD dataset). This formula can be looped over all countries ***p*** or, alternatively, be done in one step if we define $\boldsymbol{v}$ as *block-diagonal* matrix:

$$\underbrace{\boldsymbol{V}}_{mn\times m} = \underbrace{[\boldsymbol{I}-\boldsymbol{A}']^{-1}}_{mn\times mn}\underbrace{\boldsymbol{diag}(\boldsymbol{v})}_{mn\times m} \; ; \qquad \boldsymbol{diag}(\boldsymbol{v}) = \underbrace{\begin{bmatrix} \boldsymbol{v}_1 & \boldsymbol{0} & \cdots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{v}_2 & \ldots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{v}_m \end{bmatrix}}_{mn\times m}.$$

If we write out the individual blocks of $\boldsymbol{V}$ we have,

$$\underbrace{\begin{bmatrix} \boldsymbol{V}_{11} & \boldsymbol{V}_{12} & \cdots & \boldsymbol{V}_{1m} \\ \boldsymbol{V}_{21} & \boldsymbol{V}_{22} & \ldots & \boldsymbol{V}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{V}_{m1} & \boldsymbol{V}_{m2} & \cdots & \boldsymbol{V}_{mm} \end{bmatrix}}_{\boldsymbol{V}} = \underbrace{\begin{bmatrix} \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_1\boldsymbol{v}_1 & \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_1\boldsymbol{v}_2 & \cdots & \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_1\boldsymbol{v}_m \\ \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_2\boldsymbol{v}_1 & \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_2\boldsymbol{v}_2 & \ldots & \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_2\boldsymbol{v}_m \\ \vdots & \vdots & \ddots & \vdots \\ \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_m\boldsymbol{v}_1 & \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_m\boldsymbol{v}_2 & \cdots & \langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_m\boldsymbol{v}_m \end{bmatrix}}_{[\boldsymbol{I}-\boldsymbol{A}']^{-1}\boldsymbol{diag}(\boldsymbol{v})}$$

where $\langle[\boldsymbol{I}-\boldsymbol{A}']^{-1}\rangle_i$ refers to the column-blocks in row-block ***i = 1, 2, …, m*** of the global Leontief inverse. Note that the *domestic* value-added ($\boldsymbol{v}^{\boldsymbol{D}}$) from the perspective of each individual country are recorded along the block-diagonal of $\boldsymbol{V}$,

$$\boldsymbol{v}^{\boldsymbol{D}} = \boldsymbol{diag}(\boldsymbol{V})\boldsymbol{i},$$

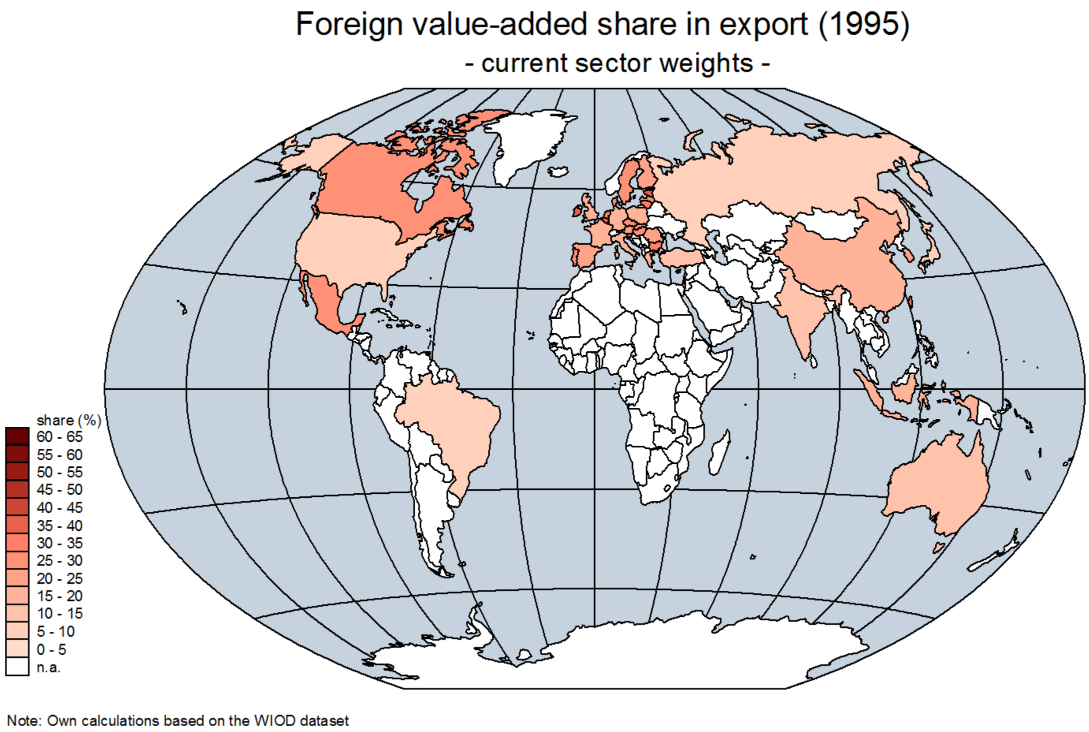
whereas the foreign value-added shares are recorded on the off-diagonal terms. The simplest way of calculating the aggregate foreign value-added share ($\boldsymbol{v}^{\boldsymbol{M}}$) is to take one minus the domestic value-added share,

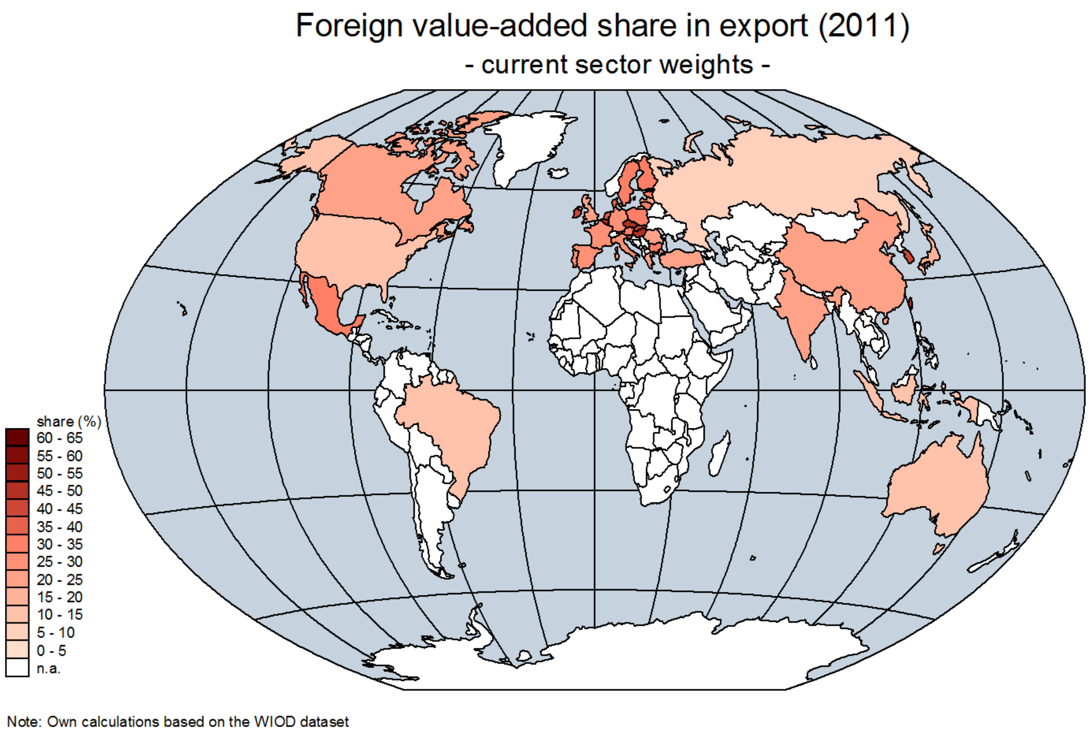
$$\boldsymbol{v}^{\boldsymbol{M}} = \boldsymbol{i} - \boldsymbol{v}^{\boldsymbol{D}}.$$

The regional shares are found by summing the appropriate columns of $\boldsymbol{V}$.

Figure 1 plots the foreign value-added share in the aggregate export of the WIO reporters, using current export weights of each sector. The foreign value-added differ substantially between countries, ranging from about 5 to 60 percent. The foreign value-added shares tend to be higher in smaller and emerging economies, which is especially clear in Europe. But also large economies such as China have a relatively large foreign value-added share, reflecting often labour-intensive assembly of foreign inputs into consumption goods for the world market.

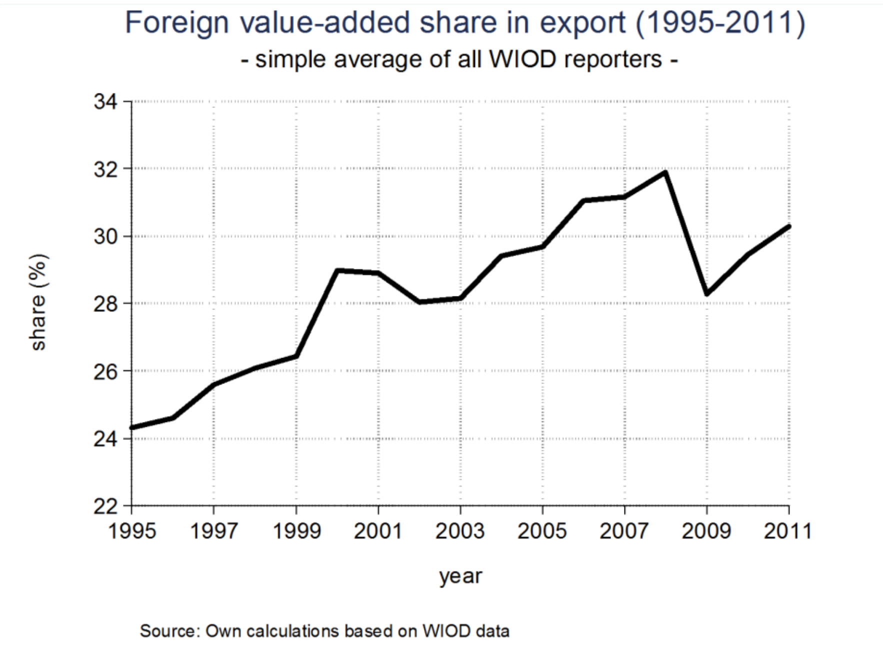
Figure 1


Foreign value-added share in export (1995)
- current sector weights -
share (%)
60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
n.a.
Note: Own calculations based on the WIOD dataset


Foreign value-added share in export (2011)
- current sector weights -
share (%)
60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
n.a.
Note: Own calculations based on the WIOD dataset

As shown in Figure 2, the foreign value-added share has increased from an average of approximately 24 percent in 1995 to just above 30 percent in 2011, reflecting an increase in the international fragmentation of production and a deeper interconnection of the economies. The trend was temporarily broken by the financial crises 2008-2009, as shown before by *Los et al.* (2014).

Figure 2



5. Geographic length of supply chains

The importance of proximity in global value chains has been studied by Los and Temurshoev (2012). Combining a global input-output table with geographic data on the distance within and between countries, they calculate the expected distance a product will travel throughout the input-output structure of the world economy, including the final leg(s) between the country-of-completion and the consumption markets around the world. The inclusion of the last leg can be questioned since firms sourcing decisions may be more sensitive to the cost and time of distance than consumers. Thus, if the issue is "why do firms source regionally rather than globally", as suggested by Baldwin and Lopez-Gonzalez (2013) amongst others, the two dimensions should perhaps be kept apart.

Another more "interpretative" issue with the Los and Temurshoev (2012) indicator is that it traces the supply chains (*plural*) forward from each production node in the world economy to the countries-of-completion. For example, steel may be used as inputs by a large number of industries in the world economy, who in turn produce processed steel for yet other industries. The output of the steel industry is thus part of very many supply chains (*plural*), each of which may be more or less regional or global in scope. From an interpretive point of view it may therefore be better to trace the supply chain (*singular*) *backward* from each industry rather than forward.

5.1 Measuring distance in the supply chain

Consider sector $j = 1, 2, \ldots, mn$. Assign zero distance to final assembly, assuming that final assembly is taking place in one location in each country. The first distance we need to measure is the distance to the first-tier suppliers of industry *j*. In lack of more specific location information in the WIOD dataset we approximate the distance to the domestic suppliers of inputs (if any) with the average distance between the most populous cities of the country, whereas the distance to foreign suppliers is approximated with the average distance between the most populous cities of each country. The data is taken from the gravity database made available by CEPII.[3]

The input-weighted distance to the *first-tier* suppliers (*i = 1,2 , …, mn*) of industry *j* is given by,

$$d_{j,1} = \sum_i a_{ij} d_{ij},$$

where subscript 1 refers to the *first-tier* supplies. In turn, the input-weighted distance to the *first-tier* suppliers (*k = 1,2 , …, mn*) of industry *i = 1,2 , …, mn* – i.e., the *second-tier* suppliers of industry *j* – is given by $d_{k,1} = \sum_i a_{ki} d_{ki}$, and so on and so forth upstream in the supply chain. The total length of the supply chain is calculated by adding the distance of the different legs of the supply chain using the inputs coefficients of of the final product as weights (per unit of output),

$$d_j = \underbrace{\sum_i a_{ij} d_{ij}}_{d_{j,1}} + \sum_i a_{ij} \underbrace{\sum_k a_{ki} d_{ki}}_{d_{i,1}} + \sum_i \sum_k a_{ij} a_{ki} \underbrace{\sum_l a_{lk} d_{lk}}_{d_{k,1}} + \cdots$$

which in matrix notation can be written as

$$\boldsymbol{d} = \boldsymbol{d_1} + \boldsymbol{A}'\boldsymbol{d_1} + \boldsymbol{A}'\boldsymbol{A}'\boldsymbol{d_1} + \cdots.$$

The solution to this equation system is,

$$\boldsymbol{d} = [\boldsymbol{I} - \boldsymbol{A}']^{-1}\,\boldsymbol{d_1}\,; \qquad \boldsymbol{d_1} = diag(\boldsymbol{A}'\boldsymbol{D})\,\boldsymbol{i}, \qquad \boldsymbol{D} = \underbrace{\begin{bmatrix} \boldsymbol{D_{11}} & \boldsymbol{D_{12}} & \cdots & \boldsymbol{D_{1m}} \\ \boldsymbol{D_{21}} & \boldsymbol{D_{22}} & \cdots & \boldsymbol{D_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{D_{m1}} & \boldsymbol{D_{m2}} & \cdots & \boldsymbol{D_{mm}} \end{bmatrix}}_{\substack{m \times m\ countries \\ n \times n\ sectors\ in\ each\ block}}$$

where $\boldsymbol{D}$ is a matrix containing the distance data within and between countries and $\boldsymbol{d_1}$ a vector containing the input-weighted distance to the first-tier suppliers (from the perspective of each sector and country in the world economy). The formula $\boldsymbol{d_1} = diag(\boldsymbol{A}'\boldsymbol{D})\boldsymbol{i}$ is just a matrix instruction on how to calculate the input-weighted distance to the first-tier suppliers, which are fond by picking out the diagonal terms of the $\boldsymbol{A}'\boldsymbol{D}$-matrix and putting them in column vector with dimension *mn×1*.

5.2 Results

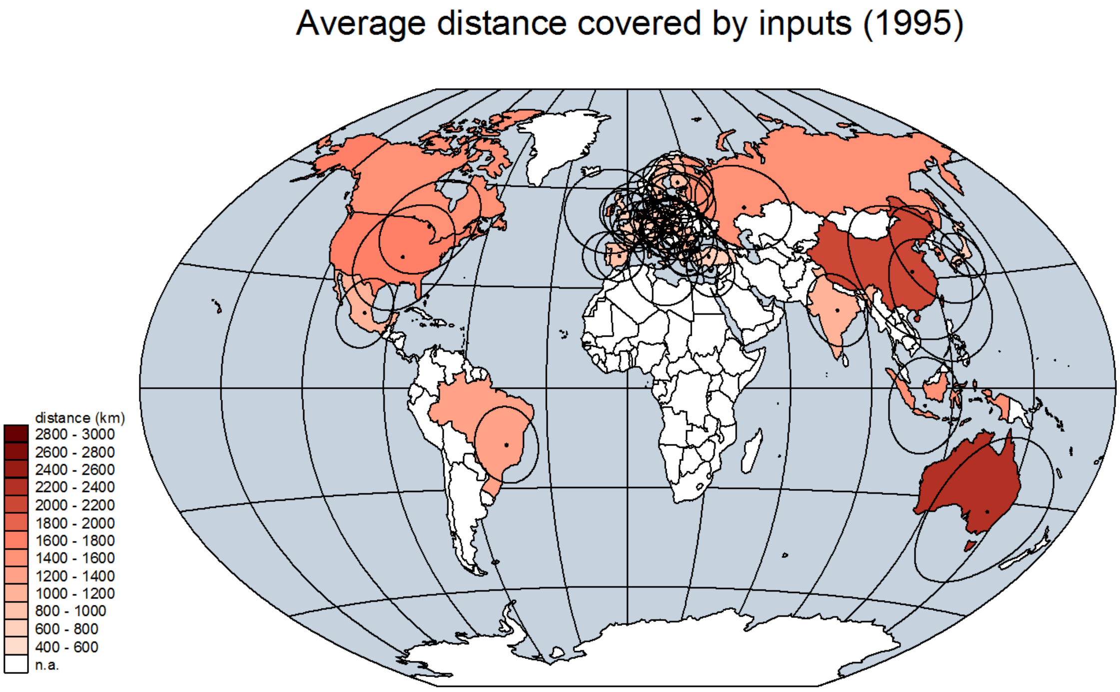
Figure 3 shows the average length of the supply chains for the WIOD sample of countries, where each sectors is weighted by their GDP weight. [4].(Change weights to export weights?). The lengths are indicated by the colour of the maps, combined with spherical circles (population-weighted centroid) with a radius equal to the length of the supply chain in order to illustrate the most likely suppliers of inputs for each country. Note that the supply chains are relatively short in Europe, which of course partly is affected by the geography. [Elaborate…]

---

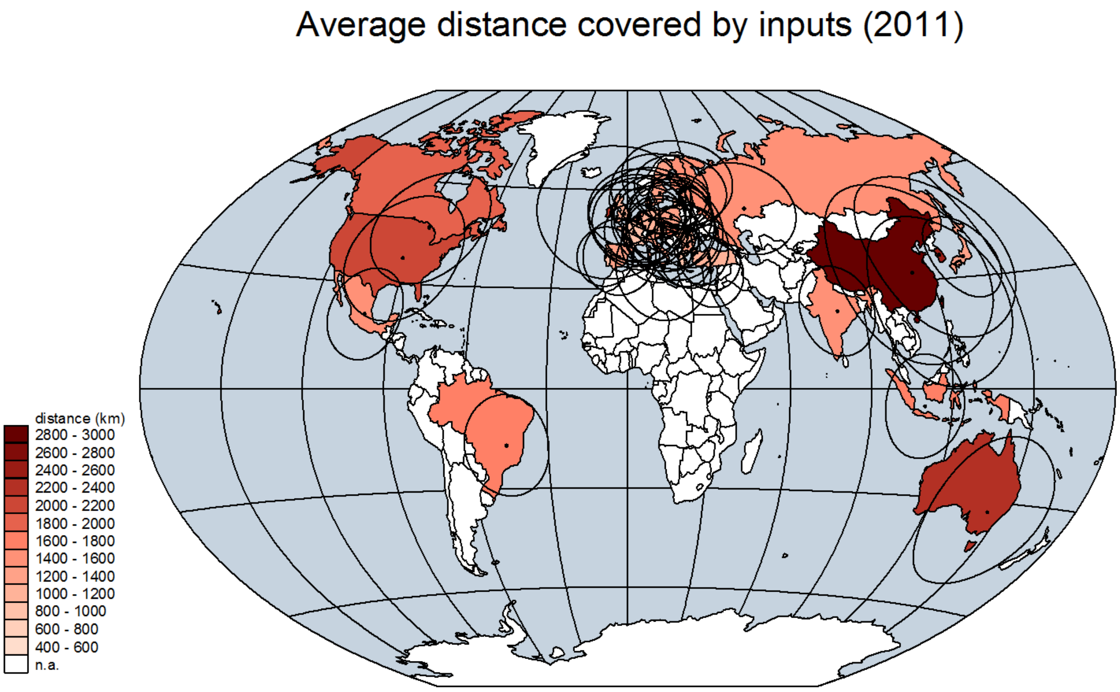
[3] Mayer and Zignago (2011). http://www.cepii.fr/anglaisgraph/bdd/distances.htm

[4] Calculations were also made using current sector weights. The results were very similar to using fixed sector weights. Results based on current sector weights are available upon request.

Figure 3



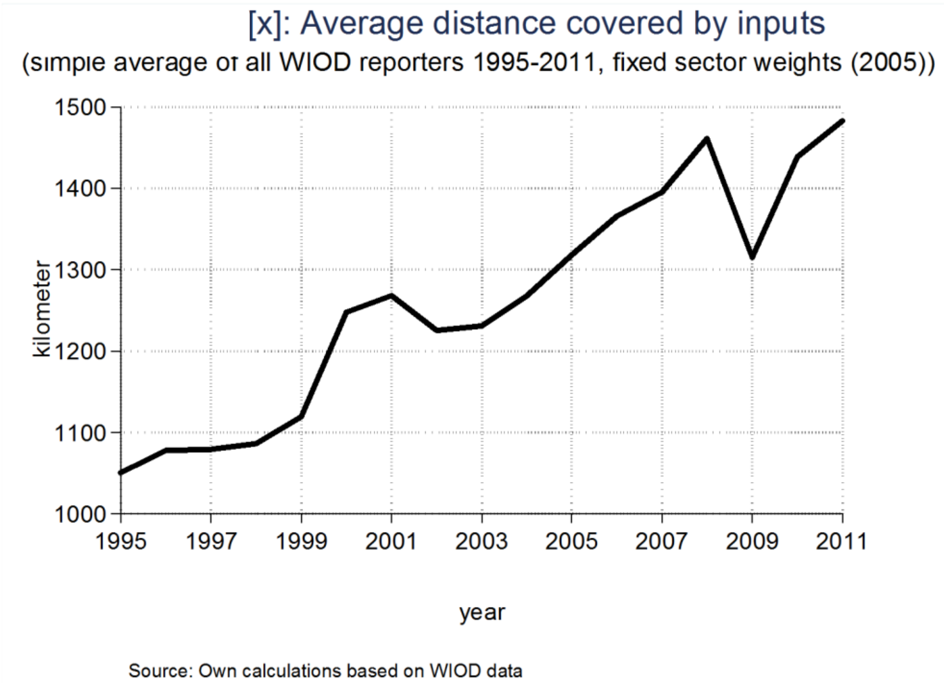
Note: Own calculations based on the WIOD dataset



Note: Own calculations based on the WIOD dataset

The global time trend between 1995 and 2011 is shown in Figure 4. The development of the average distance of all reporters in WIOD shows a clear positive trend, witrh a pro-cyclical pattern. Aside from the decline in distance during 2002 and the financial crisis in 2009, the average distance covered by inputs increased every year. In 1995, the average distance was 1050 km, a distance comparable with the straight-line distance between Paris and Madrid. In 2011, the average distance had increased to almost 1500 km, a distance comparable with the straight-line distance between Paris and Lisbon. Over the entire period the average distance increased by 41 percent.

Figure 4



As shown in Table 2, all sectors experience a significant growth in average distance, except for private Households with employed persons. The longest supply chain is found in the Coke, Refined Petroleum and Nuclear Fuel sector. Manufacturing sectors also have generally longer supply chains than services sectors, but there is also an important increase in the length of services value chains between 1995 and 2011.

Table 2. Average length of supply chains by industry

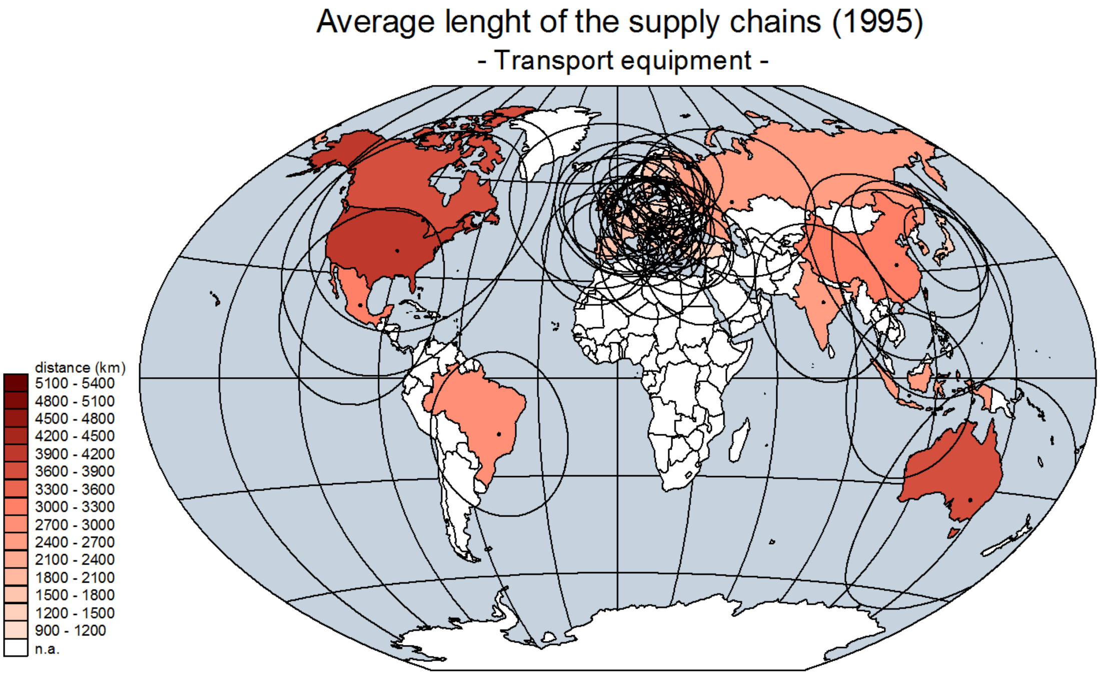
Sector	1995	2011	% change 1995/2011
Agriculture, Hunting, Forestry and Fishing	1074.1	1671.2	55.6%
Mining and Quarrying	1058.6	1555.7	47.0%
Food, Beverages and Tobacco	1581.2	2141.6	35.4%
Textiles and Textile Products	1691.0	2407.0	42.3%
Leather, Leather and Footwear	1725.1	2198.7	27.5%
Wood and Products of Wood and Cork	1614.5	2113.0	30.9%
Pulp, Paper, Paper , Printing and Publishing	1545.0	2013.5	30.3%
Coke, Refined Petroleum and Nuclear Fuel	3059.4	3877.5	26.7%
Chemicals and Chemical Products	1896.4	2738.0	44.4%
Rubber and Plastics	1917.4	2679.7	39.8%
Other Non-Metallic Mineral	1416.0	2087.1	47.4%
Basic Metals and Fabricated Metal	2035.0	2960.4	45.5%
Machinery, Nec	1894.4	2615.2	38.1%
Electrical and Optical Equipment	2312.4	3189.9	37.9%
Transport Equipment	1986.1	2927.7	47.4%
Manufacturing, Nec; Recycling	1636.4	2449.0	49.7%
Electricity, Gas and Water Supply	1401.3	2334.6	66.6%
Construction	1392.2	1900.2	36.5%
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	857.2	1227.4	43.2%
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	834.3	1146.0	37.4%
Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	713.6	968.5	35.7%
Hotels and Restaurants	1070.0	1373.0	28.3%
Inland Transport	1057.4	1798.9	70.1%
Water Transport	1639.9	2400.4	46.4%
Air Transport	1623.3	2700.0	66.3%
Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	1070.5	1532.4	43.2%
Post and Telecommunications	779.0	1257.9	61.5%
Financial Intermediation	640.0	888.5	38.8%
Real Estate Activities	403.4	633.8	57.1%
Renting of M&Eq and Other Business Activities	925.9	1160.7	25.4%
Public Admin and Defence; Compulsory Social Security	756.2	979.1	29.5%
Education	476.0	615.4	29.3%
Health and Social Work	929.4	1209.8	30.2%
Other Community, Social and Personal Services	935.1	1244.6	33.1%
Private Households with Employed Persons	38.6	30.0	-22.3%

5.2.2 Examples of developments from two industries

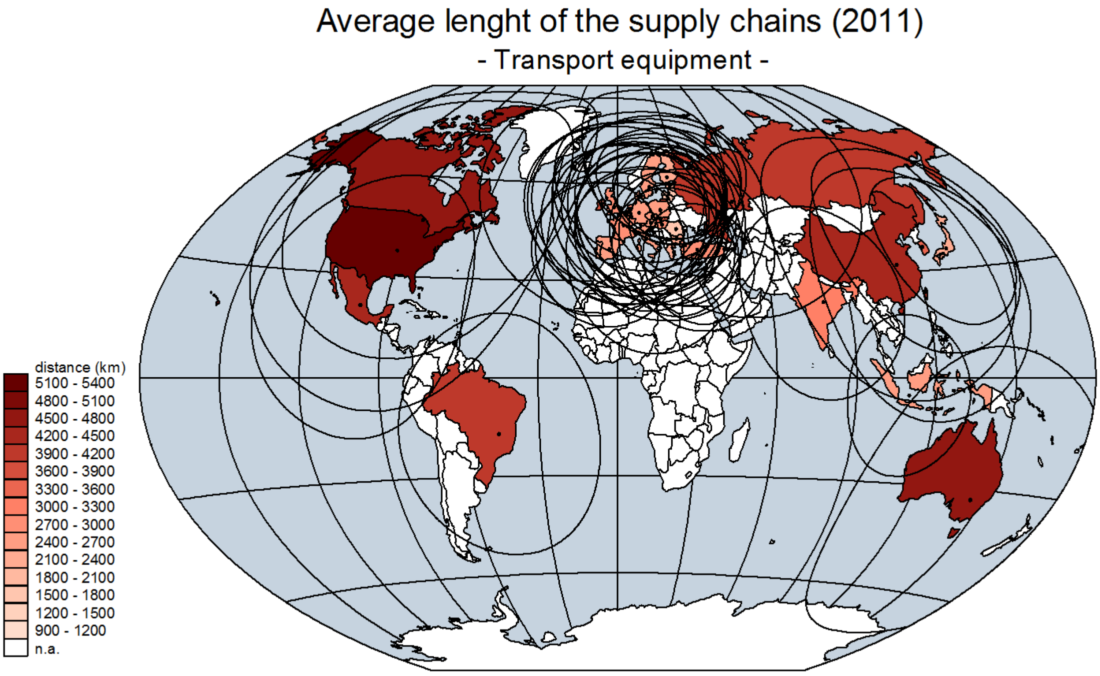
As shown in previous work by the OECD (2013), the foreign value added content of exports varies considerably between industries. For basic industries this share is substantially high due to imports of primary production inputs such as coke, basic metals etc. These are also sectors considered to be more integrated into the GVCs. The production of services tends to be less sliced up compared with manufacturing products. Distinguishing between manufacturing and service sectors, we expect service industries to have shorter distance in the value chain than manufacturing industries.

Two illustration are provided below: (a) transport equipment and (b) financial intermediation. The plots for the other sectors will be uploaded in an electronic annex.

Figure 5

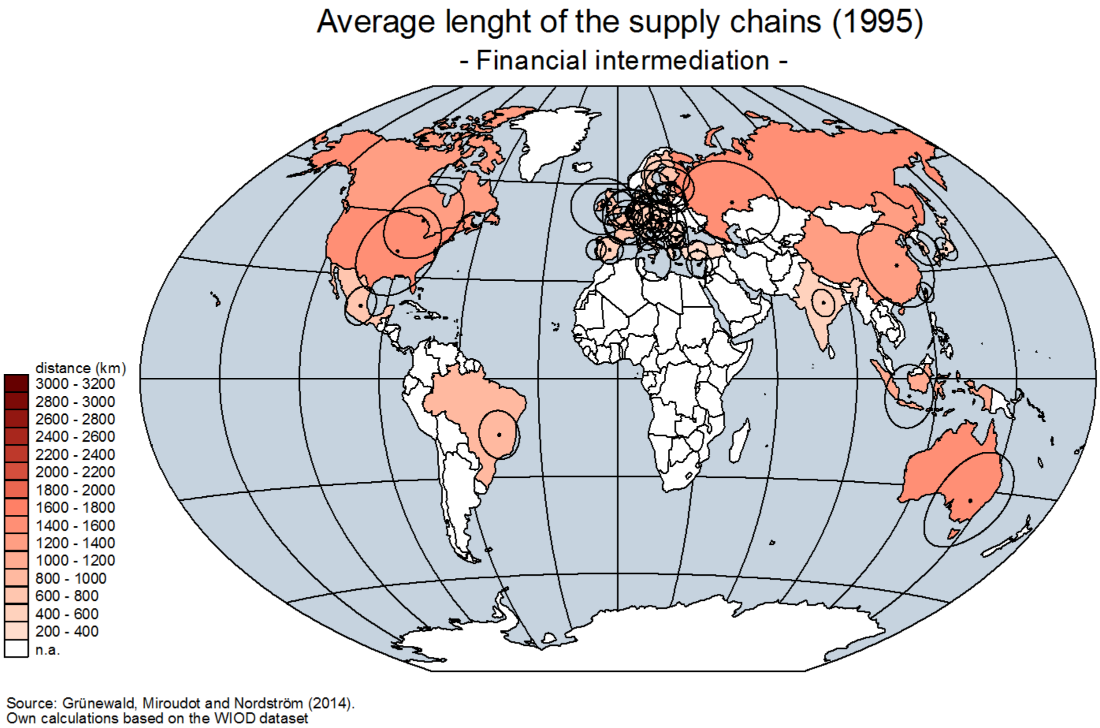


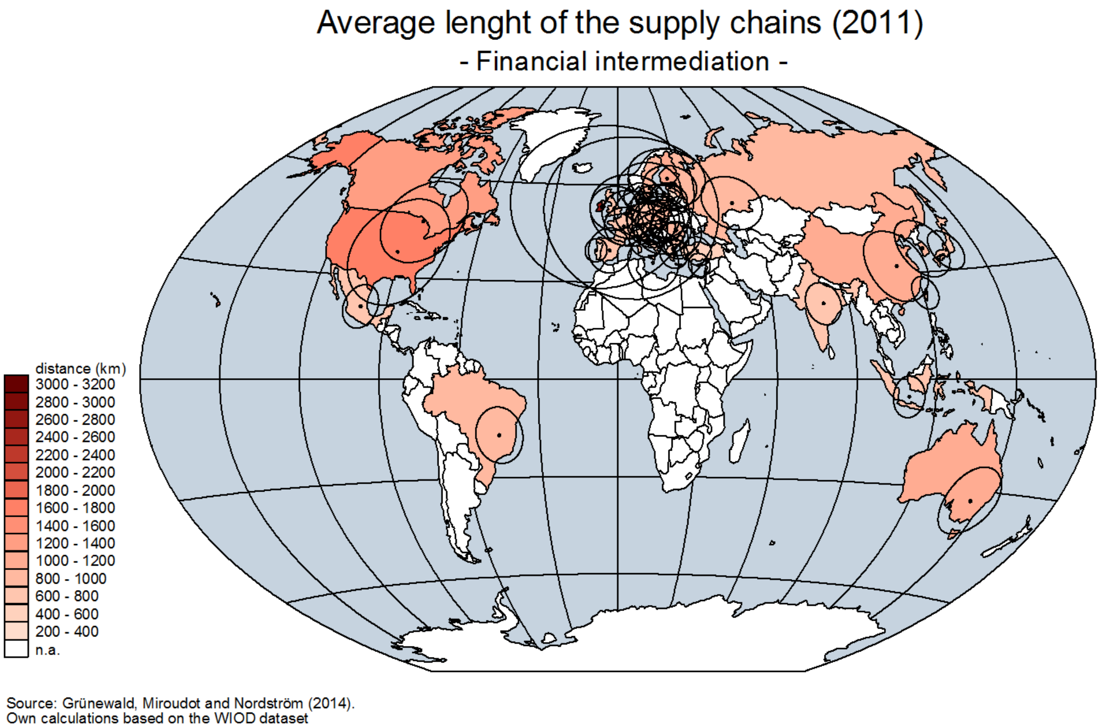
Source: Grünewald, Miroudot and Nordström (2014).
Own calculations based on the WIOD dataset



Source: Grünewald, Miroudot and Nordström (2014).
Own calculations based on the WIOD dataset

Figure 6


Average lenght of the supply chains (1995)
- Financial intermediation -
distance (km)
3000 - 3200
2800 - 3000
2600 - 2800
2400 - 2600
2200 - 2400
2000 - 2200
1800 - 2000
1600 - 1800
1400 - 1600
1200 - 1400
1000 - 1200
800 - 1000
600 - 800
400 - 600
200 - 400
n.a.
Source: Grünewald, Miroudot and Nordström (2014).
Own calculations based on the WIOD dataset


Average lenght of the supply chains (2011)
- Financial intermediation -
distance (km)
3000 - 3200
2800 - 3000
2600 - 2800
2400 - 2600
2200 - 2400
2000 - 2200
1800 - 2000
1600 - 1800
1400 - 1600
1200 - 1400
1000 - 1200
800 - 1000
600 - 800
400 - 600
200 - 400
n.a.
Source: Grünewald, Miroudot and Nordström (2014).
Own calculations based on the WIOD dataset

6. International production stages

As shown by Fally (2012), input-output tables can be used to calculate how many stages are embodied in the production of a good or service. In this section, we decompose the supply chain into domestic and international production stages.

We start by deriving Fally´s measure of embodied production stages, making use of the accounting identity that the value-added of the producing sector and the value-added embodied in the inputs used by the sector sum to 100 percent of the production costs,

$$\boldsymbol{i} = \boldsymbol{v} + \boldsymbol{A'v} + \boldsymbol{A'^2v} + \boldsymbol{A'^3v} + \cdots$$

where $\boldsymbol{i}$ is a vector of ones with the same number of rows as in $\boldsymbol{A'}$. Multiply now the first term on the right hand side with one; the second term with two; the third term with three, etcetera,

$$\begin{aligned} N &= (\boldsymbol{1} \times \boldsymbol{v}) + (\boldsymbol{2} \times \boldsymbol{A'v}) + (\boldsymbol{3} \times \boldsymbol{A'^2v}) + (\boldsymbol{4} \times \boldsymbol{A'^3v}) + \cdots \\ &= [\boldsymbol{I} + 2\boldsymbol{A'} + 3\boldsymbol{A'^2} + 4\boldsymbol{A'^3} + \cdots]\,\boldsymbol{v} \\ &= [\boldsymbol{I} - \boldsymbol{A'}]^{-2}\,\boldsymbol{v} \\ &= [\boldsymbol{I} - \boldsymbol{A'}]^{-1}\,\boldsymbol{i} \end{aligned}$$

where the last step of the calculations make use of the definition of $\boldsymbol{v} = [\boldsymbol{i} - \boldsymbol{A'i}] = [\boldsymbol{I} - \boldsymbol{A'}]\,\boldsymbol{i}$.

Why do we multiply the second term with 2, the third term with 3, etc.? The idea is that the value-added contributed by first-tier suppliers undergoes two production stages: Firstly, the production of the inputs themselves, and secondly, the assembly of the inputs into the final product. Likewise, the value added contributed by second-tier suppliers goes through three production stages: firstly, the production of the inputs; secondly, the assembly into more processed inputs by first-tier suppliers; and thirdly, final assembly into the finished product. That is, the value added at each stage is multiplied with one plus the number of remaining stages in the supply chain.

An alternative way of deriving the number of embodied production stages is to sum the *gross* value of each stage of the production process, where the first term $\boldsymbol{i}$ is the *gross value* of the finished product (normalized to one); $\boldsymbol{A'i} = \boldsymbol{0} + \boldsymbol{A'v} + \boldsymbol{A'^2v} + \boldsymbol{A'^3v} + \cdots$ is the *gross value* of the first-tier supplies; $\boldsymbol{A'^2i} = \boldsymbol{0} + \boldsymbol{0} + \boldsymbol{A'^2v} + \boldsymbol{A'^3v} + \cdots$ is the *gross value* of the second-tier supplies, etc.. Now, if we sum the *gross value* of each stage of the supply chain we get,

$$\begin{aligned} \boldsymbol{N} &= \boldsymbol{i} + \boldsymbol{A'i} + \boldsymbol{A'^2i} + \boldsymbol{A'^3i} + \cdots \\ &= [\boldsymbol{I} - \boldsymbol{A'}]^{-1}\,\boldsymbol{i} \end{aligned}$$

which is equivalent to Fally´s measure. We point out this equivalent because it facilitates the decomposition into domestic and international production stages, an issue we will address shortly. Note that the minimum number of production stages is 1 if no inputs are bought from other firms and that number of production stages approaches infinity if the value added at each stages of the supply chain approaches zero.

$$\lim_{\boldsymbol{A'i} \to 0} \boldsymbol{N} = 1$$
$$\lim_{\boldsymbol{A'i} \to 1} \boldsymbol{N} = \infty$$

Now, using $\boldsymbol{A'} = \boldsymbol{A^{D'}} + \boldsymbol{A^M}$, where $\boldsymbol{A^M} = \boldsymbol{A^{X'}}$, it is straightforward to decompose the supply chains into "national" and "international" stages from the perspective of the consecutive buyers in the supply chain (locally sourced inputs are counted as "national" production stages and imported inputs as "international" production stages):

$$\begin{aligned} \boldsymbol{N^D} &= \boldsymbol{i} + \boldsymbol{A^{D\prime}i} + \boldsymbol{A^\prime A^{D\prime} i} + \boldsymbol{A^{\prime 2} A^{D\prime} i} + \cdots \\ &= \boldsymbol{i} + [\boldsymbol{I} - \boldsymbol{A^\prime}]^{-1} \boldsymbol{A^{D\prime} i} \end{aligned}$$

$$\begin{aligned} \boldsymbol{N^M} &= \boldsymbol{0} + \boldsymbol{A^M i} + \boldsymbol{A^\prime A^M i} + \boldsymbol{A^{\prime 2} A^M i} + \cdots \\ &= [\boldsymbol{I} - \boldsymbol{A^\prime}]^{-1} \, \boldsymbol{A^M i} \end{aligned}$$

The (technical) interpretations of these measures are:

- $\boldsymbol{N^D}$**:** Number of production stages that cross no borders, weighted by the gross value of each stage of the supply chain (relative to the value of the finished product).
- $\boldsymbol{N^M}$**:** Number of production stages that cross a border, weighted by the gross value of each stage of the supply chain (relative to the value of the finished product).

The international production stages can in turn be divided into production stages in individual foreign countries $p \neq d$,

$$\begin{aligned} \boldsymbol{N_p^M} &= \boldsymbol{0} + \boldsymbol{A_p^M i} + \boldsymbol{A^\prime A_p^M i} + \boldsymbol{A^{\prime 2} A_p^M i} + \cdots \\ &= [\boldsymbol{I} - \boldsymbol{A^\prime}]^{-1} \boldsymbol{A_p^M i} \end{aligned}$$

where all blocks of $\boldsymbol{A_p^M}$ are zero apart from column $\boldsymbol{p}$ that equals the elements of $\boldsymbol{A^M}$. The results can then be added into "regions" of the world economy in order to study how many production stages that takes place domestically, regionally and extra-regionally.

6.2 Results

[TO BE INCLUDED]

7. Concluding remarks

In the past five years, the concept of "global value chain" (GVC) has become very popular to describe the way firms vertically fragment their production into different stages located in different economies. GVCs suggest that production today is truly global with inputs coming from all parts of the world before being assembled into final products also shipped all over the world, but how global are global value chains?

In this paper we look at the average distance travelled by inputs along the value chains. We also decompose the supply chain into domestic and international production stages, where there are international border crossings and where stages are within the same country. This enable us to study how many stages of the value chains that take place domestically, regionally and extra-regionally.

Our measure of the average distance travelled by inputs has increased over the period. Thus, supply chains have become longer. We also conclude that manufacturing sectors have longer supply chains than service sectors. The distance travelled by inputs has increased for all sectors implying that supply chains have become more global.

Bibliography

Antràs, P., Chor, D., Fally, T. and R. Hillberry (2012). "Measuring the Upstreamness of Production and Trade Flows", *American Economic Review* 102(3), 412-416.

Baldwin, R. and J. Lopez-Gonzalez (2013). "Supply-Chain Trade: A Portrait of Global Patterns and Several Testable Hypotheses", *NBER Working Papers* 18957, National Bureau of Economic Research.

Chenery, H. (1953). "Regional analysis". In: H. Chenery, P. Clark and V. Cao Pinna (eds), *The Structure and Growth of the Italian Economy*, Rome: US Mutual Security Agency, 91-129.

Dietzenbacher, E. and I. Romero (2007). "Production Chains in an Interregional Framework: Identification by Means of Average Propagations Lengths", *International Regional Science Review* 30, 362-383.

Dietzenbacher,E., Los, B., Stehrer, R., Timmer, M. and de Vries, G. (2013). The Construction of World Input-Output Tables in the WIOD project, *Economic Systems Research* 25(1), 71-98.

Fally, T. (2012). "Production Staging: Measurement and Facts", University of Colorado -Boulder, May.

Feenstra, R. and G. Hanson (1999). "The Impact of Outsourcing and High-Technology Capital on Wages: Estimates for the U.S., 1979-1990", *Quarterly Journal of Economics* 114(3), 907-940.

Gereffi, G., Humphrey, J., Kaplinsky, R. and T. Sturgeon (2001). "Globalisation, Value Chains and Development", *IDS Bulletin* 32(3), 1-8.

Hummels, D., Ishii, J. and K.-M. Yi (2001). "The Nature and Growth of Vertical Specialization in World Trade", *Journal of International Economics* 54(1), 75-96.

Johnson, R. and G. Noguera (2012). "Accounting for Intermediates: Production Sharing and Trade in Value Added", *Journal of International Economics* 86(2), 224-236.

Koopman, R., Wang, Z. and S.-J. Wei (2014). "Tracing Value-Added and Double Counting in Gross Exports", *American Economic Review* 104(2), 459-494.

Leontief, W. and A. Strout (1963). "Multiregional Input-Output Analysis". In: T. Barna (ed.), *Structural Interdependence and Economic Development*, New York: St-Martin's Press, 119-150.

Los, B. and U. Temurshoev (2012). "Measure of Globalization in a World with Fragmented Production", paper presented at the 20th International Input-Output Conference, Bratislava.

Los, B., Timmer, M. and G. de Vries (2014). "How Global are Global Value Chains? A New Approach to Measure International Fragmentation", *Journal of Regional Science*, forthcoming.

Mayer, T. and S. Zignago (2011). "Notes on CEPII's distances measures (GeoDist)", *CEPII Working Paper* 2011-25.

OECD (2013). Interconnected Economies: Benefiting from Global Value Chains, OECD Publishing.

Nordström, H. (2014). "A Technical Note on GVC Analysis (Using the OECD-WTO TiVA Dataset)", National Board of Trade, 7 February, mimeo.

Timmer, M. (ed) (2012). "The World Input-Output Database (WIOD): Contents, Sources and Methods", WIOD Working Paper Number 10, downloadable at http://www.wiod.org/publications/papers/wiod10.pdf

Annex

Table A1 Countries in the WIOD dataset (November 2013 release)

ISO3	Country	Region	ISO3	Country	Region
AUT	Austria	EU	PRT	Portugal	EU
BEL	Belgium	EU	ROU	Romania	EU
BGR	Bulgaria	EU	SVK	Slovakia	EU
CYP	Cyprus	EU	SVN	Slovenia	EU
ZE	Czech Republic	EU	ESP	Spain	EU
DNK	Denmark	EU	SWE	Sweden	EU
EST	Estonia	EU	GBR	United Kingdom	EU
FIN	Finland	EU	RUS	Russia	Europa
FRA	France	EU	TUR	Turkey	Western Asia
DEU	Germany	EU	IND	India	Southern Asia
GRC	Greece	EU	CHN	China	Eastern Asia
HUN	Hungary	EU	JPN	Japan	Eastern Asia
IRL	Ireland	EU	KOR	South Korea	Eastern Asia
ITA	Italy	EU	TWN	Taiwan	Eastern Asia
LVA	Latvia	EU	IDN	Indonesia	South-East Asia
LTU	Lithuania	EU	AUS	Australia	Pacific
LUX	Luxembourg	EU	BRA	Brazil	South America
MLT	Malta	EU	MEX	Mexico	NAFTA
NLD	Netherlands	EU	CAN	Canada	NAFTA
POL	Poland	EU	USA	United States	NAFTA
			ROW	Rest of World	Rest of World

Table A2 Industries in the WIOD dataset (November 2013 release)

Sector	Definition*	Category**
Agriculture, hunting, forestry and fishing	A-B	G
Mining and quarrying	C	G
Food, beverages and tobacco	15-16	G
Textiles and textile products	17-18	G
Leather, leather and footwear	19	G
Wood and products of wood and cork	20	G
Pulp, paper, paper, printing and publishing	21-22	G
Coke, refined petroleum and nuclear fuel	23	G
Chemicals and chemical products	24	G
Rubber and plastics	25	G
Other non-metallic mineral	26	G
Basic metals and fabricated metal	27-28	G
Machinery, nec	29	G
Electrical and optical equipment	30-33	G
Transport equipment	34-35	G
Manufacturing, nec; recycling	36-37	G
Electricity, gas and water supply	E	S / (G)
Construction	F	S
Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	50	S
Wholesale trade and commission trade, except of motor vehicles and motorcycles	51	S
Retail trade, except of motor vehicles and motorcycles; repair of household goods	52	S
Hotels and restaurants	H	S
Inland transport	60	S
Water transport	61	S
Air transport	62	S
Other supporting and auxiliary transport activities; activities of travel agencies	63	S
Post and telecommunications	64	S
Financial intermediation	J	S
Real estate activities	70	S
Renting of machinery and equipment and other business activities	71-74	S
Public admin and defence; compulsory social security	L	S
Education	M	S
Health and social work	N	S
Other community, social and personal services	O	S
Private households with employed persons	P	S

* International Standard Industrial Classification of all Economic Activities (ISIC), revision 3.0.
** G stands for manufacturing sectors (Goods) and S for Services sectors. “Electricity, gas and water supply” is a hybrid between goods and services.