NETWORKS OF VALUE ADDED TRADE

Working Papers 2015

João Amador | Sónia Cabral

BANCO DE PORTUGAL
EUROSYSTEM

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João Amador
Banco de Portugal
Nova SBE

Sónia Cabral
Banco de Portugal

October 2015

Abstract
Global Value Chains (GVCs) became the paradigm for the production of most goods and services around the world. Therefore, linkages among countries can no longer be adequately assessed through standard bilateral gross trade flows and new methods of analysis are needed. In this paper, we apply visualisation tools and measures of network analysis on value-added trade flows in order to understand the nature and dynamics of GVCs. The paper uses data on the bilateral foreign value added in exports from the World Input-Output Database (WIOD) for the period 1995-2011 and, in each period, the GVC is represented as a directed network of nodes (countries) and edges (value added flows). The analysis is extended beyond total trade flows with a view to discussing the distinct roles of goods and services in GVCs. Moreover, the differences between Germany, the US, China and Russia as major suppliers of value added in GVCs are also examined.

In this paper, we base on the World Input-Output Database (WIOD) for the period 1995-2011 and make use of basic network analysis tools to describe the characteristics of GVCs. The paper goes beyond total trade in order to asses the specific role played by goods and services as inputs and outputs. At this point it is important to clarify the nature of the exercise performed. The flows of value added in a GVC tend to occur in a sequential way with firms incorporating external value added as they embody intermediate goods in production that is subsequently exported for final consumption or integrated into other products or services. Therefore, the path taken by each unit of value added in the world economy before it reaches the final consumer may be extremely complex and long. In conceptual terms, this path could be identified stepwise in the global I-O matrix. However, given the structure of the matrix, the number of iterations would be huge and the resulting network virtually impossible to represent. Instead, economic theory has been focusing on the inverse Leontief matrix to capture the total impact of this iterative process. This is also the approach adopted in this paper, i.e., the network represents the final foreign value added flows and not individual flows in successive stages of the chain. Cerina *et al.* (2014) and Zhu *et al.* (2015) also focus on the final value added trade flows but aim at the entire set of country-product linkages. In a different vein, Ferrarini (2013) uses international trade data on products classified as parts and components to quantify vertical trade among countries. The author uses network visualisation tools to map the resulting global network of vertical trade, highlighting the rise of China and the importance of the automotive and electronics sectors in GVCs.

Next, we follow closely Amador *et al.* (2015) for a simple presentation of the FVAiX indicator. The most intuitive way to introduce this indicator is to start by defining the domestic value added in exports (DVAiX).

The global Leontief inverse matrix is denoted as $L = (I - A)^{-1}$, with dimension $NC \times NC$, where N stands for the number of sectors and C for the number of countries, and where I is the identity matrix and A is the $NC \times NC$ global I-O matrix. The Leontief inverse matrix is the sum of a converging infinite geometric series with common ratio A, that is, $[I - A]^{-1} = \left[I + A + A^2 + A^3 + \cdots + A^x\right]$, when $x \to \infty$.

The DVAiX^r takes the on-diagonal block in the Leontief inverse for country r, pre-multiplies by the value added coefficients in each sector and post-multiplies by the values of exports, that is:

$$\text{DVAiX}^r = v^r L^{rr} e^r \tag{1}$$

The FVAiX^{sr} provides the value added directly and indirectly created in the country from which intermediates are imported (source country s) for production of exports of country r and is calculated in a similar way. It implies pre-multiplying the Leontief inverse by the vector containing the value added coefficients for country s and zeros otherwise, denoted as v^s, and post-multiplying by the vector of exports of country r. In other words, the FVAiX^{sr} basically takes the off-diagonal blocks of the global Leontief inverse for country r, pre-multiplies by country s value added coefficients and post-multiplies by the vector of country r' exports. Formally, this is written as:

$$\text{FVAiX}^{sr} = v^s L^{sr} e^r \tag{2}$$

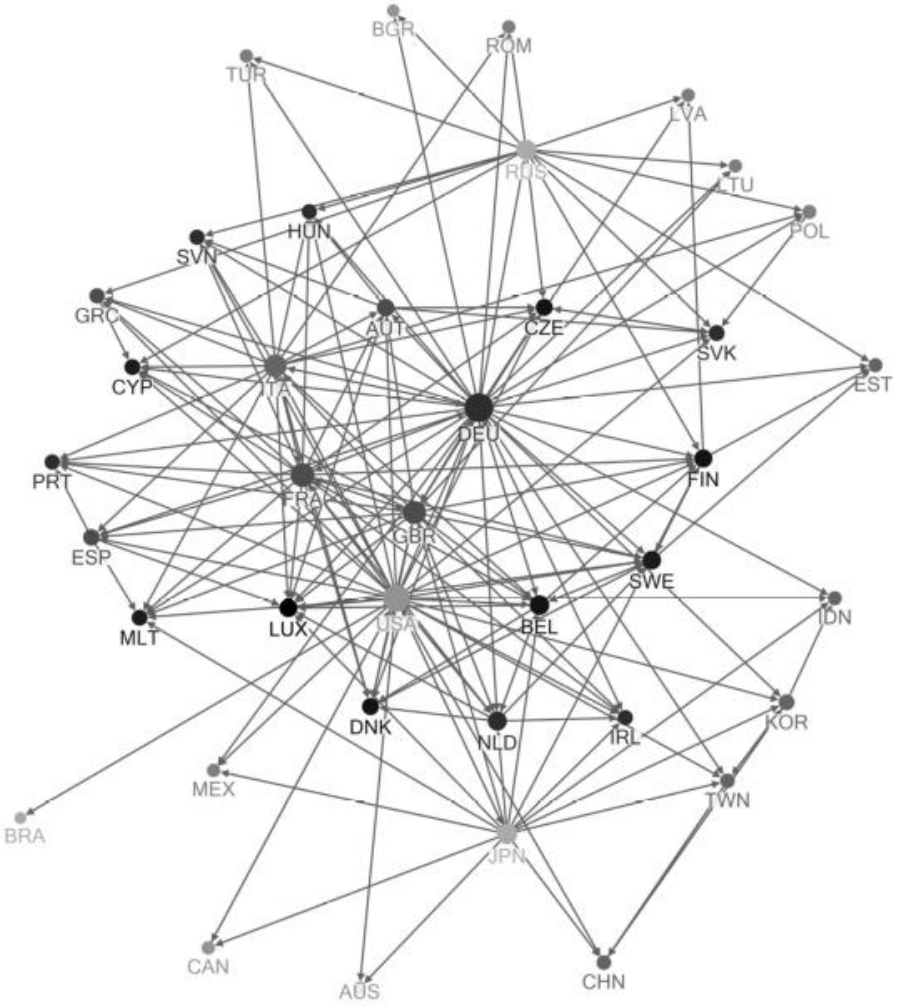
Summing up over all partner countries, the total foreign value added embodied in exports of country r is obtained as:

$$\mathrm{FVAiX}^r = \sum_{s, s \neq r} v^s L^{sr} e^r \tag{3}$$

Adding the domestic and the foreign value added in exports, as presented in equations 1 and 3, provides the value of total exports of country r in gross terms:

$$\mathrm{X}^r = \mathrm{DVAiX}^r + \mathrm{FVAiX}^r \tag{4}$$

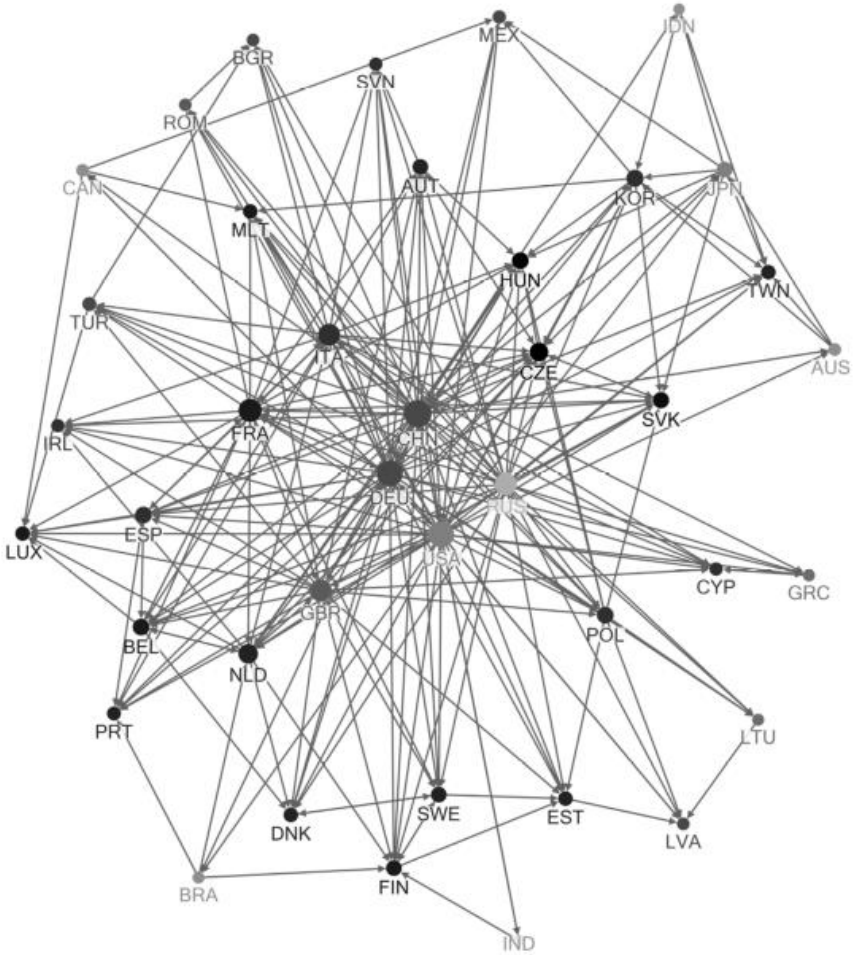
$$\overrightarrow{a_{sr}} = \begin{cases} 1 & if \quad \dfrac{\mathrm{FVAiX}^{sr}}{\mathrm{X}^r} > 0.01 \quad \text{for each country } s \neq r = 1, 2 \ldots N \\ 0 & otherwise \end{cases} \tag{5}$$



(A) 1995

FIGURE 1: Network graphs of total foreign value added in exports - 1995 and 2001

Notes: The network is directed and the arrows that represent the edges point towards countries whose exports embody more than 1 percent of value added from the source country. The size of each node is proportional to its total degree (sum of indegree and outdegree) and the color of the node is mapped to its indegree, with darker shades indicating higher values. The network graphs are based on the Harel-Koren fast multi-scale algorithm and are drawn with the use of NodeXL (see Hansen *et al.* (2010) for details), an open-source template for Excel for analysing complex networks (`http://nodexl.codeplex.com/`).



(B) 2011

FIGURE 1: Network graphs of total foreign value added in exports - 1995 and 2001

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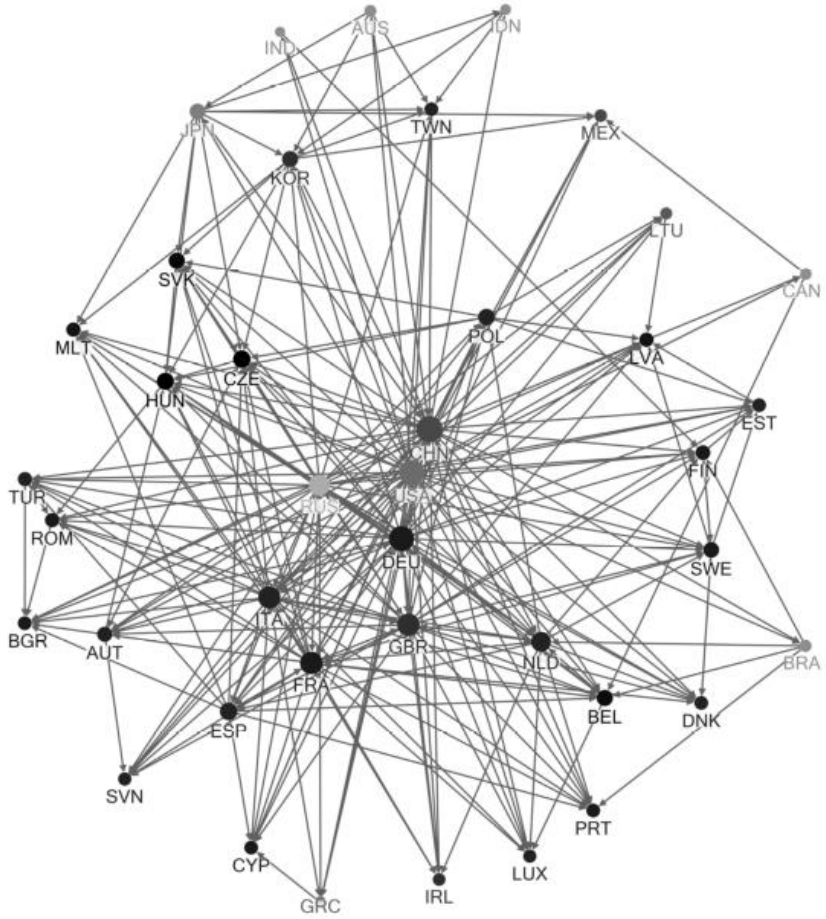
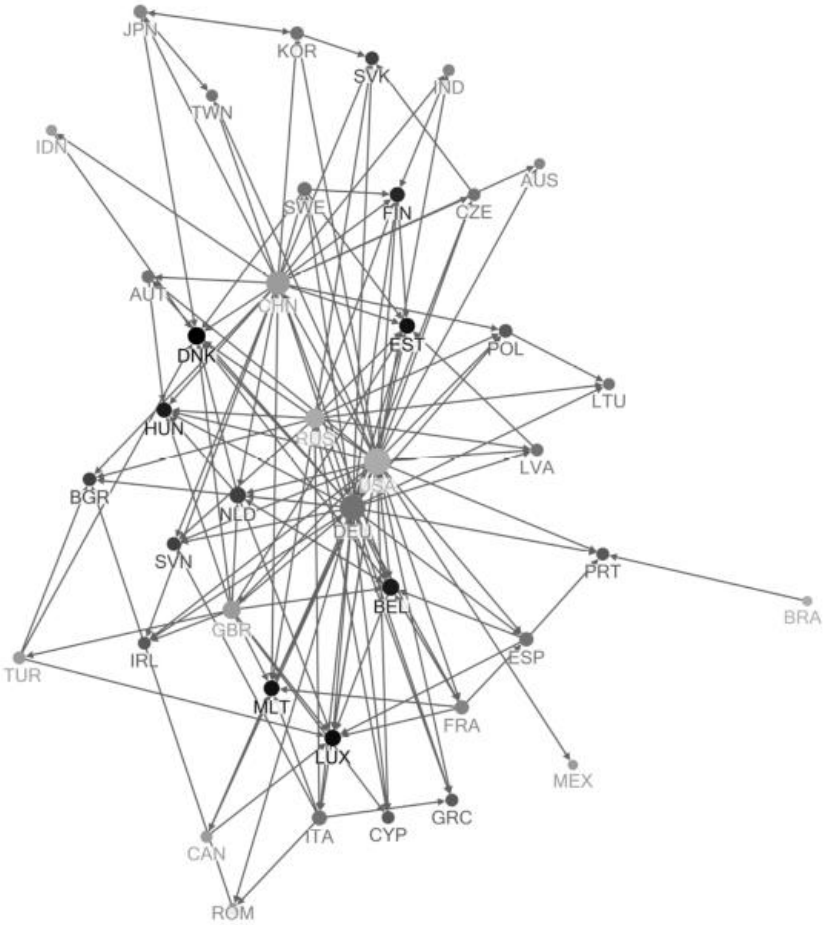


FIGURE 4: Network graphs of total foreign value added in goods and services exports

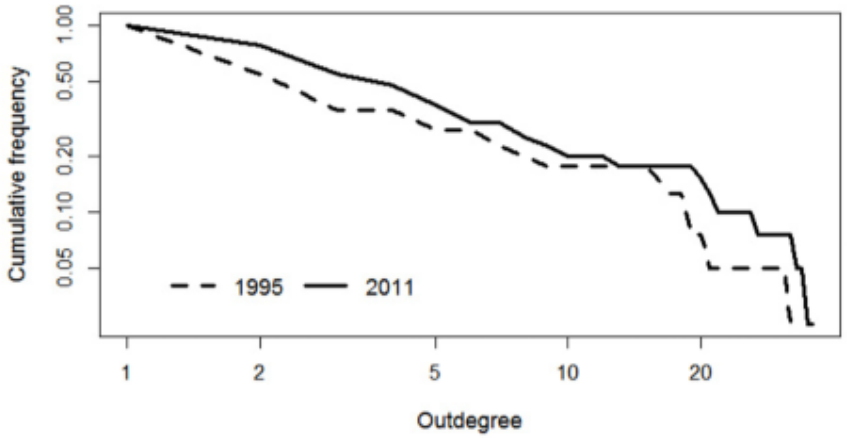
Notes: The network is directed and the arrows that represent the edges point towards countries whose exports embody more than 1 percent of value added from the source country. The size of each node is proportional to its total degree (sum of indegree and outdegree) and the color of the node is mapped to its indegree, with darker shades indicating higher values. The network graphs are based on the Harel-Koren fast multi-scale algorithm and are drawn with the use of NodeXL (see Hansen *et al.* (2010) for details), an open-source template for Excel for analysing complex networks (**http://nodexl.codeplex.com/**).



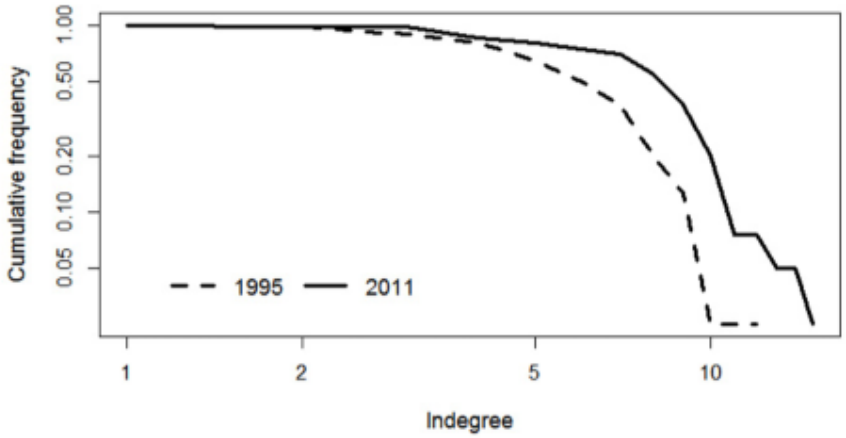
(B) Services 2011

FIGURE 4: Network graphs of total foreign value added in goods and services exports

Notes: The network is directed and the arrows that represent the edges point towards countries whose exports embody more than 1 percent of value added from the source country. The size of each node is proportional to its total degree (sum of indegree and outdegree) and the color of the node is mapped to its indegree, with darker shades indicating higher values. The network graphs are based on the Harel-Koren fast multi-scale algorithm and are drawn with the use of NodeXL (see Hansen *et al.* (2010) for details), an open-source template for Excel for analysing complex networks (`http://nodexl.codeplex.com/`).



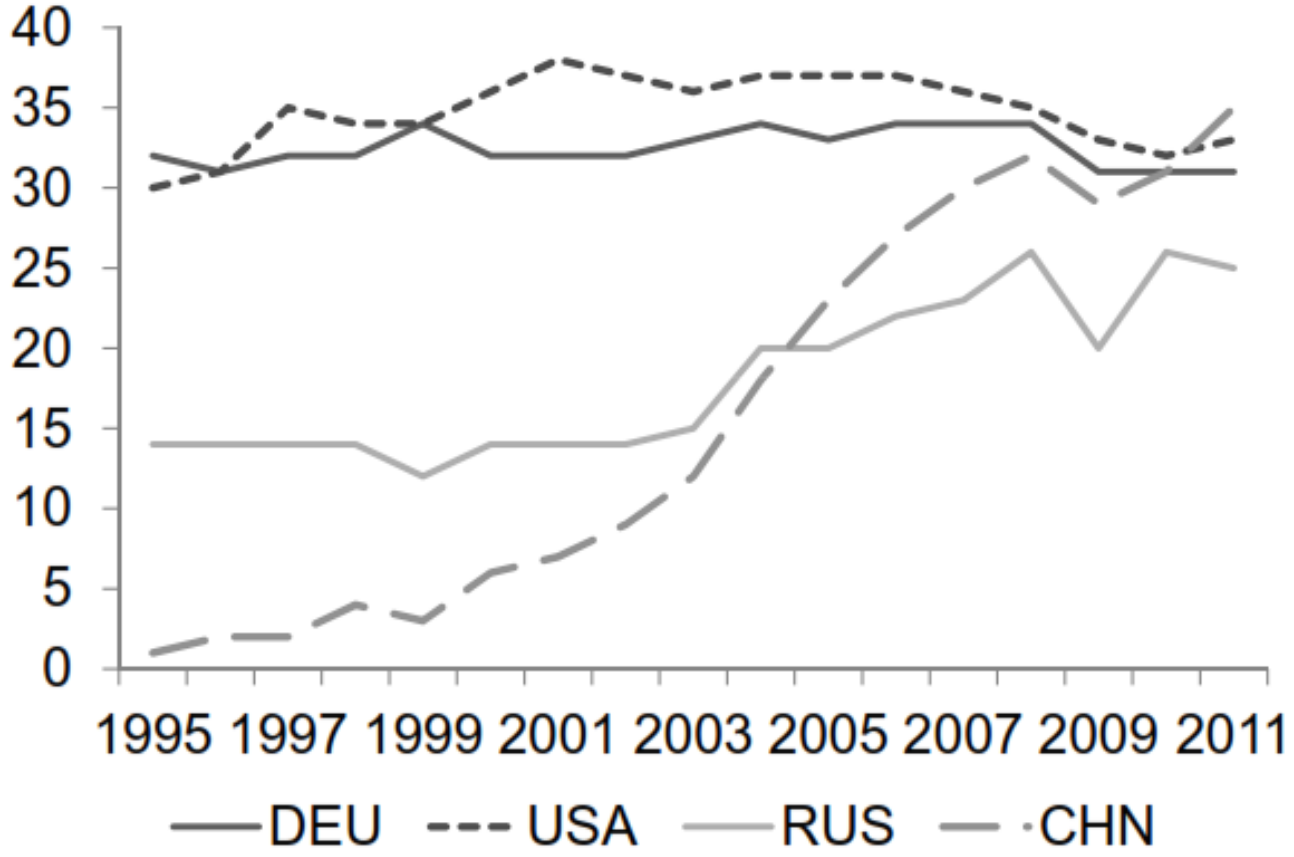
(A) Outdegree



(B) Indegree

FIGURE 2: Outdegree and indegree marginal cumulative distributions - 1995 and 2001

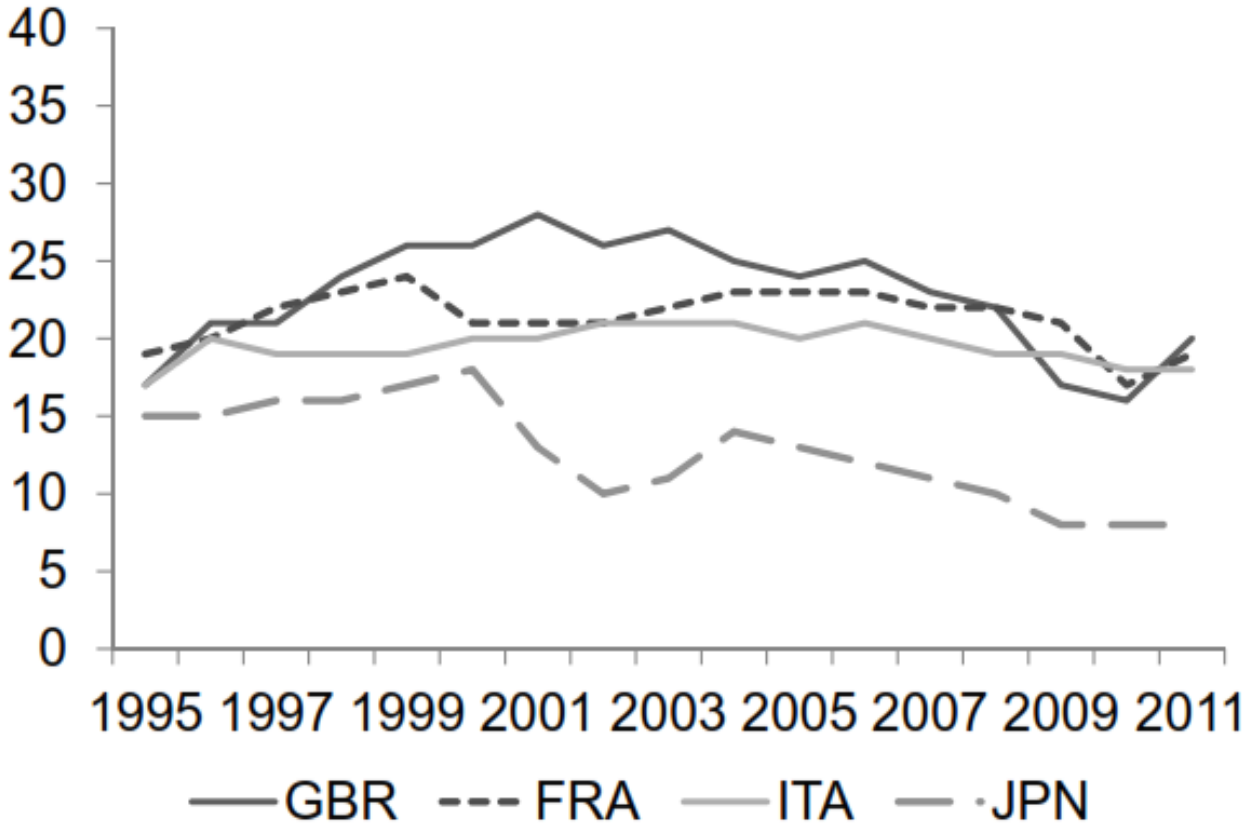
Notes: The x-axis gives the outdegree (indegree) of each country in a log scale. The y-axis, also in log scale, gives the probability of finding a country with outdegree (indegree) $\geq x$, that is, the empirical cumulative distribution P_x.



(A) Outdegree centrality

FIGURE 3: Main suppliers and users of foreign value added in exports over time

Notes: The outdegree centrality of a country reflects its relevance as a supplier of foreign value added, while the indegree centrality signals its importance as a user of foreign value added.



(B) Outdegree centrality

FIGURE 3: Main suppliers and users of foreign value added in exports over time

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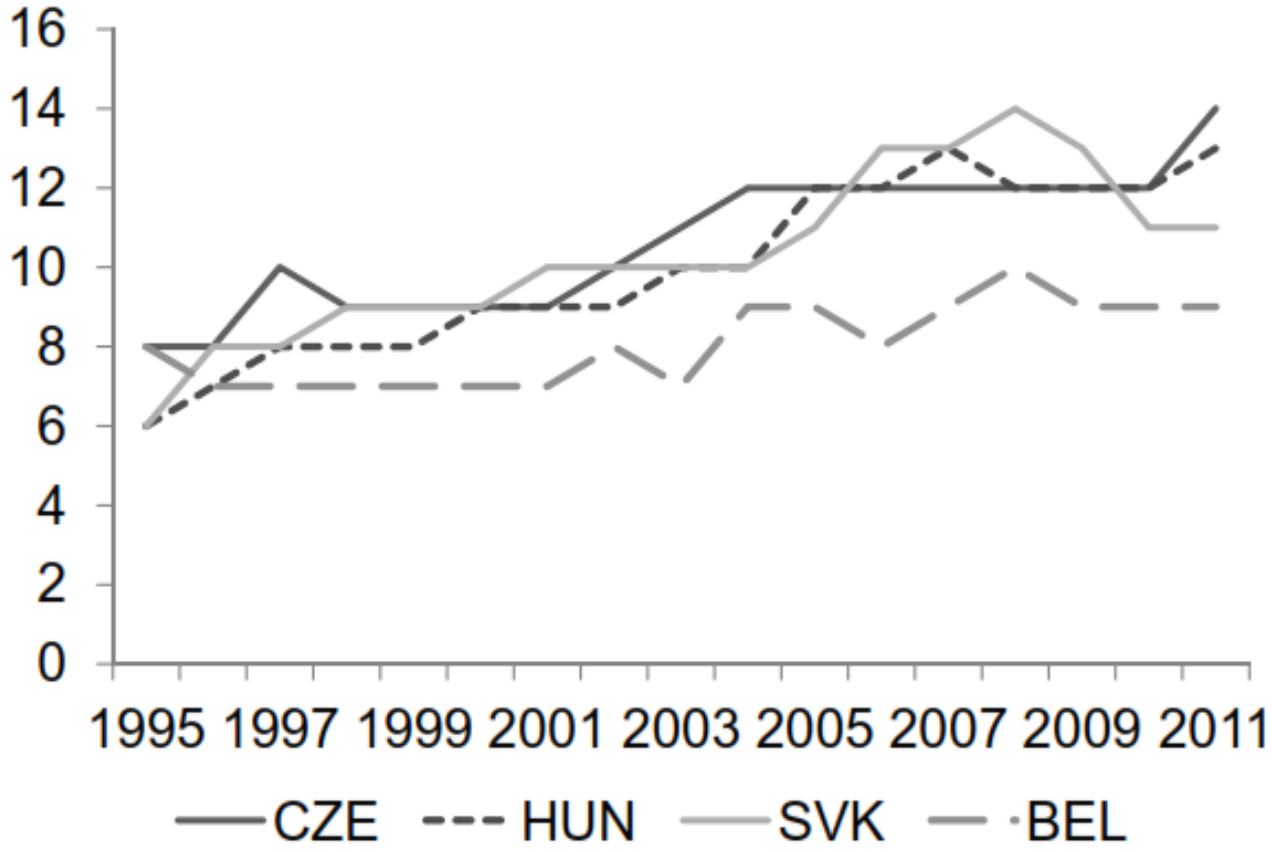

(c) Indegree centrality

FIGURE 3: Main suppliers and users of foreign value added in exports over time

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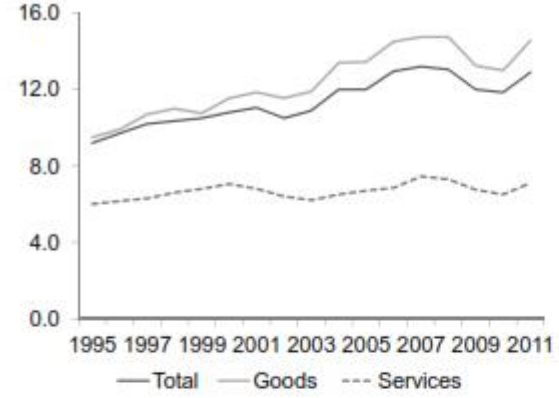
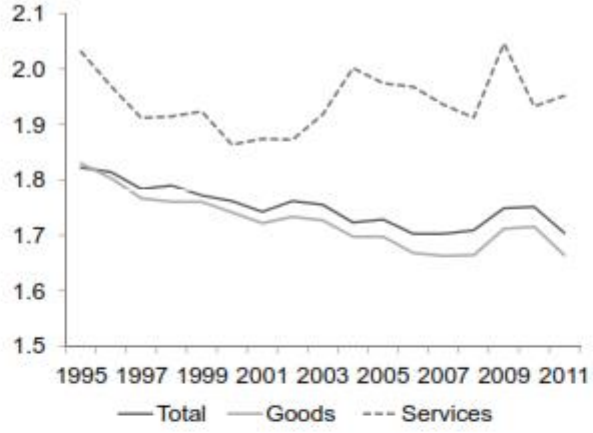
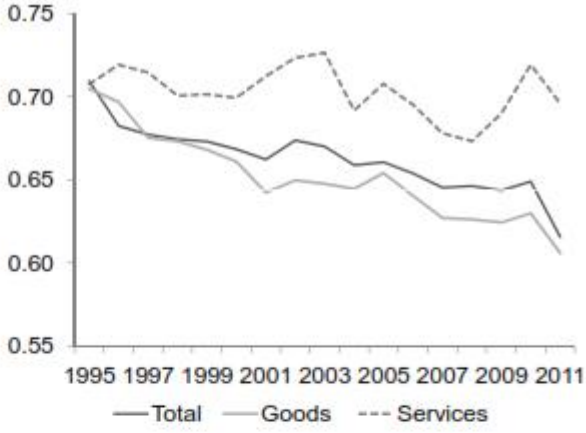


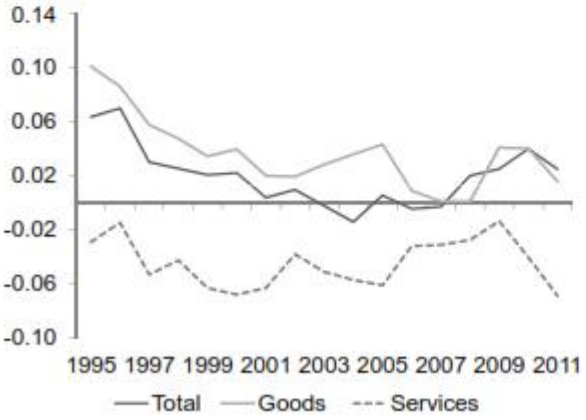
(A) Average degree



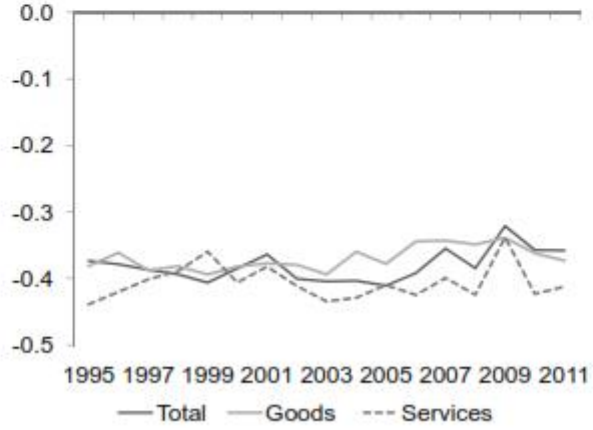
(B) Average geodesic distance



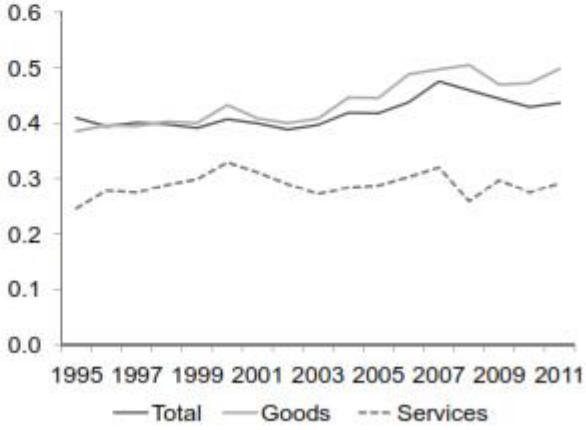
(C) Centralisation of eigenvector centrality



(D) Reciprocity correlation



(E) Degree assortativity



(F) Global clustering coefficient

FIGURE 7: Aggregate network metrics over time