REM WORKING PAPER SERIES

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REM Working Paper 086-2019

June 2019

REM – Research in Economics and Mathematics
Rua Miguel Lúpi 20,
1249-078 Lisboa,
Portugal

ISSN 2184-108X

The Evolution of the World's Production Fragmentation: 2000 – 2014, a network analysis

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Abstract♠

We employ network analysis to characterise the evolution of the world's trade in value-added between 2000 and 2014. Relatively to previous studies, more recent time points are included, consolidating some of their conclusions. A small number of countries occupy central positions in the international production chains and concentration rules, along a few main production regions. Without Germany, Europe loses its pumping engine; the same for Asia without China and, in 2014, for the whole world, without the US. Will China eventually either absorb or dominate the other hubs, becoming the new central node of the World Trade Network?

♠ Financial support from FCT (Fundação para a Ciência e a Tecnologia, Portugal) under the Strategic Project UID/ECO/00436/2019 is acknowledged.

Keywords: *Trade in Value Added; Input-Output Matrix; Network Analysis; Node and Eigenvector Centrality.*

JEL: F01; F23

1. Introduction

Global Value Chains (GVCs) translate the principle of labour division in an international or global scale. The idea behind the concept, the breakup of production in several stages, one at least taking place in a different country, has gained steam in the last decades due to an ever-increasing fragmentation of production stirred by the advances in transportation, Information and Communication Technologies and in services in general. Likewise, multinationals play a vital role in GVCs with the outsourcing of their production to third countries.

The literature on GVCs is already extensive and follows two different lines: (i) the impacts for GVC-participating countries and (ii) the appropriate measurement of GVC participation. The former includes a vast range of case studies and generic empirical models on the economic spill-overs of GVC participation, either technological (Brach and Kappel, 2009) or in productivity (Baldwin and Yan, 2014), knowledge diffusion (Saliola and Zanfei, 2009) or foreign direct investment (Martinez-Galán and Fontoura, 2018). A wide range of references focuses on the impacts of GVC participation in development, especially for countries in the later stages of development. The argument is usually that, before, developing countries had to build a whole production chain by themselves, whereas now they can specialize in a particular stage of the manufacturing process (Taglioni & Winkler, 2016). The latter –more methodological- is based on the premise that, by not accounting for the import content of a country's exports, traditional trade statistics do not fully capture the fragmentation of international production and are responsible for double-counting in import and export data. To fill this gap, a handful of internationally linked Input-Ouput (IO) datasets have emerged. Their focus is in supply-use relationships, highlighting their use as production intermediates or final demand rather than simply working with a commodity or service classification.

The World Input-Ouput Database (WIOD) is often used by researchers; its second, 2016 release included data for 43 countries and 56 sectors, an enhancement from the first one (2013), with data for 40 countries and 35 sectors. It covers 85% of the world trade and allows the study of the impacts of the international fragmentation of production in environmental and socio-economic issues. As described by Timmer et al. (2016), national IO tables are combined with bilateral international trade statistics to disagreggate the imports by country of origin and use category, to generate an international supply and use table. It is important to note that the methodology produces IO tables that are estimates rather than a precise measurement.

Since Hummels et al. (2001)'s seminal attempt that introduced the concept of Vertical Specialization (VS), to the emergence of trade in value added (TiVA), to Koopman et al. (2011 and 2014), who attempted to refine and bring together previous measures, several authors, departing from IO tables, have provided empirical evidence about the changes of international trade due to the international interdependences in production processes.

In the same way as the research on GVCs, use of network analysis methods with input-output trade data is recent and will certainly experience further developments. Authors employing network analysis to date reinforce its potentialities to understand trade in value added. Some argue that the complexity of the measures in network theory and the ability to build models that incorporate these features are powerful tools to understand GVCs, Amador and Cabral (2015); others that network analysis enables to grasp the heterogeneity of different actors and trade links in GVCs (Santoni and Taglioni, 2015) and that network-based measures can be correlated to external factors such as the presence of multinational groups, Altomonte et al. (2015).

The present work applies such methods to characterize the evolution of the world's trade in value-added (TiVA) between 2000 and 2014. It uses data from the latest release of the

WIOD to build representations suitable for graph visualisation and the computation of network parameters.

The paper organises as follows. Section 2 briefly explains the methodology used for the graph visualisation and analysis, as node and eigenvector centrality, and the use of filters for unveiling the backbone of the flows. Section 3 presents a rather comprehensive review of the available literature, highlighting the advantages of network analysis for a better understanding of the nature and topology of world trade and production systems. Section 4 describes the two basic graphs and their related descriptive statistics, to analyse the world trade in value-added in 2000 and in 2014. In section 5, we identify patterns by computing and comparing several parameters and indicators. The most robust flows, making for the roots of the GVCs dynamics, are also uncovered. Section 6 concludes.

2. Networks of trade in value-added – a brief comment on the tools and statistics used.

Graph theory is a widely recognized field in mathematics, the subsequent network analysis was developed in different areas and adopted as a methodology by social sciences due to its potentialities in assessing social phenomena. In the field of economics, several international economists –e.g. Benedictis and Tajoli (2011)- and econophysicists –e.g. Kali and Reyes (2007) and Serrano et al. (2007)- have advocated the potential of the social network analysis methodology to the analysis and visualisation of world trade.

Indeed, according to Benedictis and Tajoli (2011), trade flows between countries can be naturally represented by a straight line (trade flows) connecting two points (countries): a network structure or visualisation consisting of a set of points, called nodes or vertices, with connections between them, called edges or links.

It is possible to add complexity to the nodes or edges by weighting them. A directed network fully captures the direction of flows, while nodes can be weighted to highlight the importance of specific countries, in line with what Serrano and Boguñá (2003) call a perfect example of a real-world network that illustrates competitive relationships. All this plays an important role in the analysis of the so-called World Trade Network (WTN), International Trade Network (ITN) or World Trade Web (WTW); it is also intuitive, as the amount of trade between a pair of countries (usually measured in monetary values of imports and/or exports) is treated as the link weight (Bhattacharya et al., 2008), thus reflecting the different magnitudes of bilateral trade relationships.

Based on the idea that an IO matrix is associated to a weighted directed network, a relatively recent body of literature has applied network analysis in the study of GVCs, with the purpose of locating a country or a country-sector in the world production networks, or to explore interdependencies within them.

In the networks built in this paper, nodes represent countries and are weighted by their total trade in value-added (TTVA), bigger diameters representing higher TTVA values. The edges or links are weighted according to the size of the bilateral value-added trade flows, with greater thickness accounting for higher flows; they are coloured accordingly, with dark grey indicating the 10% highest flows. With the nodes weighted by TTVA and the edges connecting to the suppliers and users of value added it is possible to break out a country TTVA, getting a sense of the world suppliers and users and, more specifically, how domestic and foreign value-added (DVA and FVA, respectively) split in the world's economy.

As the networks are directed, they allow the visualisation of the trajectory of bilateral value-added flows (with arrows pointing to the destination, user country). Two important concepts are associated with this visualisation: the indegree, referring to the number of incoming edges (user country), and the outdegree, referring to the number of outgoing edges (supplier country). Weighted networks permit the analysis of node strengtht which, for directed networks, also divides into indegree and outdegree strength.

The computation of network-based measures of *connectivity* and *centrality* is crucial, as they allow the identification of connection partners and of key hubs inside the network. There is a wide range of such measures in network analysis whose formulas vary in presence of a weighted/unweighted network. Barabási (2016) is a standard reference to them and many related concepts that will be either mentioned or used here.

Supposing a TiVA network of countries, connectedness includes Node Degree (ND) – the number of a country's trade partners- and Node Strength (NS) -the value or intensity of a country's trade relationship. In directed networks these measures divide into indegree and outdegree. NS and ND are often referred to as Node Centrality in the literature, though *centrality* includes a wide range of measures depending whether only first order, one-step links are counted (closeness, betweenness) or also secondary, more remote links are considered (e.g. eigenvector centrality, as explained below).

A few fundamental identities apply in our weighted and directed networks: (i) NS is equal to a countries' TTVA, (ii) indegree strenght is equal to a countries' FVA and (iii) outdegree strenght is equal to a countries' DVA.

The most important centrality parameter involving secondary or indirect links is the eigenvector index. NS and ND, also centrality measures, only capture straight links and neglect indirect linkages. In order to fully understand a country's role in the users and suppliers' network, eigenvector centrality is a finer node-related measure: the rationale behind it is that nearby high-scoring nodes contribute to the score of the node in question. The measure thus contemplates further, multiple-steps away linkages, differing from other centrality indexes, as closeness or betweenness, which disregard the non-adjacent neighbours' score. Based on

Bonacich (1987), the Eigenvector Centrality Index for all the nodes in our networks is calculated, in this paper, by Tang et al. (2015)'s formula.

Kali and Reyes (2007) stress another feature of network visualisation: the possibility of adding a threshold that not only allows for a clearer visualisation but also revealing the backbone structure of world's trade. To arrive at a basic structure for the WTN, links or flows were progressively eliminated according to a sequence of minimal thresholds. This eventually produced a new set of highly informative graphs, from the same original ones, showing the backbone of the world's GVC mesh.

3. World Trade Networks – analysis with traditional trade statistics and IO matrices.

In a seminal work, Snyder and Kick (1979) studied the world's system theory by presenting a bloc-model network analysis for four types of international interactions, including trade flows, circa 1965. Their analysis corroborated the theory by finding the presence of three different areas: Core (Western Europe, North America, Australia and Japan), Semi periphery (some Latin American countries, Eastern Europe and some Asian countries) and Periphery (most of the Asian continent and all Africa). In terms of interactions, they found that every bloc has more trade linkages with the core than with any other.

Smith and White (1992) elaborated on the previous analysis by focusing solely on world trade; they included three time points (1965, 1970 and 1980) and used trade data aggregated in 15 types of commodities. The inclusion of the three years allowed for a reported stability over time and evidences of more upward than downwards mobility; the disaggregation of trade data enabled different conclusions for different sectors. For instance, they found that exports of high technology manufacturing goods flow primarily within the core and from the core to the other blocs. The inverse is true for agricultural products where international trade is more likely to happen from the periphery to the core.

Mahutga (2006) updated Smith and White (1992)'s results using the same 15 commodity types and adding the 1990 and 2000 years. The hierarchical nature of the world system remained stable from 1965 to 2000, both in terms of core/periphery patterns and of production processes; the most noticeable change was the rise of labour-intensive manufacturing in non-core zones such as Eastern Europe and the so-called Asian tigers.

Reyes et al. (2009) disaggregated trade data into four classes: raw materials, intermediate, final and capital goods. Their network analysis aimed at enriching the exploratory literature about the rising BRIICS performance in the world system. For 1995, 2000 and 2005, they found an ever-increasing role for them, in all the indicators' percentile rankings they computed. The centrality index suggested that the BRIICS (with the exception of Indonesia) were highly integrated in the WTN, though the increase in the level of integration bears some differences among countries and product types. The analyses of node strength, node degree and clustering suggest that these results are explained by multiple factors, from the establishing of new trade partners to the involvement in trade clubs, following the diminishing role of the rich club, and the overall intensification of existing trade relationships.

Papers with a more exploratory character have also reached important conclusions upon the best way of representing world trade in a network. Focus here shifts from the hierarchical position of countries within the WTN to the correlation between network-based measures to explore the properties of world trade.

Garlaschelli and Loffredo (2005) broke from previous studies focusing on a single or a few snapshots of the WTW and addressed it as a directed and evolving network from 1950 to 1996. By correlating three topological properties, they concluded that there is a negative correlation between average nearest neighbour and degree distribution, which means that countries with many trade partners are on average connected to countries with few partners. A decreasing trend between clustering coefficient and degree distribution signalled that partners of well-connected countries are less interconnected than partners of poorly connected countries (disassortative network).

Fagiolo et al. (2008) challenged the topological properties of the WTW found in previous studies, including that of Garlaschelli and Loffredo (2005). They argued that the binary approach to the world trade network is not accurate as it treats every trade link as homogeneous regardless of its actual value and used a weighted approach instead. They concluded that, for weighted networks, the disassortativeness is not statistically significant: well-connected countries are associated with higher clustering coefficients, which confirms the existence of trade clubs.

Serrano et al. (2007) built and analysed the world network of trading imbalances. In their network, the links represented the difference between exports and imports and were weighted by the magnitude of that difference. By applying a local heterogeneity analysis, the authors obtained the backbone of the WTN for 1960 and 2000: the links that carry the biggest proportion of a country's inflow or outflow. They have taken a first step into the study of GVCs using traditional trade data, by considering that producer and consumer countries do not absorb completely the incoming or outcoming fluxes. By conducting a dollar experiment for the two major source countries and two major sink countries, they clearly distinguished between the percentage of net dollars that goes into bilateral trade and the allocation of these net dollars in the world system. For instance, they found that for each net dollar the US injects into the system only 9.3% is retained in China although the direct connection imbalance between the two countries is 16.7%.

The literature applying network analysis to GVCs has addressed, till now, two major issues: (i) the analysis of countries' and country-sector's positioning and (ii) propagation of economic shocks along the world production network. The former applies network-based measures to derive its conclusions and the latter complements the study by correlating these measures with external factors that enable conclusions about which countries or sectors are most vulnerable to the persistence and/or propagation of economic shocks.

Amador and Cabral (2015), using WIOD data for 40 countries together with basic network visualization tools, described the characteristics of GVCs, in 1995 and 2011, represented by bilateral flows of FVA. They focused mainly in individual countries' centrality, finding that bigger countries tend to have higher order nodes and appear "in the centre of the network" as suppliers of value added. In terms of evolution, in 1995, mainly Western European countries and the US were in the core, whereas Asian countries lay in the periphery. By 2011, a few core countries (UK and France) partially lost their position but the US and Germany kept theirs; China joined the centre as the most important supplier of value-added. The authors built the world's networks for manufacturing and services to conclude that the density of the manufacturing one was much higher than that of the services network: nations are more interconnected in the trade of manufacturing goods.

Focusing on country-sectors rather than solely on individual countries, Santoni and Taglioni (2015) computed the network of intra-sectoral trade for the automotive sector (buyers and suppliers) and the TiVA network for country-sectors in 2009. The increasing centrality of emerging countries was most prominent in the demand side rather than in the supply side, in technology intensive GVCs; US industries were still at the core of the global trade network, alongside German business services, Chinese retail and Russian mining.

Cerina et al. (2015) configure the world trade system as a network where the nodes are the different industries in different countries for 1995 and 2011, including self-loops that represent intra-industry national trade. They found that the trade network is denser inside the same economy than in-between economies: a great part of the economic transactions still occurs within national borders and contains many self-loops (high number of industries self-feeding themselves). At the regional level, through a community-detection test that compares their network with a null of a random graph not expected to have a community structure, they concluded that "global production" is still operated nationally or, at best, regionally, given that the detected communities are individual economies or well-defined geographical regions (e.g. NAFTA countries).

Criscuolo and Timmis (2018) applied a variant of the Bonacich-Katz eigenvector centrality to OECD ICIO data, obtaining metrics based on forward and backward linkages. They stated that the existence of multiple linkages should be taken into consideration, as it is a real-world feature, where service linkages are needed at several stages of the production process. They identified profound changes in the structure of GVCs along 1995-2011: whilst some activities remained clustered around the same key hubs as in the start of the period, for others there had been dramatic relocations (e.g. manufacturing of computer and electronic sector). At the country-level, significant evolution took place around three main regions: Factory Europe, Factory Asia and Factory America; with the consolidation of Germany and the US as central hubs in their respective regions and the diminishing role of Japan as a key hub in Asia, where China now played a central role.

Carvalho (2014) argued that the structure of production networks is crucial in determining whether and how microeconomic shocks (affecting only a particular firm or technology along the chain) propagate through the economy, as such networks expose critical nodes in the chains. This is particularly evident when a small number of central hubs supply inputs to many different firms or sectors. Using also network analysis to assess propagation of economic shocks along production networks, Blochl et al. (2011) computed two measures of centrality: random walk and counting-betweenness centrality. The former is important to reveal the vertices instantaneously affected by a shock and the latter to reveal where a shock carries on longer. They computed the hierarchical clustering of the nodes' rankings in the network to find that countries with similar levels of development tend to group together.

Finally, taking on the poor economic theory character of the previous studies, Contreras and Fagiolo (2014) proposed a diffusion model that took into consideration the origin of the shock, its impact on IO linkages and the possibility that after the shock hits a certain sector, production levels adjust.

4. The world users and suppliers' network, 2000 and 2014.

We combine TTVA per country with computed bilateral TiVA flows to build and visualise the world's users and suppliers network. Two elements are fundamental in the network: the nodes, the 43 countries available in the WIOD, and the edges, the bilateral trade in value-added flows amongst the nodes, for 2000 and 2014. Even though the WIOD includes the RoW, it has been excluded from the visualisation and further network-based calculations because, as an aggregate of economies, it would profoundly influence the nodes and edges weights, since it embodies a disproportionate number of economies for which TiVA data is not specified.

Figures I and II represent the world's suppliers and users network for 2000 and 2014, respectively, with countries roughly displayed according to their geographic location. To facilitate visual insights without blurring the most relevant flows and not excluding any of the 43 countries, a threshold has been defined: only those flows accounting for at least 1% of user or supplier countries' exports appear. Analyses and calculations will be conducted using this resulting graph.

Insert Figures I and II here

From the figures one can see that the number of flows above the threshold has increased over time: the network has become slightly denser. Density is the ratio between the total number of links and the maximum possible one, ranging from 0 to 1. In both figures, were it not for the threshold, the networks would have a total density of 1, as in the original IO tables all countries have flows with each other. As focus here is only on the most relevant flows, the density goes from 0,39, in 2000, to 0,40 in 2014.

A broad pattern is common to both figures: three clear groups, North America, a EU cluster and a more sparse Asian one, with Indonesia and India further apart, and four "individualities" or "oddities", Brazil, Turkey, Russia and Australia. In the denser but also more concentrated 2014 network, Turkey gets closer to the EU and Australia to Asia. The Asian cluster becomes somewhat tighter, as India and Indonesia move closer to the other countries in it.

Table I, below confirms that flows at least 1% of the supplier or users TTVA have slightly grown from 2000 to 2014; this is also true for the total TTVA which has more than trebled.

Insert Table 1 here

Both mean and median values are low and close to the lowest bilateral flow; the distribution of bilateral TiVA flows is left-skewed, as shown by a mean higher than the median. The left bias of the distribution is further supported by the trade flows intensities displayed in Table I, where a small number of flows accounts for most of total TTVA flows. The results differ however slightly from 2000 and 2014. In 2000, only 17 countries made up 50% of the world's TTVA and, in 2014, more than half of the countries (23) under analysis accounted for half of the world TTVA. Over time, there is an increase in participation in production networks.

In spite of this, a small number of countries still does not have a substantial place in the global production networks, as 34 and 35, out of the 43 countries at stake, made for 90% of the TTVA in 2000 and 2014, respectively.

5. Network Analysis.

Visualisation and descriptive statistics

From Figure I, in 2000, the bilateral flow with the highest value was by far the one from Canada to the US with the opposite flow in the second position. "Factory America" is clearly dominated by the US, which is not only the country with the biggest node, but also accounts for the thickest intra and inter regional flows; most of the flows to and from the US are also coloured with dark grey, which means that in 2000 they belonged either to the 10% highest flows or to the top 10 highest ones.

Other noticeable flows are those between the US and Japan. Japan was, in 2000, the country with the highest TTVA in "Factory Asia", as well as the centre of intra regional flows. However, Japan's centrality within Factory Asia was not as visually evident as the US one in Factory America, other Asian countries such as China, South Korea and Taiwan already exhibited strong positions within the region. The thickest intra-regional flows were the bilateral ones between South Korea and Japan.

As for "Factory Europe", Germany is the country with the highest TTVA, though other West European economies are relevant players as well. The highest intra-regional flows were those among Western European countries; inter-regional flows to the US (e.g. UK - US) are among the top 10 highest flows.

In 2014, the flow from Canada to the US remains the highest one and the second position still belongs to the opposite flow. The US still is the country with the highest TTVA in Factory America and bears the highest intra and inter-regional flows. Factory Asia underwent the biggest changes during the period; not only the central position shifted from Japan to China, but also the density of intra and inter regional trade has increased substantially, displaying darker and thicker links.

In Factory Europe, Germany continues to be the country that accounts for the highest TTVA, though one clearly sees that trade intensity has also increased within the region with more participation from Eastern European countries, whose flows are mainly to and from Germany. Conversely, the flows between the region and the US have comparatively lost relevance within the world flows (they have thus lost their dark grey tonality), as they no longer figure amongst the top 10.

The outward flow from China to the US is higher than the opposite flow, meaning that China is a net supplier of value added to the US, contradicting the theory that the US does not have a trade in value added imbalance with China.

Node and Eigenvector Centrality

The users and suppliers networks exhibit a strong correlation between ND and NS (≈0.75) for both periods, meaning that countries with a higher number of partners have higher TTVA values. The correlation of both indegree and outdegree strength tell us that there is an almost perfect relationship ($r>0.95$) within countries from the upstream to the downstream margins of GVCs: great suppliers tend also to be great users of value added.

The distributions of ND in Figure III confirm that it is highly left-skewed, with most of the countries, in 2000 and 2014, having between 15 and 45 (out of 84) partners for both inward and outward flows; no bimodality is present. They are even more left-skewed when values are considered (NS), as in Figure IV.

Insert figures III and IV here

Most of the countries in the network hold weak TiVA relationships, with only few accounting for high values. The middle classes are empty or bear low frequencies in both periods, which reinforces the uneven distribution of the production chains. Nevertheless, in 2014, there are a little more countries in the higher classes than in 2000.

Table II lists the countries with the highest and lowest shares of indegree and outdegree strength. As the above correlation between both indicators would predict, the top countries for indegree strength are almost the same as the top five ones for outdegree strength. This applies for both periods considered and also for the bottom five countries.

Insert Table 2 here

The ranking of nodes, in terms of strength, shows that smaller countries tend to have lower positions[1]. Table II confirms this, with the exception of Bulgaria that has noticeably moved out of the bottom five from 2000 to 2014, nearly the same four small European countries share the bottom positions in both periods, together with also small entrants like Malta. However, the top five positions are shared between big and medium economies.

The US is the country with the highest inward and outward flows for both periods considered. Few has changed in those 15 years, with the noticeable and well documented rise of China as a supplier and user of value added in detriment to Japan which has lost its position in the top 5 countries with the highest DVA and FVA. China has entered directly to the third position in both years, surpassing European countries as the UK and France. France actually

[1] Individual values of the several node statistics mentioned in this Section can be obtained from the Corresponding Author.

lost in 2014 the fourth position in terms of indegree strength to another relevant supplier of value added, the Netherlands, In Figure II it is possible to see that the arrow from this country to Germany is within the top 10 highest TiVA flows.

The distributions of Eigenvector Centrality are, once again, left-skewed, meaning that most of the countries do not hold significant supply-use relationships (Figure V). The tendency has been constant in both periods considered, with a slight overall increase in the middle classes in 2014.

Insert Figure V here

Table III displays the correlation between node and eigenvector centrality. They are all positive, which means that more and more intense direct supply-use relationships contribute to a more central position within the network. An interesting aspect is that the correlation with NS is much higher than that with ND, emphasizing the character of this measure that plays down the number of partners in favour of their importance within the network.

Insert Table 3 here

Countries such as Canada and Mexico have a low number of partners but are strongly connected to the US, which has a high centrality; thus, they also account for a high Eigenvector Centrality. The opposite occurs in countries such as Belgium and Italy, with a relatively high number of trade partners only moderately central within the network. The percentile rank analysis summed up in Table IV displays the same top and bottom countries as in the related Indegree and Outdegree Strength analysis.

Insert Table 4 here

One noticeable difference between the NS ranking and that of the Eigenvector Centrality Index is that Canada is now in the second position, due to its connection to the US. China has got the fourth position in 2014, meaning that the country is well established in the supply-use networks; however, comparison with its NS third position, suggests that China's relevance is bigger when the intensities of the flows with its direct partners are taken into consideration. Another significant change is the entrance of the Netherlands to the fifth position: from NS analysis, we can see that this centrality is mostly due to its upstream position in the production chain as it accounts for a higher outdegree than indegree centrality. At the same time, the strong tie with Germany also contributes to this high rank.

Nearly the same small European countries occupy the bottom positions, in parallel to the results of the NS percentile analysis. Once again, the importance of size is stressed out; furthermore, Malta's and Cyprus' small dimension, combined with their insular position, has an effect of increasing freight rates due to distance between main trading partners and the small size of individual shipments, World Bank (2017).

It is enlightening to compare the top and bottom economies in Table IV, showing how the two parameters convey similar information. Moreover, an extended look at the full NS and Eigenvector Centrality rankings -not shown here- allows conclusions for countries outside the top and bottom positions. Almost all emerging economies have increased their centrality in GVCs. Indonesia and India are noteworthy evolutions; both are improving their positioning as suppliers of value added. Russia has impressively progressed both as a supplier and importer of value-added. Turkey is also gaining momentum in the international GVC scene, but still lags behind its emerging partners.

Root GVC Patterns for 2000 and 2014

To identify root or backbone patterns, a threshold that only allows the visualisation of flows above the 90th percentile was used. Figures VI and VII represent the 10 % most robust flows of the world's user and supplier's network for 2000 and 2014, respectively.

Insert Figures VI and VII here

Comparing both networks, one sees that in 2014 there is a greater number of relevant flows, as well as more countries. Russia, India, Luxembourg, Czech Republic and Brazil enter this more restricted trade scene, while Indonesia has lost relative importance as a supplier of intermediates to Japan, and Sweden as a consumer of German intermediates.

In both periods, most of the flows above the threshold make for bilateral ones between a country and its partner. Geography also plays a role: in 2000, 38% of the most relevant flows were between countries that share territorial borders; in 2014 this increased to more than 40%.

The analysis can be enriched by aggregating nodes and flows in the world's big production regions, Factories Asia, Europe and North America, as shown in Figures VIII and IX.

Insert Figures VIII and IX here

Most of the global production activities still take place within regions, as seen from the width of the regional self-loops. This is nevertheless slightly decreasing in all regions but Asia, where the share of intra-regional trade in value added has gone from 34% to 36%.

Noticeably, the share of Asian TTVA with North America has lost relative importance, from 38% to 26%. Various factors can help explain this: not only intra-Asian TTVA has increased but also Asia (mostly China) has deepened its ties with Europe and emerging economies as Russia and Brazil.

The figures also show a decrease in the share of European TTVA with North America. The importance of intra-European trade in intermediates is more evident than in the other two regions. In fact, the share of the European TTVA is well above 60% in both periods and it has only slightly decreased from 66% to 65%.

Western European countries are mostly suppliers of value added to their European counterparts. From 2000 to 2014, only the UK has switched from a net supplier to a net user of value added for the countries that integrate the 10% most relevant flows. The country holds a steady trade link with Norway, mainly due to its imports of primary commodities. Ireland and Luxembourg are importers of value added from the UK, mainly services, what is consistent with the role of Luxembourg as a financial centre and that of Ireland as a location for headquarters of multinational corporations. Ireland also maintains a strong tie with the US; France remains essentially European in its production networks, with a somewhat robust input link with North America.

Germany, as previously stated, remains at the core of Factory Europe, and holds the most relevant inter-regional production relations with the US and China, being, in both cases, a net supplier of value-added. It is also responsible for the presence of Poland in the 10% most relevant flows in 2000 and 2014. as well as the Czech Republic's emergence in 2014. These countries' trade with Germany significantly supplies medium-technology intermediates to the chemical and automotive industries. According to the World Bank's 2017 GVC report, each national industry specializes in different tasks along the automotive production chain; the Czech in medium-low technology inputs and the Polish in medium-high ones. Germany maintained important supply and use relationships with bordering countries such as

Switzerland, besides with Austria, Belgium and mostly with the Netherlands, one of its net suppliers.

Russia has emerged in the global production scene at the upstream margin of GVC, something typical for countries that specialize in primary commodities. The country's most valuable exports go to China and Germany, the latter also an important supplier of value added to Russia.

Factory Asia has not only been intensifying its internal production links as experiencing rapid transformation, with China seemingly adopting the model of its Asian neighbours that have entered the GVCs in the final stages of the manufacturing process. South Korea, a former major player in Japanese production chains, is now home to multinationals in the field of electronics (Samsung, LG) but also in the automotive sector (KIA, Hyundai). It still holds large TTVA links with Japan but has evolved as a crucial supplier and user of China's inputs. This model is the core of intra-Asian production chains and helps explaining why China has become a supplier of value added to India.

In 2014, 9% of Asia's TTVA was with Australia, a country profoundly integrated in the Asian production processes. In 2000, it was already an important supplier of production inputs to Japan; in 2014, the link is still strong but a new one with China has surpassed it.

The most relevant ties within NAFTA are centred around the US. Mexico has been gradually increasing its role as a supplier of value added to the US, especially in the automotive sector. It has even supplanted Canada as the main provider of automotive components to the US, World Bank (2017).

Notwithstanding Brazil's still modest participation in the global production networks - it mostly trades with its MERCOSUL neighbours-, the country has entered the world's most robust flows in 2014 as a net exporter of value-added to China and a net importer from the US; a situation that conditions its production possibilities.

6. Conclusions.

The present work stands as one of the recent empirical contributions to the network analysis of the world web of suppliers and users of value-added. It belongs to a new line of the studies that represent IO matrices as graphs, as these are now weighted and directed networks, simultaneously displaying the different values of supply and use flows among countries or countries-sectors.

From 2000 to 2014, the world's trade in value-added has more than trebled and its geographical spread has become less unequal, with more countries and bilateral flows relevant for the GVCs. Countries with a greater number of partners also account for higher values of trade in value-added; major suppliers tend to also be major users.

Most of the countries, however, do not hold meaningful trade relationships or a significant number of partners, and their total trade in value-added is still small. Thus, the distribution of all centralities parameters is left-skewed.

When one takes into consideration the importance of partners instead of the value of trade, the centralities that emerge highlight that shared borders and trade agreements matter, as among Canada, Mexico and the US, or Netherlands with Germany.

Notwithstanding patterns in the global production networks show a strong regional dimension and that geographic borders matter, it is hard to conceive the GVCs phenomenon without the initial contracting out trend in the US and the steady industrial capacity of Germany.

The networks associated to the two time-frames here analysed clearly support this point, as well as how crucial Asia was, with its virtuous dynamics, combining the evolving roles of Japan, South Korea and China (besides less important players, like Vietnam and Thailand, not included in the WIOD). Despite the latter, the US still seems to keep a position of global winner from the phenomenon, with the outward flow from China to it slightly higher than the opposite flow, as highlighted in section 5. Until at least 2014 -our most recent date-, China was a net supplier of value-added to the US, contradicting the informal view the US has been running an unfavourable TiVA balance with China.

The above stresses the importance of departing from network analysis with traditional trade statistics as such reversals from so-called common knowledge cannot be identified in standard trade in goods flows, leading to unfortunate if not wrong trade policies.

The GVCs phenomenon remains however, as shown by the distribution of the several centrality measures, highly asymmetric, even if a certain diversification of world production centres is in course.

Is the model possible without strong regional hubs enjoying the possibility of linkages to other major markets?

We venture that with only a strictly regional market, or a fully globalised one, GVCs would perhaps be unfeasible or, at least, less frequent. The regional hub property provides a basis for a process of continuous outsourcing and supply that feeds the growth and upgrading of the centre, while the linkages to other major markets add needed more consumers to keep and ever-increase scale gains, besides multiplying the fragmentation options. The regional dimension is also key for the smaller firms, given the greater impact of transportation and logistics costs on them.

But, at the end of the day, concentration seems to be the name of the game. Without Germany, factory Europe loses its pumping engine; the same for Asia without China and, in 2014, for the whole world, without the US.

Emerging countries have intensified their positioning in the world trade network from 2000 to 2014, driven by upping the intensity of previous relationships with the key hubs. Will, following this evolution, China eventually either absorb or dominate the other hubs, becoming the new central node of the WTN?

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Figure I: World's suppliers and users network for 2000

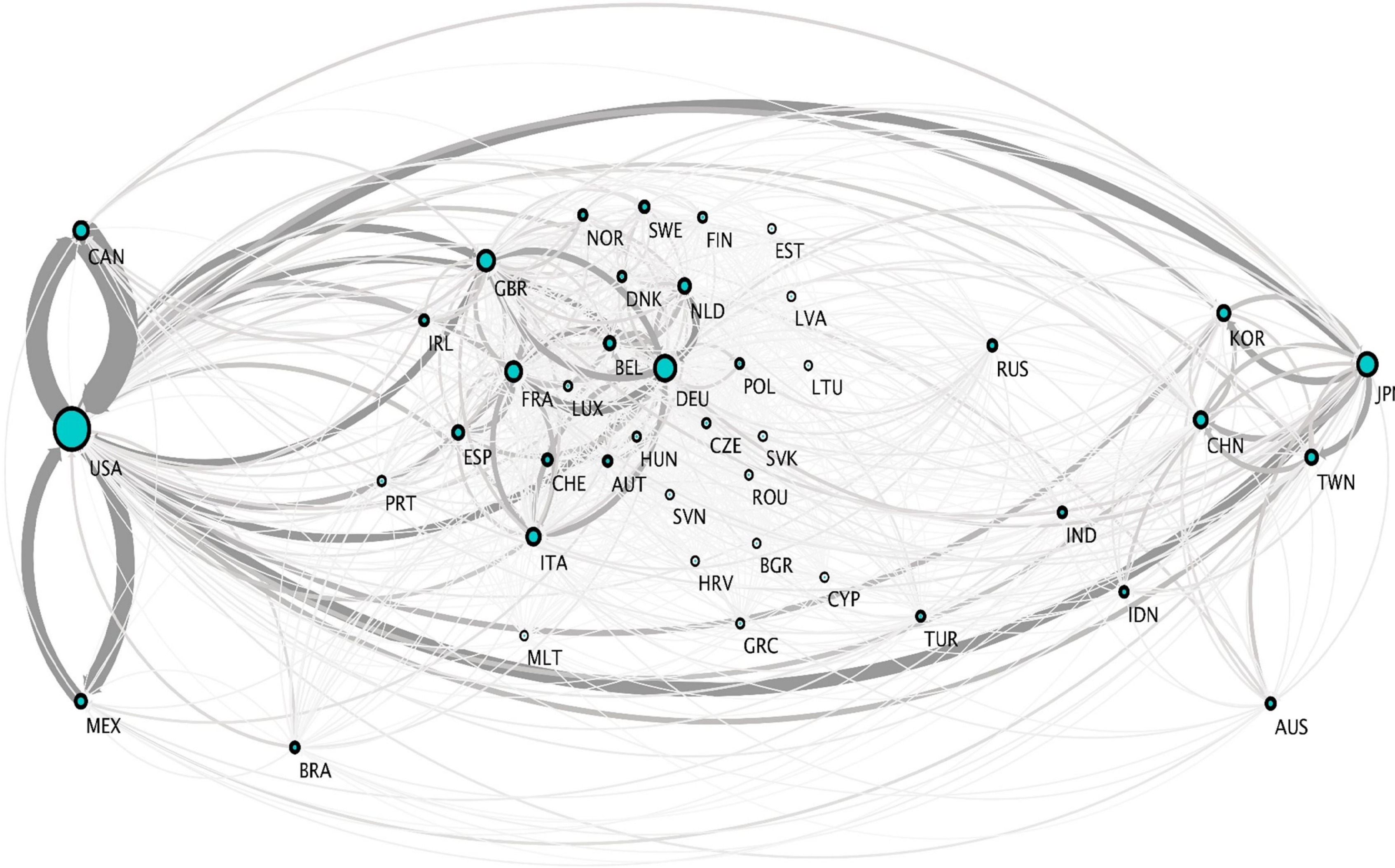

Figure II: World suppliers' and users' network for 2014

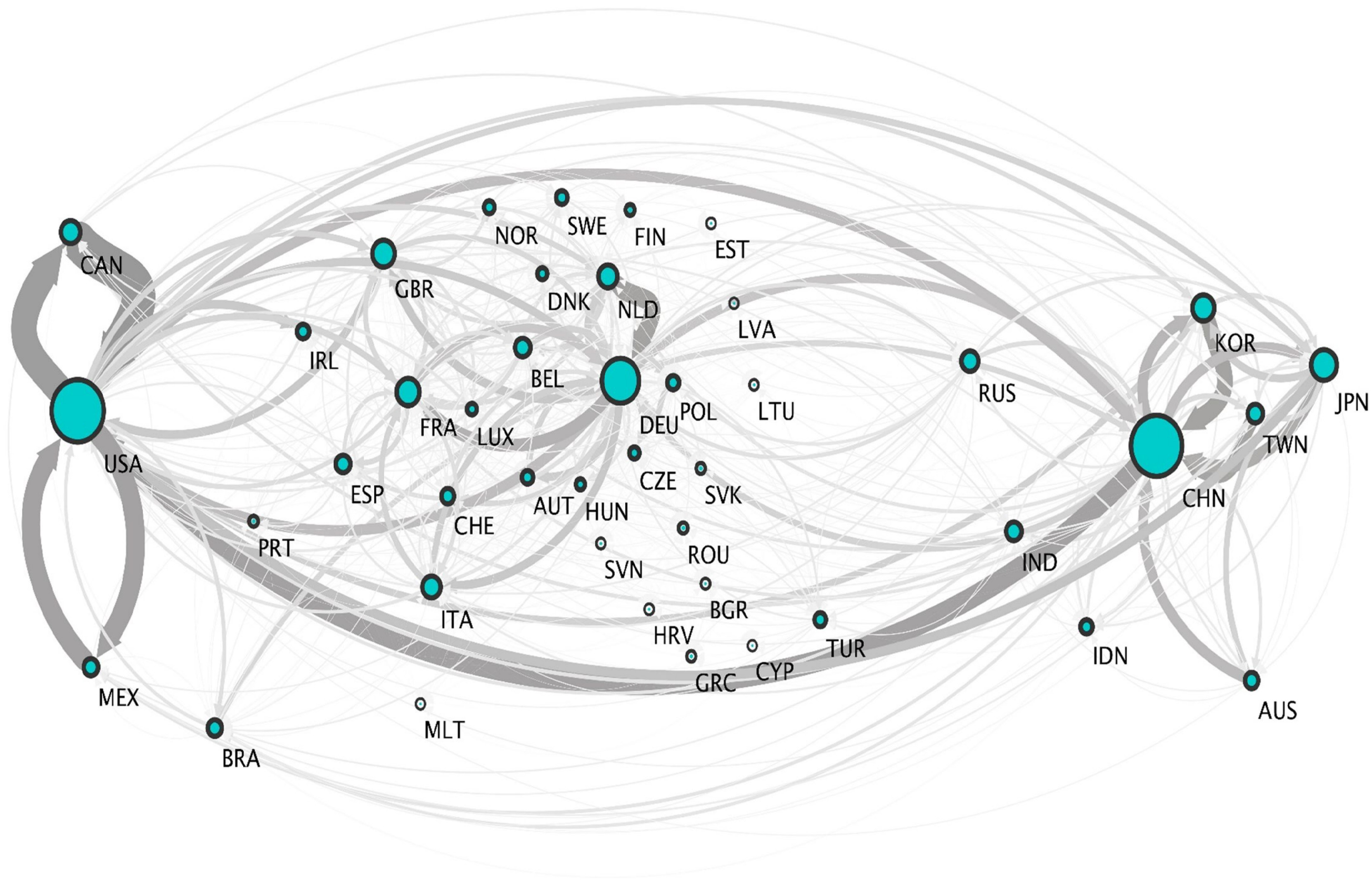

Table 1: Descriptive statistics and flow intensities

	2000	2014
Total No of Countries	43	43
Total No of flows	713	730
Total value of TTVA *(Billion US dollars)*	2408,7	6790,7
Lowest bilateral flow *(Billion US dollars)*	2,1	7,0
Highest bilateral trade flow *(Billion US dollars)*	874,1	1885,2
Average, TTVA *(Billion US dollars)*	3,4	9,3
Median, TTVA *(Billion US dollars)*	1,0	3,4
No of countries making up 50% of TTVA	17	23
No of flows making up 50% of TTVA	45	57
No of countries making up 90% of TTVA	34	35
No of flows making up 90% of TTVA	260	316
% of TTVA belonging to the top 10% flows	61,7%	56,3%
% of TTVA belonging to the top 10 flows	23,2%	19,5%

Source: Author's calculations based on WIOD IO data for 2000 and 2014

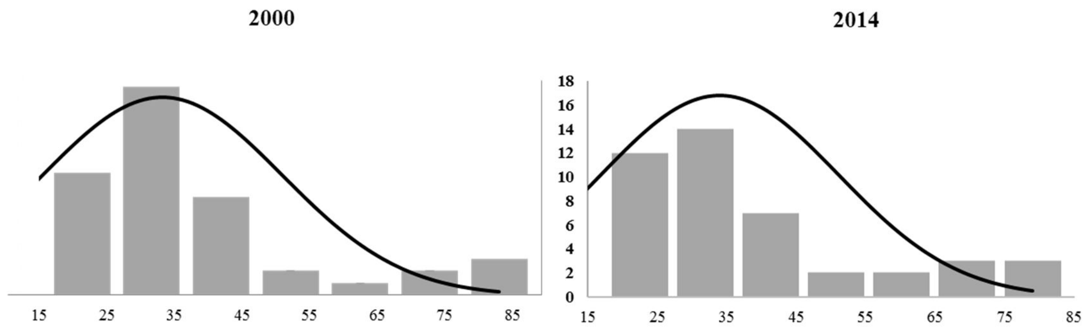

Figure III: Total node degree distribution 2000 and 2014
Source: Authors calculations based on WIOD IO data for 2000 and 2014

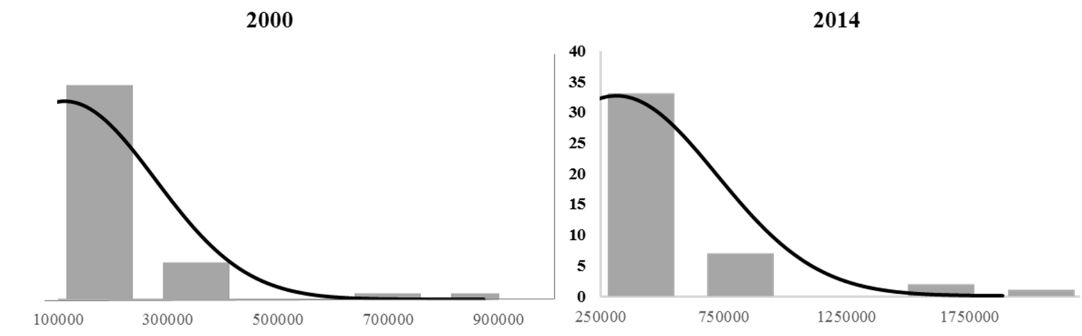

Figure IV: Total node strength distribution 2000 and 2014
Source: Authors calculations based on WIOD IO data for 2000 and 2014

Table 2: Top 5 and Bottom 5 countries in Indegree and Outdegree Strength

	Indegree (FVA) Strength		Outdegree (DVA) Strength	
	2000	**2014**	**2000**	**2014**
Top 5	USA	USA	USA	USA
	DEU	DEU	DEU	DEU
	FRA	CHN	JPN	CHN
	GBR	FRA	GBR	NLD
	JPN	GBR	FRA	GBR
Bottom 5	BGR	LTU	CYP	HRV
	CYP	MLT	LTU	MLT
	LTU	EST	EST	EST
	LVA	LVA	LVA	CYP
	EST	CYP	BGR	LVA

Source: Author calculations based on WIOD IO data for 2000 and 2014. Full percent rank analysis available from the Authors.

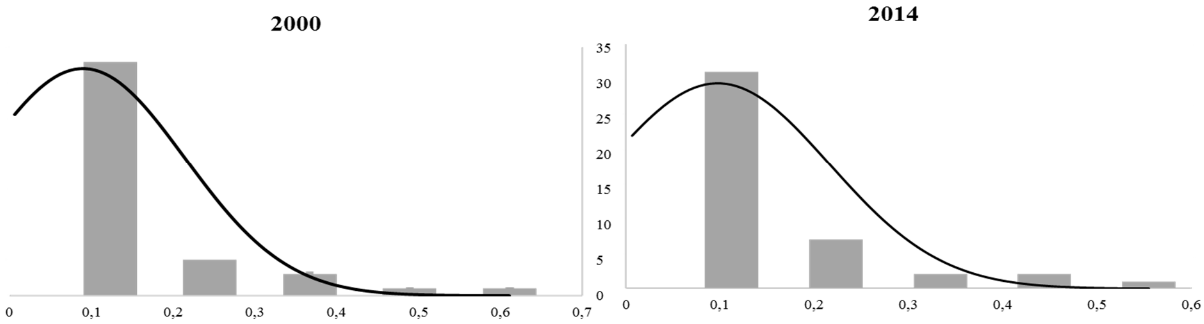

Figure V: Eigenvector centrality distribution 2000 and 2014
Source: Author calculations based on WIOD IO data for 2000 and 2014.

Table 3: Correlation coefficient of centrality measures

	2000	2014
EC – NS	0,94	0,92
EC – ND	0,58	0,59

Source: Authors calculations based on WIOD IO data for 2000 and 2014. Formula for eigenvector centrality follows Tang et al. (2015).

Table 4: Eigenvector Centrality rank analysis

	Percent Rank	
	2000	**2014**
Top 5	USA	USA
	CAN	CAN
	DEU	DEU
	JPN	CHN
	GBR	NLD
Bottom 5	HRV	HRV
	LVA	MLT
	BGR	EST
	LTU	LVA
	EST	CYP

Source: Authors calculations based on WIOD IO data for 2000 and 2014. Formula for eigenvector centrality follows Tang et al. (2015).

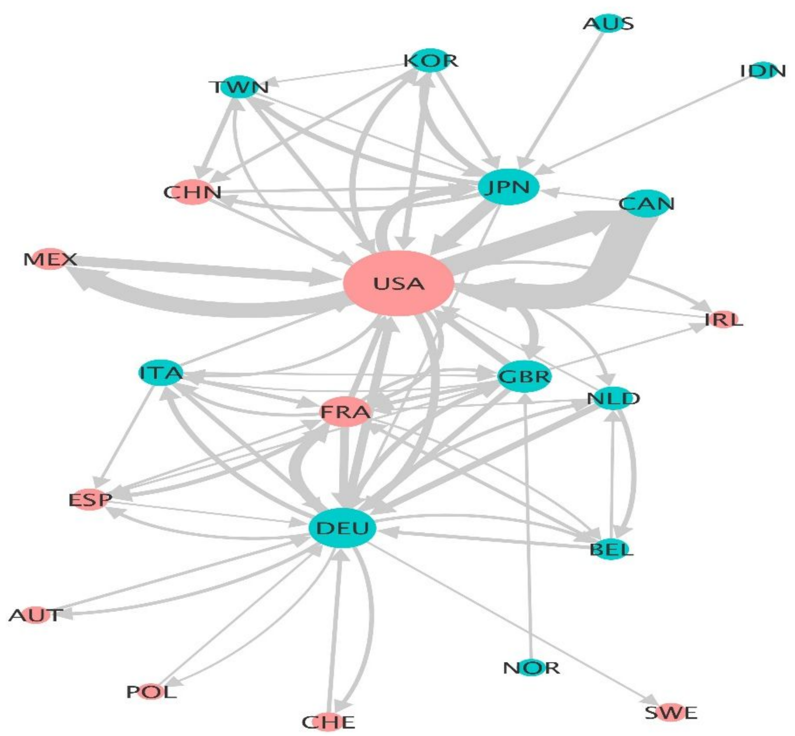

Figure VI – 2000 world's supplier and user network cut by the 10% highest flows. Pink nodes represent net importers of intermediates and blue nodes represent net exporters of intermediates to the countries included in this threshold.

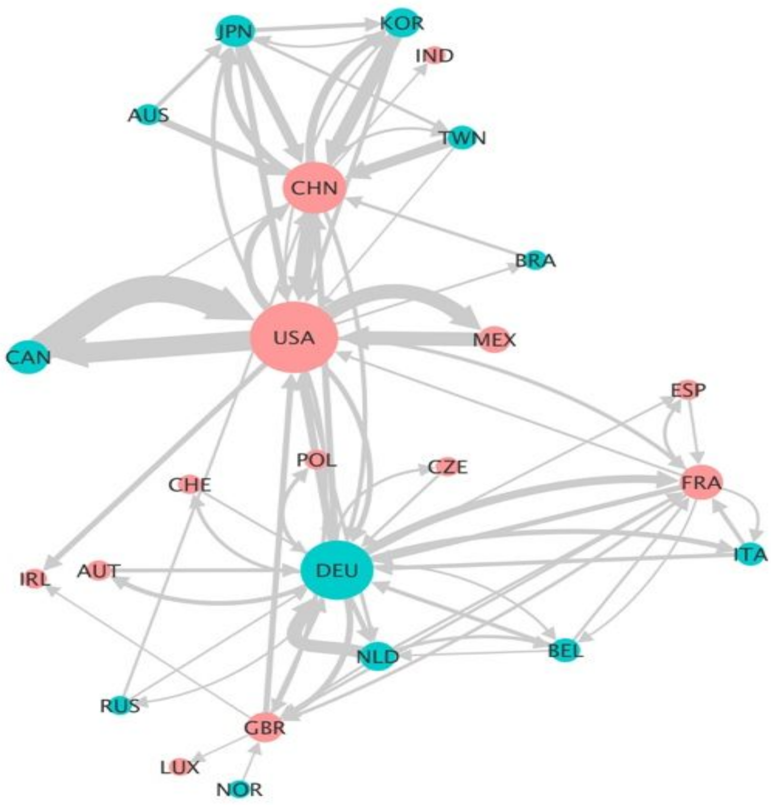

Figure VII – 2014 world's supplier and user network cut by the 10% highest flows. Pink nodes represent net importers of intermediates and blue nodes represent net exporters of intermediates to the countries included in this threshold.

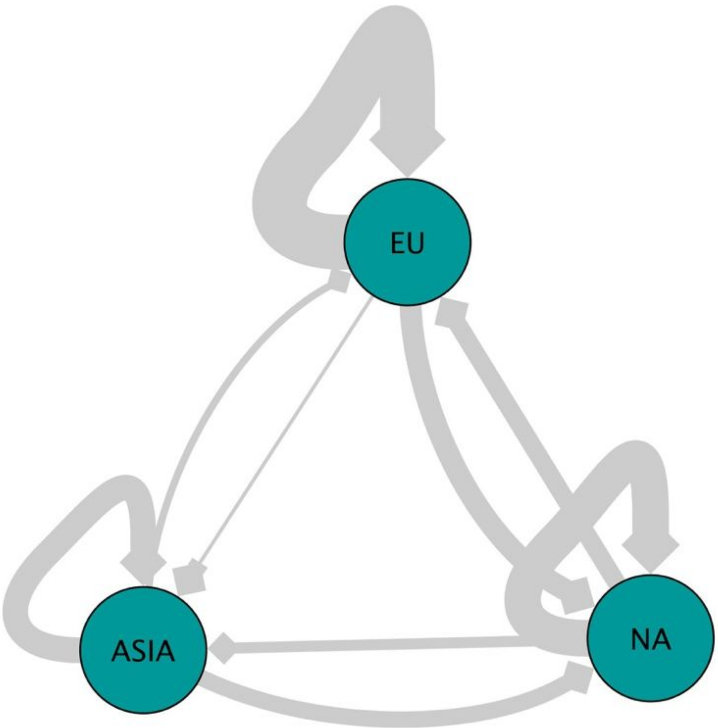

Figure VIII – 2000 world's supplier and user regional network. Asia include China, South Korea, Japan, India, Indonesia and Taiwan; Europe included all 27 EU countries, plus Switzerland and Norway. NA corresponds to all 3 NAFTA countries.

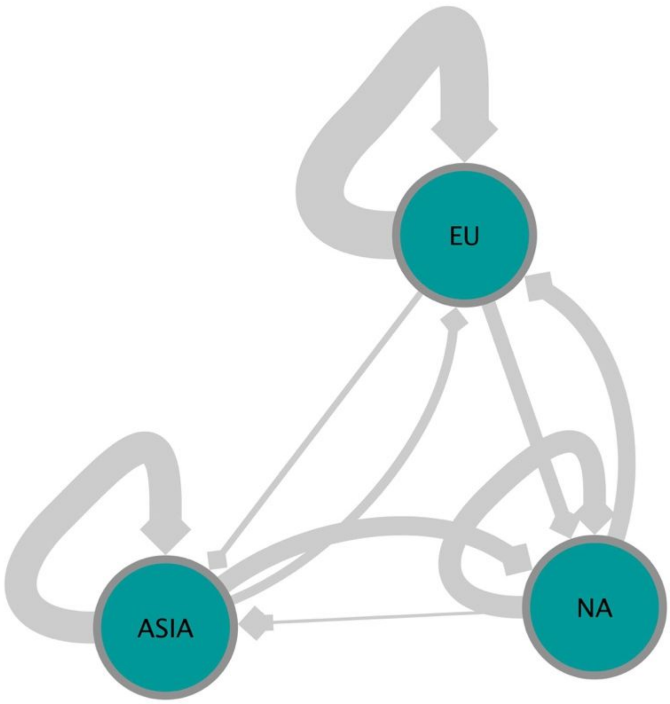

Figure IX – 2000 world's supplier and user regional network. Asia include China, South Korea, Japan, India, Indonesia and Taiwan; Europe included all 27 EU countries, plus Switzerland and Norway. NA corresponds to all 3 NAFTA countries.