

STRUCTURE, INTERDEPENDENCE, AND EVOLUTION OF GLOBALIZATION IN GLOBAL VALUE CHAINS

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Abstract

Global value chains (GVCs) are the practical expressions and principal engines of today's globalization. There is a burgeoning body of literature that takes a GVC perspective to understand the changing reality of globalization and its profound economic and political implications. We map globalization with Inter-Country Input-Output (ICIO) Tables, and we construct measures to describe the structure, interdependence, and power dynamic of globalization by tracing origins of value added in global trade. Our approach views GVCs as exchange networks, and relies on the Leontief Decomposition method to summarize the network structure and relationships by incorporating direct and higher-order value added interdependence. In the empirical analysis, we combine the OECD Input-Output Tables and the UNCTAD-Eora Global Value Chain Database. The data and measures reveal the structure, process and interdependence....

Keywords: Global Value Chains, Complex Networks, Globalization, Interdependence, Leontief Decomposition, Inter-Country Input-Output Tables

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1 Introduction

Global value chains (GVCs) are such a prominent feature of today's globalization that "[u]nderstanding the forces of globalization requires... the recognition of the role that GVCs play (Nyambura and Wanja, 2014, p.3). " The expanding and deepening of GVCs challenge the conventional wisdom about globalization and economic interdependence.¹ Because GVCs are essentially about how values are generated and distributed in the global production network, mapping globalization from the perspective of GVCs systemically reveals the distribution of gains and losses among participants in globalization, which is crucial to understand politics of globalization.

This paper takes the GVC perspective to understand the structure, interdependence, and evolution of globalization. There is a fast growing literature on mapping globalization and re-analyzing trade using inter-country input-output tables (ICIO) or multi-region input-output tables (MRIO) with the Leontief Decomposition method and its extensions (Koopman et al., 2010; Koopman, Wang and Wei, 2014; Wang et al., 2017). By applying the decomposition methods, many high-quality and high-resolution ICIO databases have been built and continuously updated, such as the World Input-Output Database funded by the European Union (Timmer, 2012), the OECD Inter-Country Input-Output (ICIO) Tables², and the UNCTAD-Eora GVC Database. Those massive datasets have been widely used in GVC-related studies. We seek to take advantage of these methods and data to systematically map globalization from the perspective of international political economy.

We construct measures to summarize the structural features, dynamic evolution and interdependence of GVCs and hence globalization. The measures used trace the origins of value added in the gross exports of every country-sector in the network. The measures are distinct from those describing gross trade flows of trade in intermediates. The measures describe the "value added contribution" of a country-sector to the exports of another country. In other words, they describe the gross exports of one country as composed of direct and indirect value added from another

¹<http://www.oecd.org/sti/ind/global-value-chains.htm>

²<http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm>

country - foreign value added - and the country's own domestic value added.

The measures not only take into account direct trade interdependence, but also incorporate “contributions” via indirect trade in the continuous flows of trade in the global trade network. Therefore, the measures are about the full value “chain”, namely, “chain dependence” or “chain influence”, in the sense that one country-sector's exports depends on all the upstream and downstream countries in terms of how value added is generated and distributed in the system. In the globally fragmented but well-integrated production networks, any change in the upstream or downstream exports would affect the export of this country-sector, though in different degrees. Hence, the two features of ultimate value added contributions and the “chain” effect differentiate the proposed measures from alternative measures of GVCs, such as trade of intermediates.

We use the UNCTAD-EORA Global Value Chain Database to construct the measures at the country level. The database covers more than 190 countries from 1990 to 2020 ³. Because the country-sector level data are not well cleaned in the database, we use the database of OECD Trade in Value Added to generate the country-sector level measures. After merging its 2016 and 2018 editions, we have the measures at the country-sector level for 36 sectors in 64 major economies from 1995 to 2016. ⁴.

The measures facilitate understanding the structure and process of globalization from the global production perspective and help to quantify interdependence in the gains from trade dimension. Our initial focus is on what the measures tell us about power. We first show that the GVC system has gotten more integrated and more hierarchical over time. Looking at the distribution of a measure of countries' influence, the difference between influential and non-influential countries has grown since 2010, after being relatively constant from 1990-2010. This has largely been driven by increased “forward linkage,” wherein a country sends more of its value added abroad. Trends in these measures have stayed relatively steady for the advanced economies, albeit it with decreases from 2005-2010. Among developing economies, forward linkages have increased substantially for China and India, but decreased substantially for Russia and Turkey. Some developing economies

³<https://worldmrio.com/unctadgvc/>

⁴<https://stats.oecd.org/index.aspx?queryid=75537> and <https://stats.oecd.org/Index.aspx?DataSetCode=TIVA2018C1>

have been much more successful than others in forward-integrating their value added. This signals an increase in their power and influence because the exports of other countries increasingly rely on value-added originating in new and a smaller number of countries.

We then focus on comparing measures between the United States and China. Two growing bodies of literature are seemingly in tension. On the one hand, the “rise of China” and “China shock” literatures describe the magnitude and impact of China’s entry in the global trading system. As the term “shock” implies, this rise has been swift and intense. On the other hand, the literature on “new interdependence” and “weaponized interdependence” emphasizes the degree to which established countries, namely the United States and United Kingdom, are able to use their positions in the global economic network to ward off competitors and maintain dominance. According to these accounts, the United States’ centrality in trade and financial networks allows it to manipulate supply chains for political and economic gain. Incidents like the US campaign against Huawei Technologies underscore its ability to disrupt global supply chains with targeted economic strikes.

Our measures suggest mixed evidence for each proposal. Across many monadic measures, Chinese influence has increased sharply and surpassed that of the United States. Looking dyadically and within-region, US influence has remained steady or grown in North, Central, and South America, while Chinese influence grew sharply and then has begun to wane after the Great Recession. Both trends appear when looking at US or Chinese influence as a supplier of value added and as a purchaser of value added from other countries. Looking specifically at the US and Chinese relationship also shows a more complicated picture. A greater proportion of US value added of its exports go to China. But a greater proportion of Chinese exports consist of value added originating in the United States.

Finally, we present a very initial description of the full value added network, from the perspective of suppliers and buyers. We also briefly describe initial efforts at analysis of clusters within that network.

GVCs have profound impacts on almost all aspects of the international political economy, and a wide range of IPE research questions have been re-investigated from the perspective of

GVCs. Examples include analyses of the impacts of GVCs on trade policies or firms' preferences (In Song Kim, 2019; Osgood, 2018; J. Bradford Jensen and Weymouth, 2015), economic growth and development strategies (Emily J. Blanchard and Johnson, 2016), national policy autonomy (Bruhn, 2014), investor-state relations (Johns and Wellhausen, 2016; Amendolagine et al., 2017), and inter-governmental negotiations and international regimes (KommerSkollegium, 2015; Galar, 2013), just to name a few. The data constructed in this paper can be used to study various political implications of GVCs. Besides, the measures of asymmetric interdependence we proposed in this paper can be applied to empirically test theories regarding the political implications of economic interdependence and help to settle great debates such as the relationship between economic interdependence and military conflicts (Mansfield and Pollins, 2003; Maoz, 2009).

The rest of the paper is organized as the following. In Section 2, we review the literature on mapping globalization from the perspective of GVCs. Then we focus on explaining and interpreting the Leontief Decomposition method, which is important to understand the measures we later construct. Section 3 introduces the measures and further explains their substantive meanings. In section 4, we report the empirical findings based on the measures about the structure, interdependence, and evolution of globalization. The final section concludes.

2 GVCs As Complex Networks and the Leontief Decomposition

The term of global value chains is often used interchangeably with trade in value-added, production sharing, supply chains, outsourcing, offshoring, vertical integration, etc. All those terms are to describe the changing reality that the production process has becoming more fragmented around the globe than ever. At the same time, "the high complexity and the different scales of analysis make it virtually impossible to define, measure and map GVCs in a single way (Amador and Cabral, 2014, p.1)." The conception of global value chains is essentially about how "value added" is generated and captured in the global production network (Amador and Cabral, 2014). As Gereffi

(2014) puts it, “an understanding GVCs is mainly about tracing and linking value added from different sources...The GVC framework focuses on globally expanding supply chains and how value is created and captured therein [p.12].” Tracing value added is important because globalization is so sophisticated and complicated that what you see not what you get (Maurer and Degain, 2012). Value added is crucial for us to go beyond the face value of globalization and study the gain and loss of participation in GVCs (Amador and Cabral, 2014). In this section, we briefly review the literature on analyzing GVCs based on ICIO tables, and introduce the Leontief Decomposition as a method to analyze the complex network presented by ICIO tables.

2.1 Mapping GVCs with Inter-Country Input-Output Tables

2.1.1 Value Added and Global Value Chains

Earlier GVC studies mainly focus on particular products or industries in a single country or region, and little was known about the global patterns and macro implications of GVCs due to the unavailability of data with broader coverage and at the national level. Inter-Country Input-Output Tables (ICIOT) were constructed to meet the urgency of analyzing the global structure and macro processes of GVCs. ICIOTs are among the four main types of data that have been used to map GVCs in the literature. The other three types of data are trade statistics of products, customs statistics on processing trade, and firm-level survey data. Trade in value added derived from ICIOTs has a good balance between accuracy and coverage, though they are highly complex data (Amador and Cabral, 2014). Recent ICIO data projects include the university-based Global Trade Analysis Project⁵, ICIO data projects sponsored by national governments (e.g., IDE-JETRO (Bo Meng and Inomata, 2013)), and large-scale and regular time-series databases constructed and harmonized by professional research teams organized and funded international organizations (e.g., the World Input-Output Database funded by the European Union (Timmer, 2012),⁶ the OECD Inter-Country

⁵<https://www.gtap.agecon.purdue.edu/about/project.asp>

⁶<http://www.wiod.org/home>

Input-Output (ICIO) Tables⁷, and the UNCTAD-Eora GVC Database.⁸.

ICIO data are crucial for GVC analysis because “the measurement of trade in value-added requires world I-O tables with information on all bilateral exchanges of intermediate and final goods to allocate the value-added along the GVC to each producer (OECD, 2013)”. Value added is the focus of GVC studies for several reasons. First, value added is important for accurately mapping and understanding GVCs. With the expansion and deepening of GVCs, gross trade statistics are increasingly misleading due to the growing intermediate trade and their continuous flows in the global complex and dynamic production network (Koopman et al., 2010; Koopman, Wang and Wei, 2014). The gross volume of exports may not accurately indicate competitiveness, and trade deficits are not necessarily a sign of a relative loss. When taking into account the indirect value added trade, this gap between trade exchanges and value-added relationships can be large. For many years, the United States has a huge and increasing trade deficits with China, but in terms of the value added contributions embedded in their trade, China is the one that is in deficit most of the time.

Second, value added is important for study the implications of GVCs. ICIO tables provide information about value added connectivities which are important to explain systemic risks and network-wise contagion. Also, because value added is generated by labor input, management, R&D, etc, it helps us understand the impacts of trade on jobs, inequality, and economic development and competitiveness of countries.

Thirdly, value added is important for policy-making. Value added analysis of GVCs can reveal the right sectors for governments to target to increase national competitiveness. Last but not least, the distribution of value added in the global production system directly reflect the economic gain from interdependence. International Relations scholars have been long interested in interdependence, and the absolute and relative gain is essentially important to research questions involving the concept of interdependence (Keohane and Nye, 1977; Baldwin, 1980; Mansfield and Pollins, 2001, 2003).

⁷<http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm>

⁸<http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm>

2.1.2 Inter-Country Input-Output Tables

All the ICIO databases use similar methodologies to gather and harmonize three original major data sources: national accounts statistics (NAS), supply-use tables (SUTs), and international trade statistics (ITS).⁹ Figure 1 shows the structure of a typical ICIOT. Reading the table horizontally, each row is a country-industry. Summing across a row yields a vector, X , which is the total output of that country-sector. That total output consists of two things. First, some of that output was used as intermediate inputs into other country-sectors (or as an input to other production within that same country sector). The rows in the matrix denoted Z show this the matrix of intermediate use, recording how much the country-sectors in the column use the output of the country-sector in the row as input in their production. Second, the matrix Y records the output that is used to satisfy final demand rather than used as intermediates, and it is called the final demand matrix. The final column, the vector X , thus shows total output viewed from the demand perspective; that is, $X = Z + Y$, the total output is equal to the sum of how the output is used, either used for final consumption or as intermediates.

Reading the first part of the table vertically shows output as the sum of intermediates and value added. Looking at the first part, each column is again a country-sector. The final row, X , is again a vector of the total output for each column. That final output consists of the value of the inputs (Z) and the value added vector, denoted by Va . Value is added to products by using inputs besides intermediate goods, such as labor, capital, technology, management, taxes, etc. Reading the table this way thus shows output from the supply perspective, $X = Z + Va$. The last column and last row should be equal, and the supply and demand are balanced. This equality is important because the ICIO table is based on the assumption of a global general equilibrium—demand is equal to supply at both the country level and the global level.

An ICIO table is a numeric presentation of a complex network of the global production system. Cerina et al. (2015) uses a hypothetical two-country-two-industry IO table to demonstrate that the

⁹For instance, the WIOD data project explains their methodology and procedure in great detail (refer to Erumbana et al. (2011); Timmer (2012); OECD (2014)).

Figure 1: Inter-Country Input-Output Table Structure

OECD, Inter-Country Input-Output (ICIO) Tables, 2016 edition

	Intermediates use	Final Demand							Output (X)
	ctry 1 x indy 1 [...] ctry 71 x indy 71	Households Final Consumption Expenditure (HFCE)	Non-Profit Institutions Serving Households (NPISH)	General Government Final Consumption (GGFC)	Gross Fixed Capital Formation (GFCF)	Change in Inventories and Valuables (INVNT)	Direct purchases by non-residents (DIRP)	Discrepancy (DISC)	
country 1 x industry 1	(Z)	(Y)							(X)
country 1 x industry 2									
[...]									
[...]									
country 71 x industry 1									
[...]	(Va)	Note : FD = Total final expenditures + discrepancy (i.e. exports to unspecified partners)							(X)
country 71 x industry 34									
Value added + taxes - subsidies on intermediate products (VA)									
Output (X)									

Source: ICIO Database.

ICIOT can be translated into a graphically-displayed network, which has different types of nodes and ties and consists of multiple networks. As shown in Figure 2, the network typology of ICIOT has three types of nodes, and the nodes indicated by E are countries-sectors in the international trade network of intermediate inputs; the nodes marked by V are the country-sectors that generate value added, and those indicated by F are the country-sectors that use outputs of other country-sectors as final goods. The ties are all weighted and directed. Ties between E nodes are directed flows of intermediates, ties between V and E are defined by the relations of adding value, and ties between E and Y are about how the intermediates produced by E are finally used for consumption by Y . And the weights of the ties are the volume of flows of goods or value added. Each sub-network can be a dense and complex network in reality. The right-lower panel in Figure 2 shows an example of the network of Z matrix based on real ICIOT from the WIOD database, and nodes in the same color are industries residing in the same country.

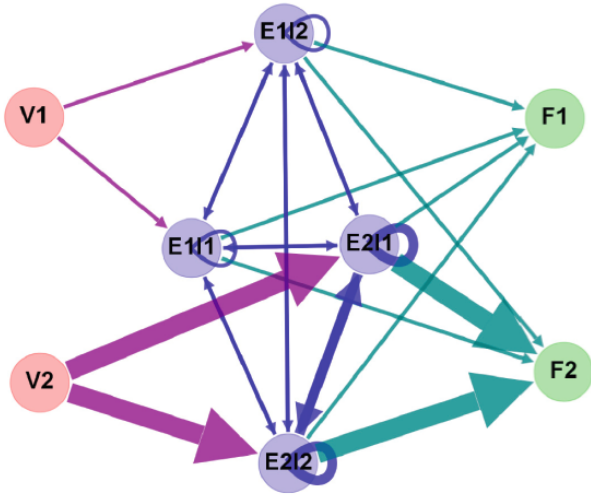
Some research focuses on direct analysis of this network of GVCs. For example, Cerina et al. (2015) use network analysis tools to describe the pattern and structure of the global trade of intermediate inputs, using the Z matrix. But we are interested in using this input-output network to trace the origins of value added back to their original countries. One method that can help achieve this goal is the Leontief Decomposition method introduced below.

Figure 2: ICIOT as a Complex Network

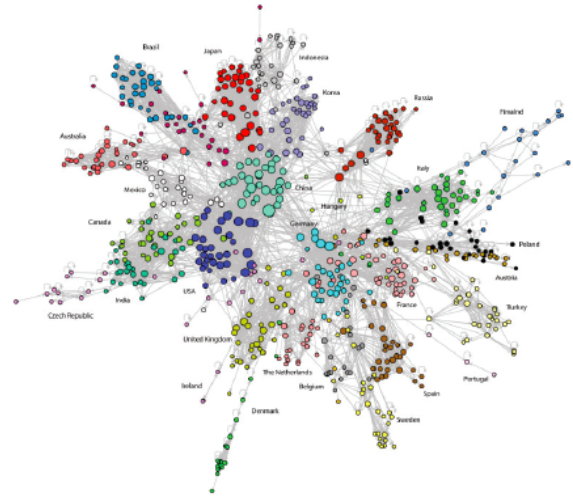
ICIOT in a 2-country-2-industry world

Seller Industry		Buyer Industry						Total Output
		Economy 1		Economy 2		Final Demand		
		Industry 1	Industry 2	Industry 1	Industry 2	Economy 1	Economy 2	
Economy 1	Industry 1	5	10	20	10	45	10	100
	Industry 2	10	5	10	20	50	5	100
Economy 2	Industry 1	30	15	800	500	5	8650	10000
	Industry 2	35	30	1000	1000	25	7910	10000
Value Added		20	40	8170	8470			
Total Output		100	100	10000	10000			

Network Typology of GIOT



Network Typology of Z in GIOT



Source: Cerina et al. (2015)

2.2 The Underlying Production Structure and the Leontief Decomposition

The Leontief Decomposition traces the origins of value added and calculates value added contributions between participants in GVCs. Here, we briefly describe the method proposed by Koopman et al. (2010) and Koopman, Wang and Wei (2014).

Suppose that the global production system consists of G countries each of which has N industries. In an open system of production, the total output of each country-sector is used by itself and all other country-sectors either as intermediate input or for final consumption. The input-output

model can be written as follows:

$$\mathbf{X}_{NG \times 1} = \mathbf{A}_{NG \times NG} \mathbf{X}_{NG \times 1} + \mathbf{Y}_{NG \times 1}, \quad (1)$$

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1,NG} \\ a_{21} & a_{22} & \cdots & a_{2,NG} \\ \vdots & \vdots & \ddots & \vdots \\ a_{NG,1} & a_{NG,2} & \cdots & a_{NG,NG} \end{bmatrix} = \begin{bmatrix} \frac{Z_{11}}{X_1} & \frac{Z_{12}}{X_1} & \cdots & \frac{Z_{1,NG}}{X_1} \\ \frac{Z_{21}}{X_2} & \frac{Z_{22}}{X_2} & \cdots & \frac{Z_{2,NG}}{X_2} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{Z_{NG,1}}{X_{NG}} & \frac{Z_{NG,2}}{X_{NG}} & \cdots & \frac{Z_{NG,NG}}{X_{NG}} \end{bmatrix}. \quad (2)$$

The matrix \mathbf{A} is called the Input-Output coefficient matrix or technical coefficient matrix in the Input-Output literature. From the network perspective, \mathbf{A} can be viewed as a flow system, and each element a_{ij} is the share of the output of country-sector i flowing to country-sector j as an intermediate input. Accordingly, the matrix $\mathbf{Z} = \mathbf{A}\mathbf{X}$ is a flow network of trade of intermediate input¹⁰. It is easy to see that \mathbf{A} is a one-step transition matrix, indicating the strength of the direct connection between country-sectors via intermediate trade.

But the value in goods and services is in a continuous flow in the global production network until they are finally consumed. There are (many) more than just one step as goods are produced and used as inputs in various other countries and industries. Production activities of two country-sectors are linked not only by their direct exchange of intermediates but also by all value added embodied in the inputs used by one country-sector, which can be traced back to the production of each other.

To account for all the direct and indirect connectivity of value added between country-sectors, we sum up all rounds or “steps” of these transitions in the system as follows:

$$1 + \mathbf{A} + \mathbf{A}\mathbf{A} + \mathbf{A}\mathbf{A}\mathbf{A} + \dots + \underbrace{\mathbf{A}\mathbf{A}\dots\mathbf{A}}_n = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \dots \mathbf{A}^n. \quad (3)$$

¹⁰Refer to Peiteng Shi (2014) for more details about flow networks.

Then we define

$$\mathbf{B} \equiv \lim_{n \rightarrow \infty} \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \dots \mathbf{A}^n \quad (4)$$

$$= (\mathbf{I} - \mathbf{A})^{-1}. \quad (5)$$

The power series of \mathbf{A} is convergent to $(\mathbf{I} - \mathbf{A})^{-1}$ as long as \mathbf{A} is in full rank (Miller and Blair, 2009).

The matrix \mathbf{B} is known as the Leontief Inverse Matrix (Leontief, 1936), often called the total requirement coefficients in input-output analysis. Re-arrange the equation $\mathbf{X} = \mathbf{A}\mathbf{X} + \mathbf{Y}$, and we have $\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y} = \mathbf{B}\mathbf{Y}$, which is called the Leontief Insight. The Leontief Insight is an important discovery of how to trace the production process. As explained by Zhi Wang and Zhu (2016), the Leontief Insights tells us that "[u]sing the linkages across industries and countries, gross output in all stages of production that is needed to produce one unit of final goods can be traced. Value added production and trade can be simply derived by multiplying these flows with the value added to gross output ratio in each country/industry [pp.5-6]." In other words, the Leontief Inverse \mathbf{B} is the underlying structure of the system that determines how value added is distributed in the equilibrium of a flow network. From the network perspective, the \mathbf{B} matrix is a solution to the question of what is the value-added connection between nodes in a complex network with value being added to flowing intermediates in the system. The value-added connectivity revealed by \mathbf{B} matrix takes into account of the first-order connectivity of direct interdependence as well as higher-order connectivity of the systemic interdependence.

To trace value added connections, now we turn to the domestic value-added coefficient vector, which is denoted as \mathbf{V}^s for country s and is a $1 \times N$ vector with each element as the coefficient of value added in a sector in the country. By definition, each element V_j^s is the ratio of value added to output in sector j :

$$V_j^s = Va_j^s / X_j^s, \quad (6)$$

When multiplying the Leontief Inverse with the value added coefficients \mathbf{V} , we have a value-added share matrix which is the basic measure of value-added shares by sources of production:

$$\hat{\mathbf{V}}\mathbf{B} = \begin{bmatrix} \mathbf{V}_1 & 0 & \cdots & 0 \\ 0 & \mathbf{V}_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \mathbf{V}_G \end{bmatrix}_{NG \times NG} \begin{bmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} & \cdots & \mathbf{B}_{1G} \\ \mathbf{B}_{21} & \mathbf{B}_{22} & \cdots & \mathbf{B}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{B}_{G1} & \mathbf{B}_{G2} & \cdots & \mathbf{B}_{GG} \end{bmatrix}_{NG \times NG} \quad (7)$$

$$= \begin{bmatrix} \mathbf{V}_1\mathbf{B}_{11} & \mathbf{V}_1\mathbf{B}_{12} & \cdots & \mathbf{V}_1\mathbf{B}_{1G} \\ \mathbf{V}_2\mathbf{B}_{21} & \mathbf{V}_2\mathbf{B}_{22} & \cdots & \mathbf{V}_2\mathbf{B}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{V}_G\mathbf{B}_{G1} & \mathbf{V}_G\mathbf{B}_{G2} & \cdots & \mathbf{V}_G\mathbf{B}_{GG} \end{bmatrix}_{NG \times NG}, \quad (8)$$

where each block matrix $\mathbf{V}_i\mathbf{B}_{ij}$ in $\hat{\mathbf{V}}\mathbf{B}$ is a $1 \times N$ matrix. Note that for $\hat{\mathbf{V}}\mathbf{B}$, each column of $\mathbf{V}\mathbf{B}$ is sum up to 1:

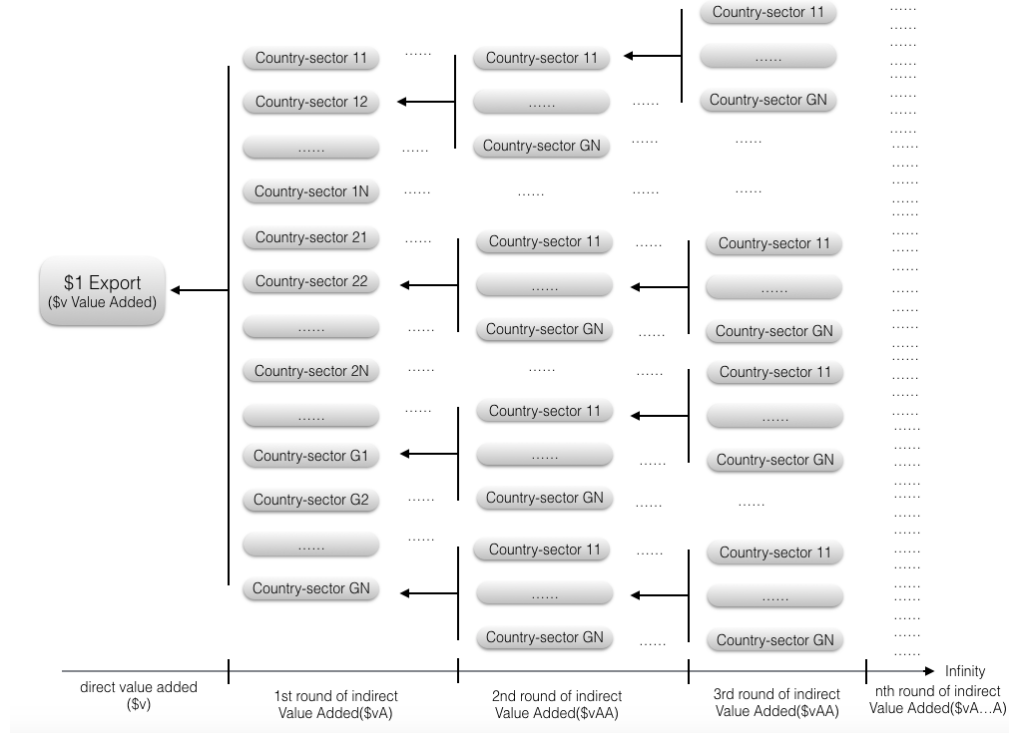
$$\mathbf{V}_1\mathbf{B}_{1s} + \mathbf{V}_2\mathbf{B}_{2s} + \dots + \mathbf{V}_r\mathbf{B}_{rs} + \dots + \mathbf{V}_G\mathbf{B}_{Gs} = \mathbf{j}, \quad (9)$$

that is, each term on the left-hand side of the equation is the share of value added from each country r to one unit value added in country s .

This is an important matrix with an important substantive interpretation. As Koopman, Wang and Wei (2014) explains, “the $\hat{\mathbf{V}}\mathbf{B}$ matrix is not any arbitrary share matrix, but rather the one that reflects the underlying production structure embedded in the ICIO model... It contains all the needed information on value-added production by source [p.465].” The simple intuition behind $\hat{\mathbf{V}}\mathbf{B}$ is as follows: when one unit of export is produced, the direct domestic value added is generated. Trace backwards, and intermediate inputs are used to produce the one unit export, and their production also generate value added which forms the second around of value added. And we can trace further backwards to infinity, and the $\hat{\mathbf{V}}\mathbf{B}$ sums up all the direct and indirect value added induced by the one unit export.

Figure 3 graphically shows the intuition of $\hat{V}\hat{B}$ and how it relates to the one-step transition matrix \hat{A} . It heuristically demonstrates how the Leontief Decomposition Method traces the original sources of value added throughout the system and back to infinity. The real chain is much thinner and more sparse than what is portrayed in Figure 3, since not every product is an input of an input of an input (etc) for every other product. But the figure shows the backwards tracing of the origin of value added for one dollar's worth of exports.

Figure 3: ICIO Production Structure: Global Value Added Chain (Tree)



Multiplying $\hat{V}\hat{B}$ times gross trade, we have $\hat{V}\hat{B}\hat{E}$ where \hat{E} is defined similarly as a block matrix with the diagonal matrix as exports of country-sectors. The matrix/table of $\hat{V}\hat{B}\hat{E}$ is the value-added decomposition of global trade under the assumption that the structure of value added is the same in exports as in GDP.

Figure 4 demonstrates what the matrix $\hat{V}\hat{B}\hat{E}$ looks like. When we look at the columns, each column sums up to the exports of a country (or country-sector, depending on how we aggregate) which consist of domestic values added (DVA) and foreign value added (FVA). Note that DVA

Figure 3. Value-Added Content of Trade

		DVX						
		Country 1	Country 2	Country 3	...	Country k	...	Country N
DVA	Country 1	T_v^{11}	T_v^{12}	T_v^{13}	...	T_v^{1k}	...	T_v^{1N}
	Country 2	T_v^{21}	T_v^{22}	T_v^{23}	...	T_v^{2k}	...	T_v^{2N}
FVA	Country 3	T_v^{31}	T_v^{32}	T_v^{33}	...	T_v^{3k}	...	T_v^{3N}

	Country k	T_v^{k1}	T_v^{k2}	T_v^{k3}	...	T_v^{kk}	...	T_v^{kN}

	Country N	T_v^{N1}	T_v^{N2}	T_v^{N3}	...	T_v^{Nk}	...	T_v^{NN}

Source: UNCTAD (2013).

Figure 4: Decomposition of Trade

and FVA are both origins of value added but not the value added in intermediate supply of a foreign country. For example, Country 2 may not have *any* direct trade relationship with Country 2, but the cell (2, 1) can be a positive or even a large value if the exports from other countries to Country 1 carry value added from Country 2. In other words, T_v^{21} is the sum of value added directly and indirectly from Country 2 in Country i's exports. When we look at the rows, each row is decomposed as domestic value added (DVA) and the indirect value added exports (DVX).

To summarize each constituent part, the decomposition of trade generates

- Domestic value added embodied in gross exports (DVA): refers to the value added generated by the domestic economy in the production (direct and indirect) of goods and services for export. It includes the value added embodied in all exported goods and services produced by national industries, including the domestic value added that was previously exported and the re-imported to be used in production of intermediates.
- Foreign value added embodied in gross exports (FVA): refers to the value added of foreign goods and services that are used as intermediates to produce goods and services for export. FVA is usually analysed by the country of origin.

- Indirect value added exports (DVX): refers to the portion of this domestic value added used as inputs by industries in other countries, which produce goods or services for export to third countries. (Javorsek and Camacho, 2015, p.8)

One important feature of $\hat{VB}\hat{E}$ is worthy of a special notice: the sum of each column j is equal to the gross export E produced by the country-sector j , and the sum of each row i is equal to the value added exported from country-sector i . When the matrix is row-standardized or column standardized, each cell is the share of value added exported by i that is in the export of j , or the share of foreign value added from i to the exports of j . And the row is known as “forward linkage,” showing the strength of value added linkages of the i th country-sector as an upstream sector with all its downstream sectors directly and indirectly in GVCs. By the same token, the column is about the “backward linkage,” which is the strength of value added linkages of the j th country-sector as a downstream sector with its direct and indirect upstream partners around the world.

2.3 Differences Between Decomposition and Network Analysis

An ICIO table consists of a huge and complex network of the global production system, and network analysis seems to be a natural tool to analyze the ICIO data. In fact, network analysis has been increasingly applied to investigate the structural features of GVCs based on ICIO data. For example, Zhu et al. (2015) build a GVC network based on value-added exports, apply a breadth-first search algorithm to compute the global value trees, and calculate a tree-based importance measure of the country-industries in GVCs. Similarly, Amador and Cabral (2016) and Amador and di Mauro (2015) use the WIOD database to build networks of value-added gross trade from 1995 to 2011, describe the characteristics of GVCs with a variety of network metrics, and find that “value-added trade networks became denser, more complex and intensely connected.” They also discover that the GVC network is highly centralized and hierarchical with “a very asymmetric linkage structure dominated by a few hubs,” and raise the concern that such a network “is more exposed to aggregated fluctuations.” Those findings are confirmed by Tsekeris (2017) who builds similar value added networks using the WIOD and tries to identify the main drivers of structural

change of GVCs from 1995 to 2011. He finds that the size, strength, and connectivity of the networks increase significantly during those years, and there are a few most influential country sectors around which other nodes are highly clustered.

The most important difference between network analysis and the Leontief Decomposition method is that, when analyzing higher-order connectivity, network analysis focuses on static paths and their lengths from one node to another in the network. If there are n different paths between a and b , then the weights and lengths of the n paths determine the connectivity between a and b . Differently, for the Decomposition method, connectivity between a and b depends not only on the static paths between a and b (which is A) but also on continuous flows throughout the system (the infinite iterations of A). Value embedded in intermediates keeps flowing and being added in the channels defined by the matrix A of intermediates exchange until they are finally consumed, and each round of transition weakly increases connectivity between dyads. Therefore, we tend to view the the decomposition method as a method to analyze complex and flow networks rather than a method to construct a value-added trade network, since the dyadic relations revealed by the decomposition method incorporate all indirect connectivities between dyads.

3 Measures of Structure, Interdependence, and the Evolution of Globalization

The availability of ICIO databases and development of the decomposition methods have led to a burgeoning literature to empirically describe and analyze the structure of today's globalization.¹¹ The existing measures constructed based on ICIO tables are mainly GVC participation and positioning. Examples include that Winkler (2016) uses value added gross exports to measure seller- and buyer-related participation based on data of the WIOD, TiVA, and World Bank Export of Value Added database. And Amendolagine et al. (2017) and Wang et al. (2017) apply more decomposed measures for GVC participation and positioning in GVCs. However, those existing measures are

¹¹For example, see: Hernandez and Pedersen (2015) and Frederick (2014) for recent reviews.

almost exclusively from the perspective of economics.

The measures we introduce in this section are constructed from the perspective of International Political Economy. Power, especially power of state actors, is the focus of our measures. GVCs are formed by vertical integration, and participants in GVCs are connected with forward and backward linkages. A country's positioning in a GVC affects its bargaining power Sturgeon (2009). As Dallas, Ponte and Sturgeon (2017) states, "power has been a foundational concept in examining global value chains and production networks (p.1)." And in GVCs, "power differentials are a joint function of the value of the resource desired and the availability of that resource (or its equivalent) from alternative sources (Mahutga, 2014, p.161)." Earlier studies analyze how the "lead" firms in global commodity chains enjoy disproportional bargaining power (Gereffi, 1994).

So far, the discussion of power in GVCs has been dominated by firm-level analyses. "What is crucial to the operation of power in exchange networks, however, is that power differentials allow powerful firms to bargain their potential exchange partners against each other and thereby extract economic concessions" (Mahutga, 2014). Sectoral and national power can be calculated by aggregating power of firms in the sector or nation. Mahutga (2014) measures national-level power differentials by constructing measures of relative bargaining power based on industry-specific international trade networks. Just as Mahutga (2014) correctly points out, "the units of analysis that predominate in both GPN and GCC/GVC research—firms and the transnational networks in which they are embedded—pose a bit of a methodological challenge in drawing conclusive links between networked production and economic development, particularly when statistics on both development and economic behaviour are compiled cross-nationally [p.164]." This is especially true for IPE/IR scholars who are much more interested in power relations involving state actors. In this section, we introduce several measures to reveal the power relations in GVCs by focusing on the gain dimension of interdependence quantified as value added contributions. We measure power both as a network concept (Strange, 1996; Hafner-Burton, Kahler and Montgomery, 2009; Hafner-Burton and Montgomery, 2009; Oatley et al., 2013) and as a dyadic concept (Dahl, 1957; Keohane and Nye, 1977, 1987).

3.1 Measures: Structure, Evolution, and Structural Power

As Keohane and Nye (1987) write, “systems have two dimensions: structure and process... We used the term ‘structure’ in the neorealist sense to refer principally to the distribution of capabilities among units. Process refers to patterns of interaction: the ways in which the units relate to each other [p.745].” We measure the system of globalization in the era of GVCs with two sets of measures. One set of measures focus on the structure—the distribution of participation, influence, and vulnerability of participants in GVCs. And the second set includes measures of process, mainly about interactions and how countries relate to each other in GVCs.

3.1.1 Measuring Structure Of Globalization: Participation, Influence, and Vulnerability

GVC Participation To measure the depth of globalization, we first consider a set of measures of the degree of participation of countries and country-sectors in GVCs. The participation measures are based on well-established concepts and theories in the literature (Aslam, Novta and Rodrigues-Bastos, 2017; OECD, 2019). The measures are about GVC “linkage” and related to the concept of “vertical specialization”(David Hummels and Yi, 2001) “which requires three characteristics, the third of which distinguishes a value chain from simple outsourcing: 1. goods are produced in stages; 2. two or more countries provide value added in the production sequence; 3. at least one country uses imported inputs in its stage of the production process and exports some of the resulting product to either a third country or back to the country of origin.”

The well-known VS1 indicator is from the export perspective and focuses on DVX in Figure 4. It counts the portion of exports that are used by another country in the production of its export goods. It is a monadic measure. It is calculated for each country as the sum over all products and destinations of its exports of intermediates multiplied by the ratio of exports to gross output for that industry in the destination country. This is an approximation that assumes that the usage of each intermediate input is proportionately the same for exports as for products sold domestically Aslam, Novta and Rodrigues-Bastos (2017)

We construct the following measures of GVC participation:

- **Participation as Buyer:** the participation of a country S as buyer in global value chain is measured by the sum of its value added backward linkage in GVCs to its gross export. This measure is also referred to as “backward linkage.” It reflects how much the gross export of the country S depends on the value added generated by foreign countries. The indicator is calculated based on the formula as below:

$$Participation.as.Buyer = \frac{\sum_{r \neq s} FVA_{r \rightarrow s}}{Export_s} \quad (10)$$

$$\text{where } Export_s = DVA_s + \sum_{r \neq s} FVA_{r \rightarrow s} \quad (11)$$

- **Participation as Supplier** , the participation of a country S as supplier in global value chain is measured by the sum of its value added forward linkage in GVCs to its gross export. This measure is also referred to as "forward linkage." It reflects how much value added the country S generates for the gross export of foreign countries. The indicator is calculated based on the formula as below:

$$Participation.as.Supplier = \frac{\sum_{r \neq s} FVA_{s \rightarrow r}}{Export_s} \quad (12)$$

$$\text{where } Export_s = DVA_s + \sum_{r \neq s} FVA_{r \rightarrow s}, \text{ and } \sum_{r \neq s} FVA_{r \rightarrow s} = \sum_{r \neq s} DVX_{s \rightarrow r} \quad (13)$$

- **Participation:** the participation of a country S as either buyer or supplier in global value chain.

$$Participation = Participation.as.Supplier + Participation.as.Buyer \quad (14)$$

As either ratio gets larger, and as their sum increases, the greater the intensity of involvement of a particular country in GVCs.

Positions We then further measure the relative position of a country in GVCs and its structural influence. We call those measures as indicators of influence. Mahutga (2014) correctly argues,

“[e]xtending the exchange theoretic conceptualization of power in production networks up to its implications for national development requires the measurement of the aggregate positional power of resident firms according to the exchange theoretic determinants of power.” Our measures capture this idea at the aggregated country or country-sector level, as opposed to at the firm level. Our measures of influence are essentially based on the concept of “value capture”—“disproportionate value capture is a function of the scarcity of the requisite resources to buying...[and the] exchange theoretic approach to power in production networks that adopts the network language of the GPN approach and then synthesize it with insights from power-dependence theory”(Mahutga, 2014). The measures include:

- **Upstream Position:** This index that characterizes the relative upstreamness of a country in GVCs. It is measured as the log ratio of a country’s supply of intermediates used in other countries’ exports to the use of imported intermediates in its own exports. The indicator is calculated based on the formula provided by Aslam et al. (2017) ¹²

$$UpstreamsPosition_s = \log \left(1 + \frac{\sum_{r \neq s} FVA_{s \rightarrow r}}{Export_s} \right) - \log \left(1 + \frac{\sum_{r \neq s} FVA_{r \rightarrow s}}{Export_s} \right) \quad (15)$$

$$\text{where } Export_s = DVA_s + \sum_{r \neq s} FVA_{r \rightarrow s} \quad (16)$$

- **Influence as Supplier:** We measure the influence of a country S as supplier in global value chain with the sum of the logarithm of the share made by its value added exports of intermediate to the gross export of its partners around the world. The measure is calculated based on the formula as below:

$$Influence.as.Supplier.log = \sum_{r \neq s} \log \left(\frac{FVA_{s \rightarrow r}}{Export_r} + 1 \right) \quad (17)$$

$$\text{where } Export_r = DVA_r + \sum_{s \neq r} FVA_{s \rightarrow r} \quad (18)$$

¹²Aslam Aqib, et al. 2017. Calculating Trade in Value Added. IMF Working Paper, WP/17/178, PP.1-24.

We add 1 to the share for computational reasons. The logarithm is on the base of 10. The value of *Influence.as.Supplier.log* is bigger when the country S has more downstream partners and its value-added exports of intermediate to its partners count a larger share of the partners' gross export.

- **Influence as Buyer:** We measure the influence of a country S as buyer in global value chain as the sum of the logarithm of the share made by its value added imports of intermediate from its partners to its partners' gross export around the world. The indicator is calculated based on the formula as below:

$$Influence.as.Buyer.log = \sum_{r \neq s} \log \left(\frac{FVA_{r \rightarrow s}}{Export_r} + 1 \right) \quad (19)$$

$$\text{where } Export_r = DVA_r + \sum_{s \neq r} FVA_{s \rightarrow r} \quad (20)$$

The value of *Influence.as.Buyer.log* increases when the country S has more upstream partners and its value added imports from its partners count a larger share of its partners' gross export.

- **Influence**, is the total influence of a country S in global value chain.

$$Influence.log = Influence.as.Supplier.log + Influence.as.Buyer.log \quad (21)$$

Those measures are constructed with value-added data from UNCTAD-Eora Global Value Chain Database, and cover 188 countries from 1990 to 2019, with total 5640 as the sample size. We also generate measures at the country-sector level by using using Database of OECD Trade in Value Added (2016 and 2018 editions), and cover 36 sectors in 64 major economies between 1995 and 2016. The data have 2916 country-sectors in 22 years, with the total sample size as 47,500.

3.2 Interdependence and Dyadic Power

In the GVC literature, interdependence has been widely discussed in the context of power relations between firms (Gereffi, 1994; Sturgeon, 2009; Cox and Wartenbe, 2018). The power-dependency principal states that power of i on j is a function of dependency of j on i (Mahutga, 2014). The linkage between dependency and power has long been recognized in the IPE/IR literature that relates “interdependence to power through the concept of asymmetrical interdependence as a power resource (Keohane and Nye, 1987, p.728).”

Mansfield and Pollins (2003) argue that more research effort should be made to measure interdependence in the gain dimension, since “the micro-theory underpinning the central liberal claim hinges not on trade flows, *per se*, but on the gains from trade (p.12).” However, gains in interactions are difficult to trace, and costs of disrupting the relationship require information about availability and accessibility of substitutes, which makes it challenging to measure the gain dimension of interdependence.

Our data on value added contributions are explicitly and directly about gains, and the interdependence measures we construct are the gain-dimension measures. In addition, Maoz (2009) criticizes the existing measures of interdependence as marred by serious problems, including treating interdependence purely as dyadic relations and only considering first-order interdependence. The Decomposition method applied to ICIO tables incorporates direct and all indirect value added connectivities between dyadic pairs by tracing the value added process throughout the whole network.

We construct two sets of measures of interdependence at different levels. The first is the country-level, and the second is cross-level interdependence between countries and sectors of other countries. We do not consider measures at the pure country-sector level, because what is essential interesting to us is the interdependence and power involving state.

Because the connections in the GVC networks are directed, and countries are placed in relative positions with one another, our measures differentiate upstream and downstream dependence. More specifically, we consider the following:

- **Dependence (of S) as buyer (from R):** This measures how much Country S, as a buyer, depends on the value added supplied by Country R. The more value added from R to S, the more dependent S is to R's supply. The indicator is calculated based on the formula as below:

$$Sens.Dep.sr.buyer = \frac{FVA_{r \rightarrow s}}{Export_s} \quad (22)$$

$FVA_{r \rightarrow s}$ is how much value added originated from country R is embodied in the export of country S, and the higher the value, the more dependent the export of country S is on country R's supply as an upstream country in the GVC. The measure is also normalized with $Export_s$, so the measure is actually about the proportion of value added contributed by country R to the export of country S.

Note that

$$\frac{DVA_s}{Export_s} + \frac{FVA_{r \rightarrow s}}{Export_s} = 1 \quad (23)$$

but

$$\frac{DVA_s}{Export_s} + \frac{FVA_{s \rightarrow r}}{Export_s} \neq 1, \quad (24)$$

because $\sum_{r \neq s} FVA_{s \rightarrow r}$ is the "indirect value added exports," which is conventionally labeled as DVX as in Koopman et al. (2011) and "gives a rough, though not perfect, proxy of the double counting embedded in the gross (official) trade figures."¹³ Although at the world level $FVA = DVX$, but at the country level, the two are not necessarily equal to each other. At the country level, DVX is the total value added originated from country S in foreign countries' exports, but the export of country S includes final and intermediate goods that can be consumed as final goods in a foreign country or to be exported by a foreign country.

¹³UNCTAD, Global Value. 2013. Development: Investment and value added trade in the global economy. In United Nations Conference on Trade and Development (UNCTAD) publication. New York and Geneva: United Nations.

Also, “More precisely, part of the DVA exported and incorporated in third countries? export can itself return home and thus generate some further double counting, as the original DVA measure would include a share of domestic value added that is returned home after being processed abroad.”¹⁴

- **Asymmetry of Dependence as Buyer:** the asymmetry of interdependence between Country S and Country R as each other’s supplier.

$$Asy.Sens.Dep.sr.buyer = Sens.Dep.sr.buyer - Sens.Dep.rs.buyer$$

If the measure is positive, then *S* is more dependent on *R* as supplier, and vice versa.

- **Dependence (of S) as Supplier (to R),** how much does Country S depend on Country R as a buyer. The more S sells to R, the more dependent S is on R’s choice of purchase. The indicator is calculated based on the formula as below:

$$Sens.Dep.sr.supplier = \frac{FVA_{s \rightarrow r}}{Export_s} \quad (25)$$

$$\text{where } Export_s = DVA_s + \sum_{r \neq s} FVA_{r \rightarrow s} \quad (26)$$

where dependence of country S is normalized by its gross export $Export_s$ which is the sum of domestic and foreign value added. The math expression makes it clear that if the export of country R contains more value added originated from country S, country S as supplier depends more on country R as a buyer, and a shock to the demand of country R for its export will cause a larger impact on country S as a supplier, holding the export of country S constant. At the same time, the larger the export of country S, the less dependent country S is on country R, holding the value added by country S to country R.

- **Asymmetry of Dependence as Supplier,** the asymmetry of interdependence between Coun-

¹⁴UNCTAD, Global Value. 2013. Development: Investment and value added trade in the global economy. In United Nations Conference on Trade and Development (UNCTAD) publication. New York and Geneva: United Nations.

try S and Country R as each other's buyer:

$$Asy.Sens.Dep.sr.supplier = Sens.Dep.sr.supplier - Sens.Dep.rs.supplier$$

- **Dependence**, how much country S depends on country R in the global value chain in the upstream and downstream.

$$Sens.Dep.sr = Sens.Dep.sr.supplier + Sens.Dep.sr.buyer$$

- **Interdependence**: the strength of mutual dependence (interdependence) between Country S and Country R.

$$Sens.Dep.Mutur = Sens.Dep.sr + Sens.Dep.rs$$

- **Asymmetry of Interdependence**: the asymmetry of interdependence between Country S and Country R in the GVC as mutual upstream and downstream countries.

$$Asy.Sens.Dep.sr = Asy.Sens.Dep.sr.supplier + Asy.Sens.Dep.sr.buyer$$

The country-level dependence measures are also constructed with the Eora database, and cover 17,578 country pairs between 1990 and 2019, with the total sample size of 527,340.

The measures on dependence between a country and a foreign country-sector are defined similarly. We construct measures using Database of OECD Trade in Value Added (2016 and 2018 editions), and cover 36 sectors in 64 major economies between 1995 and 2016. There are 186,048 country-foreign country-sector pairs and the total sample size is 3,018,240.

4 Empirical Findings

4.1 Participation and Hierarchy of Network Influence

We first look at the system-wide distribution of measures of participation and inequality of participation in the global GVC network. Figure 5 (a) shows the average level of GVC participation of countries as buyer, supplier, or both in 1990 to 2019. In general, participation has increased, especially countries' participation in GVCs as suppliers. On average, a greater proportion of countries' exports consist of value added that becomes part of another country's exports. Countries are increasingly "forward linked." However, participation as buyers has largely stayed the same for almost three decades. Countries have not become more "backward linked," on average.

Figure 5: Average Participation and Inequality of Network Influence

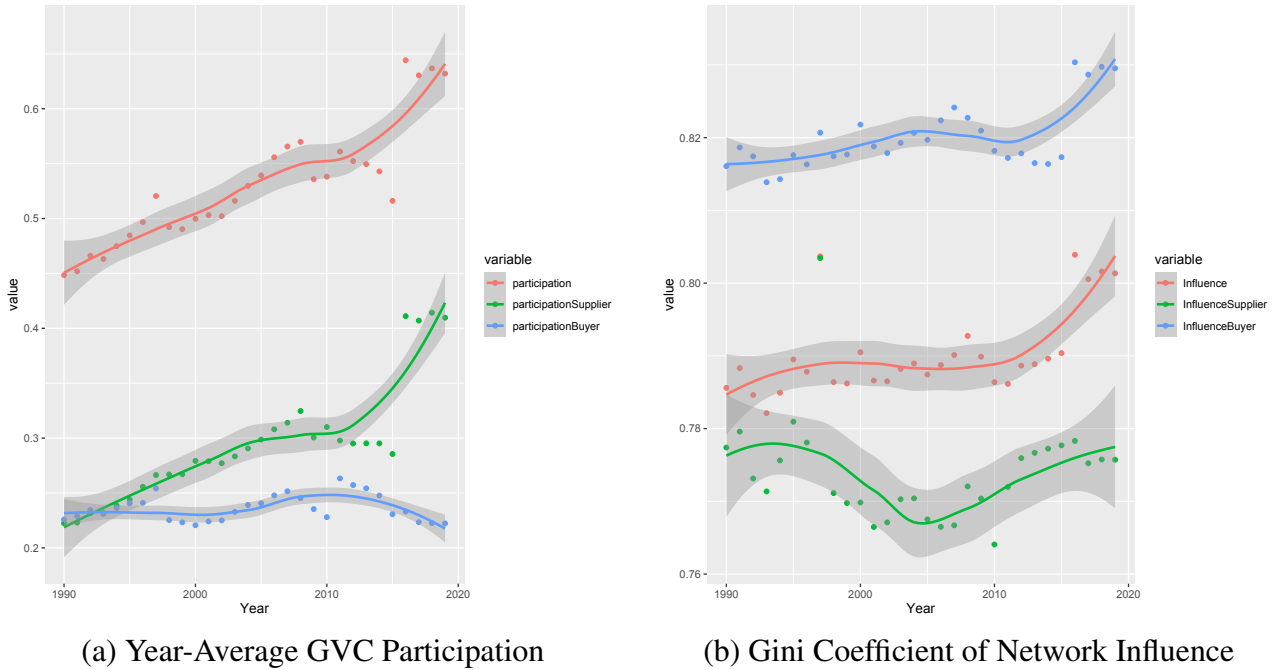
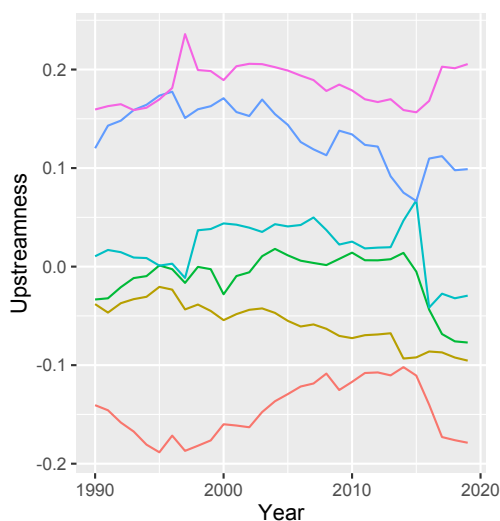


Figure 5 (b) plots the Gini coefficient of the GVC network influence of countries in each sample year. We use Gini coefficient to measure the inequality of GVC influence distribution in the system. In general, inequality is high in the GVC system in terms of countries' influence; inequality of influence as buyer is the highest and above 0.8. Inequality in the supplier participation

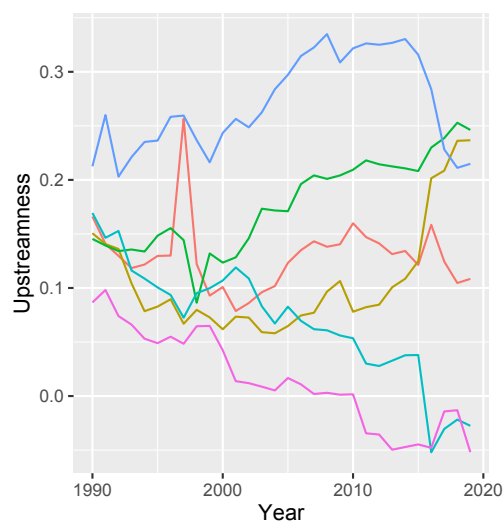
measure is lower, but still above 0.75. Also, inequality grows over time, especially after the Great Recession. Most interestingly, inequality of influence as supplier decreases in the years before the Great Recession, and then takes off during and afterwards.

Figure 6 show how emerging economies diverge over time in terms how they move upstream or downstream in GVCs. Countries like Turkey and Poland continuously move relatively downstream over time, while China and India keep moving upstream. And countries like Russia and Brazil move up and down. In contrast, for the advanced economies, their GVC positions are relatively stable, with some local fluctuations.

Figure 6: Changing Positions in GVCs (Selected Countries)



(a) Advanced Economies



(b) Emerging Economies

4.2 US and China: All Sectors

The previous section considered the global distribution of participation and influence over time. These were measures at the country/monadic level and averaged up to the global level. How have different dyadic relationships changed over time?

Figure 7: Average Participation and Inequality of Network Influence

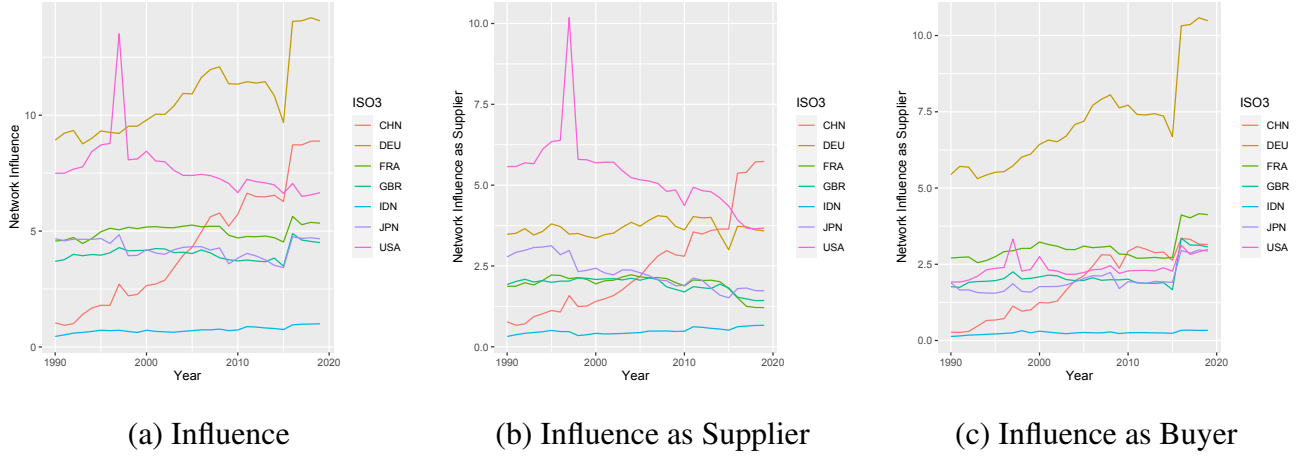


fig:sensdepsupp shows the dependence of other countries on the US and China as suppliers, broken down by region. For each region, we averaged the measure across the ten largest economies in that region.¹⁵ These measures describe the proportion of a country's exports that consist of value-added that originate in the US or China, at some earlier point in the value chain.

The explosion of other countries' sensitivity to Chinese production is clear. For every region, this measure increases sharply from 1990 until the Great Recession. Dependence on FVA originating in China grows most strongly in Asia and in Europe, and least strongly in North/Central America. After the Great Recession, dependence on FVA from China initially grows but then decreases sharply in every region. In 2018, dependence on Chinese FDI in most regions decreased back to the levels seen in approximately 2009.

Dependence on FVA originating in the US remains very stable over this same time period, across regions. For the US, the most striking features are that North, Central, and South America are approximately three times as dependent on FVA supplied from the US, compared to the rest of the world, including Europe. The Great Recession appears to have had little effect on other countries' dependence on US-supplied FVA. In North/Central America, the pattern resembles that of China, with an increase in dependence on the US around 2010-2011, but then a decrease. In

¹⁵Africa, Asia, Europe, Middle East/Central Asia, North/Central American, South America. The World lines include all countries; they aren't just the average of the regions.

most other regions, levels of dependence remain fairly flat.

Figure 8: Dependence on USA/CHN as Supplier

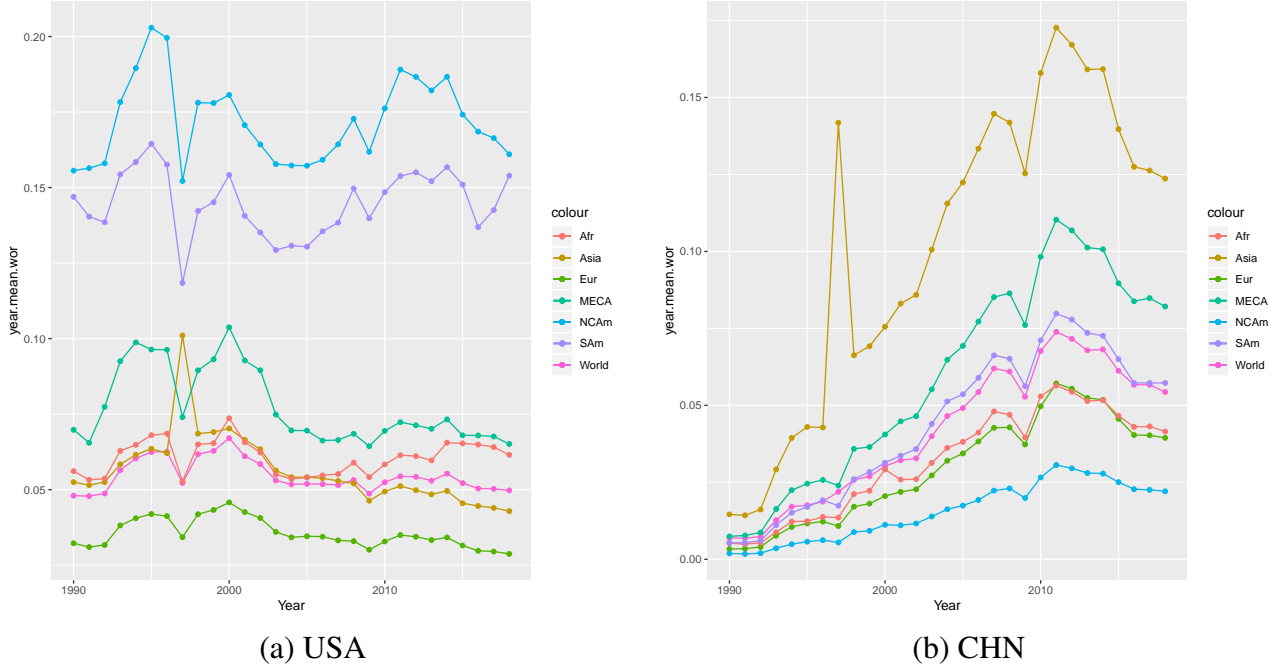
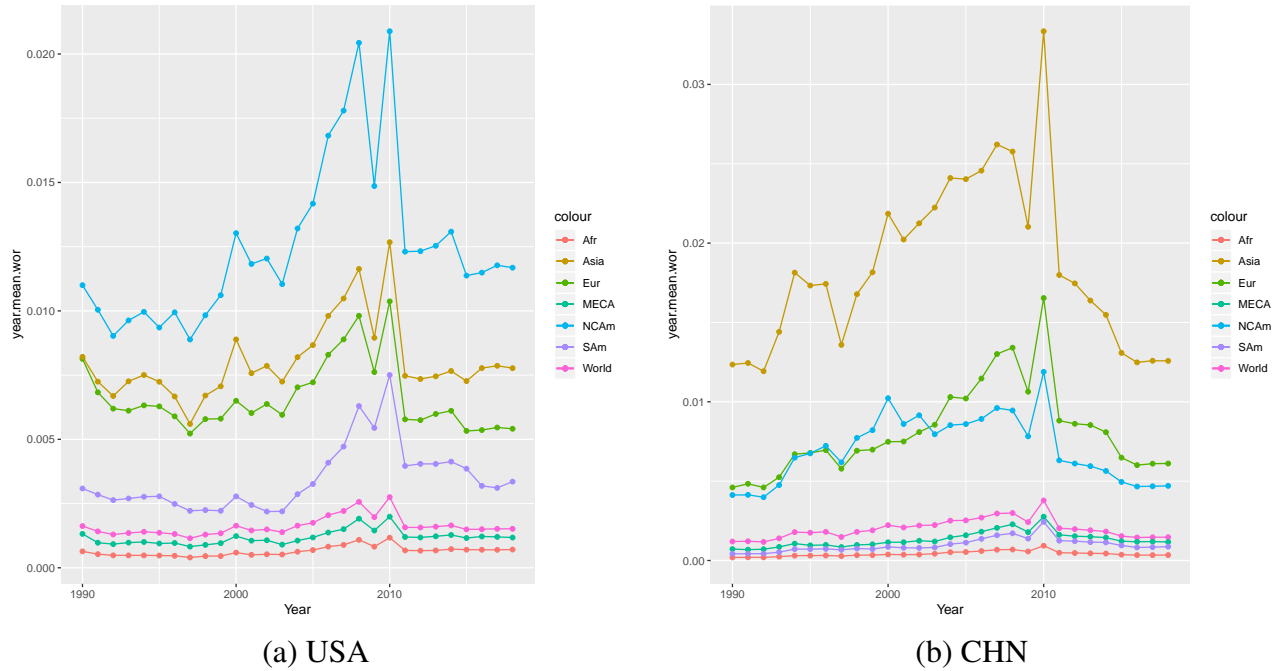


fig:sensdepbuy shows similar plots for other countries' dependence on the US and China as buyers of FVA originating in that country. Here, one striking feature is how the US and Chinese plots look very similar, just for different regions. In the case of the USA-North/Central America, dependence on the US increases strongly until the Great Recession, then drops sharply. For China, the same is true for their neighbors in the Asia region.

One difference between the US and China is that, after the Great Recession, other countries' dependence on the US as a buyer levels off and begins to regrow slowly in a few regions. For China, the decline continues more sharply through 2018.

What about characteristics of the bilateral relationship between the United States and China? fig:usachn shows two measures, *Sens.Dep.sr.buyer* and *Sens.Dep.sr.supplier*, with the US and China as country r and s respectively. The top two panes show the degree to which country s 's exports consist of FVA originating in country r . The bottom two panes show the degree to which country r is a purchaser of FVA originating from country s . The patterns are complicated. Looking

Figure 9: Dependence on USA/CHN as Buyer

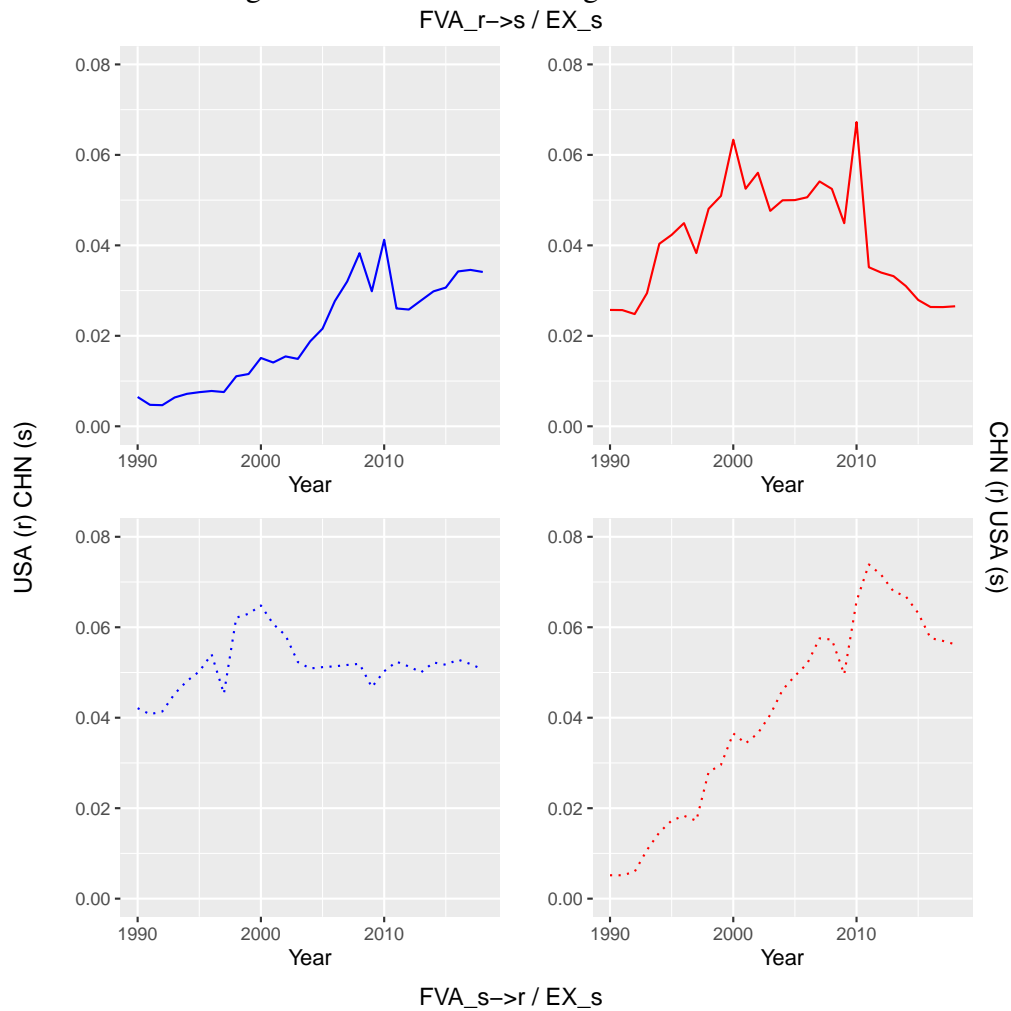


first at the bottom row, this measure is flat for the US side (left) and sharply increasing for the Chinese side (right). The right side suggests that, of all the US exports, an increasing amount of their FVA is being purchased by China. The reverse is not true. The US is not purchasing an increasing proportion of Chinese exported value added.

Looking at the top right, Chinese exports increasingly consist of value added that originated in the US. The reverse is not true. US exports were increasingly made up of value added originating in China, but after the Great Recession, this proportion decreased back to the levels seen in 1990.

Taken together, these measures suggest gross Chinese exports have increasingly consisted of value added that originated in the United States. At the same time, US exported value added has increasingly gone through China, relative to other possible destinations.

Figure 10: Measures Relating USA and CHN



4.3 US and China: Specific Sectors

When broken down by specific sectors, different trends emerge for the US and China, as well. fig:sensdepsuppsect shows the average of other countries' dependence on the US and China as a supplier, broken down into three sectors: D26, "Computer, electronic and optical products," D25 "Fabricated metal products," and D24 "Basic metals." We chose the computers sector to contrast it with sectors more associated with basic manufacturing.

The trends are apparent for the Computers sector. Dependence on the US plummets at approximately the same time that dependence on China skyrockets. The value of the vertical axes is also telling. Dependence on the US in this sector peaks in 2000. Dependence on China at this time was

at a similar level. However, in the ensuing years, dependence on China would continue to grow, nearly doubling by 2016. Dependence on the US plunged to levels near zero, falling even below that of Basic Metals.

Figure 11: Dependence on USA/CHN as Supplier, Three Sectors

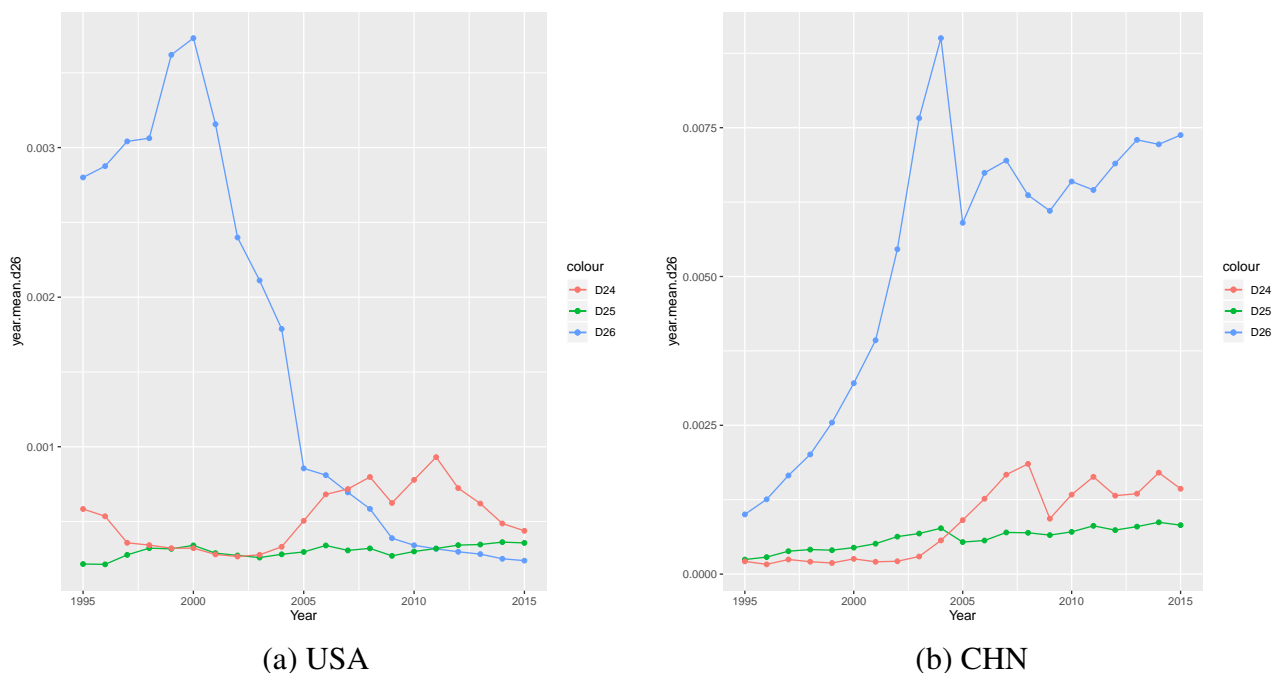
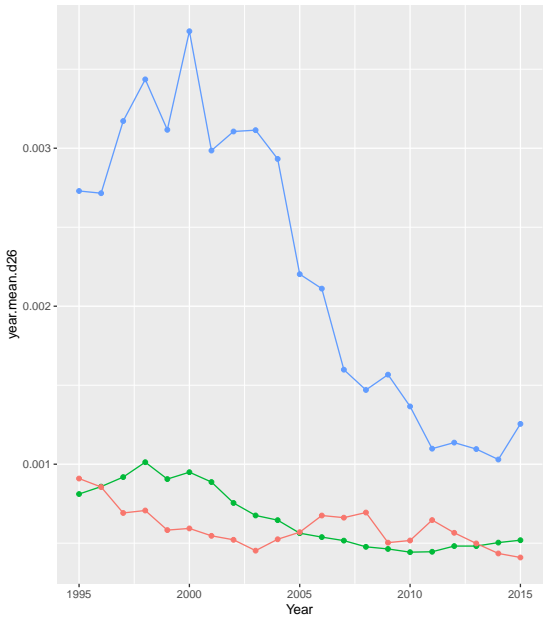
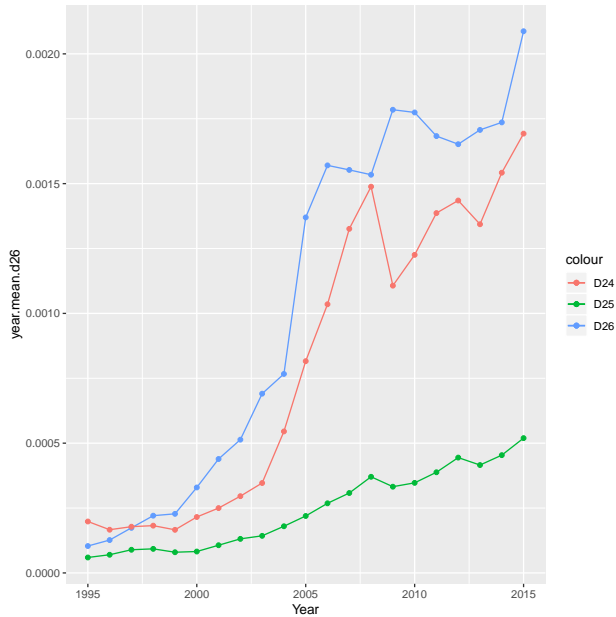


fig:sensdepbuysect shows the same plots, but with dependence on the US and China as buyers of FVA. Chinese dominance in the Computers sector is apparent, not just as suppliers, but here, too, as buyers. Other countries' reliance on the US as buyers in this sector declines sharply. Interestingly, dependence on China as a buyer in the two other sectors, basic metals and fabricated metal products increase very sharply over this time period as well.

Figure 12: Dependence on USA/CHN as Buyer, Three Sectors



(a) USA



(b) CHN

4.4 Interdependence

We can also use the measures of interdependence to build "interdependence" networks to see how the system of GVC power relationships evolves over time. In Figures 13 and 14, we show the value-added suppliers' network and value-added buyers' network in selected years. Because the GVC networks are very dense, we make them sparse by focusing only on the 64 major economies and the top 10% value-added shares in exports. The sample countries are the same as in the OECD TiVA database but we use the Eora data for a longer time span from 1990 to 2019. The networks are weighed by the value-added shares. In both networks, the ties are directed from the upstream country to the downstream country. The larger the label of a node, the more central the node in terms of its in-strength centrality (in the buyer's network) or out-strength centrality (in the supplier's network).

Figure 13 is about the connections of countries in the GVC network by value-added supply relationship. Node r is connected (directed) to s , and the weight of this tie increases as r sends more value added to s . Panel (a) shows the first sample year of 1990, the system seems to be a bipolar one with Germany and the United States are the two most important value-added suppliers. Japan is the third central supplier but much weaker than the top two. Panel (b) is the first year when China becomes the third most important supplier. It is at the beginning of the Great Recession. Then after the Recession, China becomes almost as central as the United States, but Germany remains the supplier with the largest total shares of value added in other countries' exports, as shown in Panel (c). Then in the last sample year 2019, China replaces Germany to be the most central supplier in the GVC system.

Figure 14 shows the buyer network, where r and s are connected (directed) and the weight of the tie increases as r purchases a larger portion of s 's exported value added. This network seems to be dominated by Germany in the whole period from 1990 to 2019, which means that the exports of Germany carry the largest share of value added originated from the other countries in their exports.

We can also do cluster analysis to detect the communities in GVC networks. Figure 15 and Figure 16 show some examples with different colors indicate different communities. We can see

that there are mainly regional clusters, that is, the globalization process of GVCs is also the regionalization process.

5 Conclusion

A growing body of literature recognizes that the global trade network is more complex than can be captured in bilateral trade flows or gross exports. As a result, one country's dependence on or influence over another depends on multiple links in the global value chain. This paper presented myriad ways to measure these ties and linked them with broader trends among major economies.

In developing this research, we hope to more closely tie particular measures to the notion of power. We hope this will help answer questions about how the global dynamics, within the trade network, have evolved over the last 20 years.

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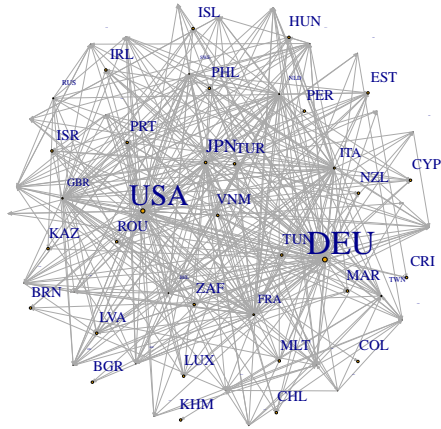
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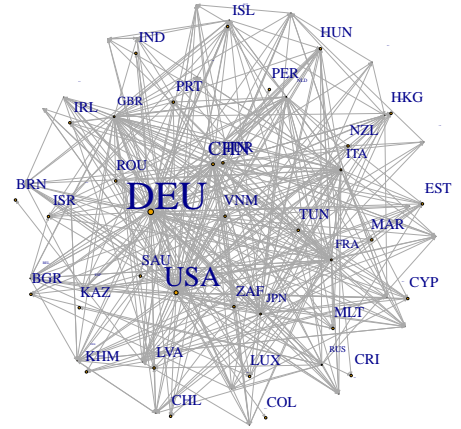
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Figure 13: GVC Interdependence Network of Value-Added Suppliers

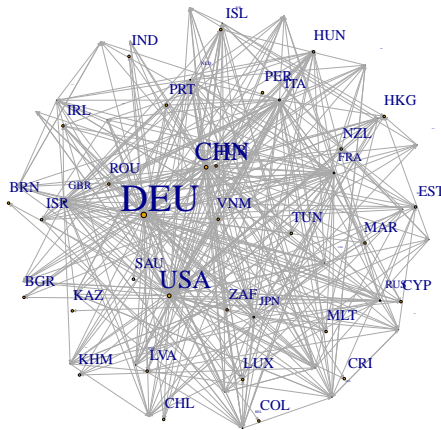
(a) 1990: 1st sample year



(b) 2007: CHN emerges



(c) 2012: CHN as central as USA



(d) 2019: CHN is the most central one

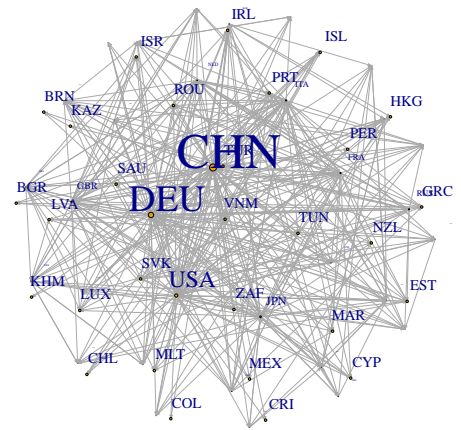


Figure 14: GVC Interdependence Network of Value-Added Buyers

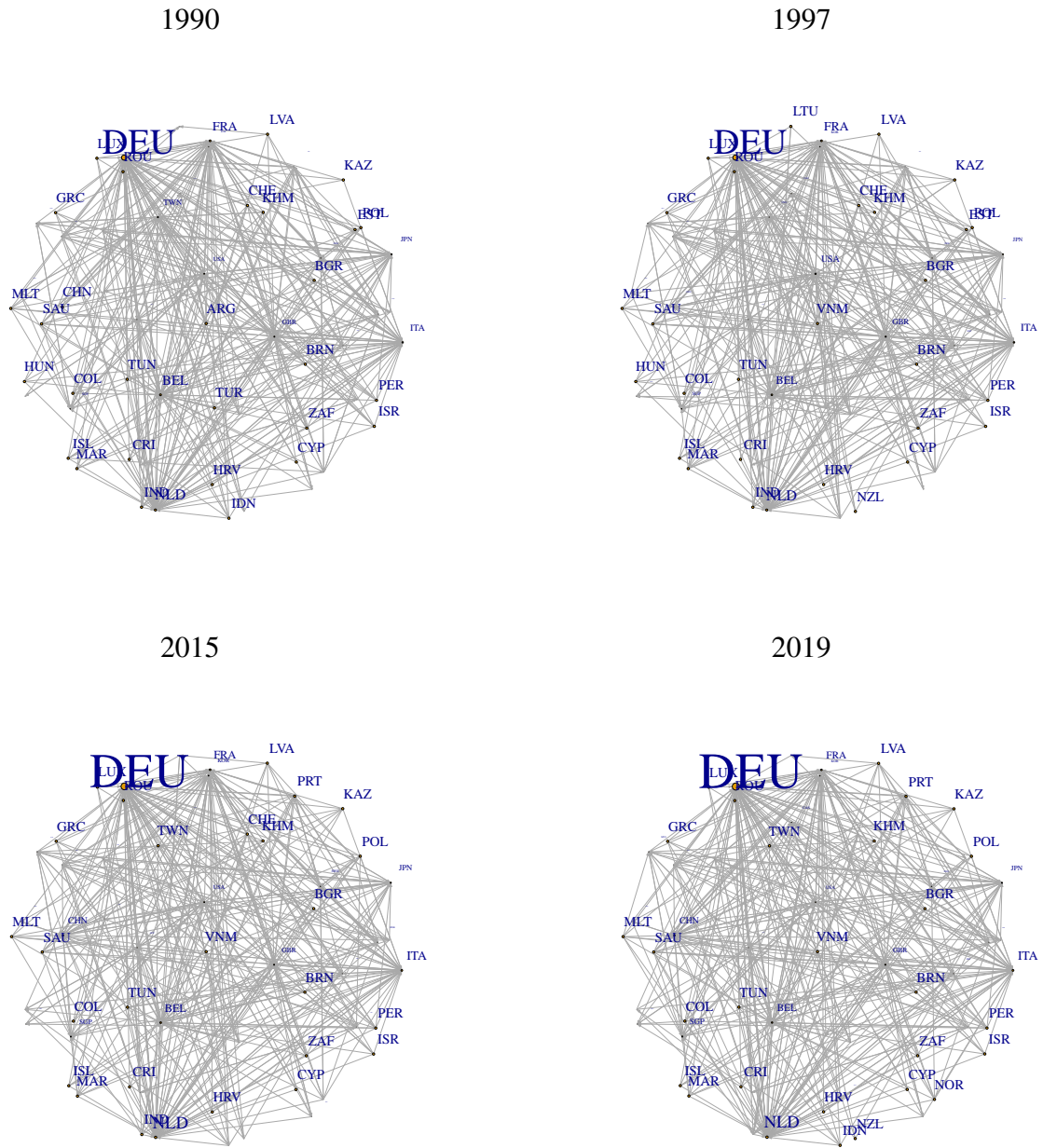
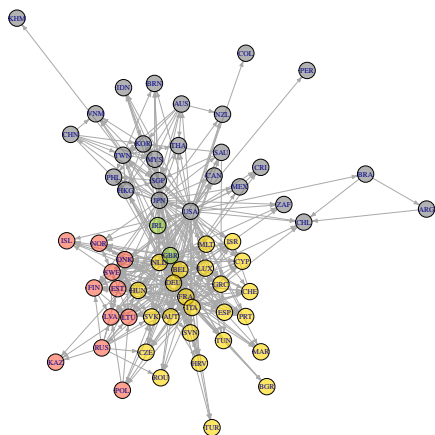
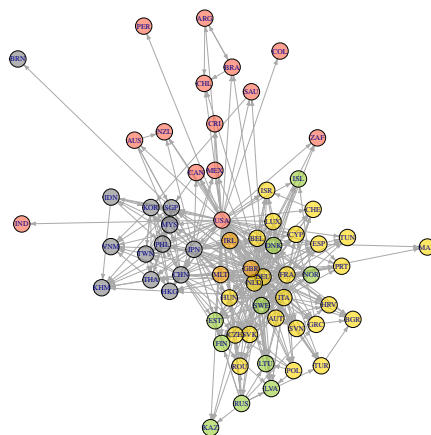


Figure 15: Clusters in GVC Interdependence Network of Value-Added Suppliers

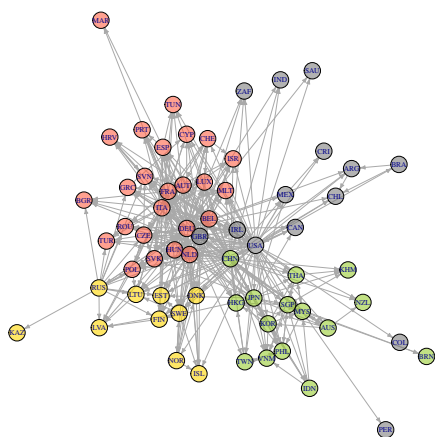
(a) 1990



(b) 2000



(c) 2010



(d) 2019

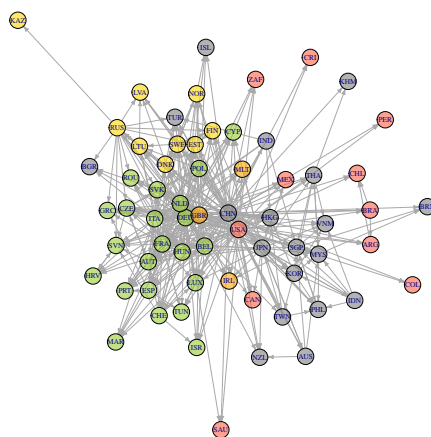


Figure 16: Clusters in GVC Interdependence Network of Value-Added Buyers

