Measuring Globalization From the GVC Perspective: A Decomposition Method For Inter-Country Input-Output Tables

Xun PANG

Institute of International Relations, Tsinghua University,
Haidian District, Beijing 100084, China
xpang@tsinghua.edu.cn

Shuai WANG

Institute of Economics, Tsinghua University,
Haidian District, Beijing 100084, China
wangshuai8220028@126.com

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Abstract

Global value chains are the practical expressions and principal engines of today's globalization. There is a burgeoning body of literature that takes the perspective of global value chains to understand the changing reality of globalization and its profound economic and political implications. This paper applies a revised Leontief Decomposition method to analyze the complex network of GVCs expressed as Inter-Country Input-Output (ICIO) Tables. The method is developed and applied to trace original sources of value added in the dynamic flow system of global production and to establish asymptotic connectivity between dyad pairs by incorporating direct and all indirect value added contributions in n-step transitions as n goes to infinity. Based on the method and ICIO database, we generate original data of value-added contributions between dyad pairs formed by 35 sectors in 64 countries from 1995 to 2011. The data facilitate us to measure the structure and process of globalization from the global production perspective and to quantify interdependence in the gain dimension. The data and measures reveal several important features of today's globalization, including: globalization has been continuously expanding and deepening; the global production network is highly hierarchical with most influence concentrated in a very few large economies; and asymmetry of interdependence increases with strengthened interdependence. The data and measures could have a wide range of potential applications in IR/IPE studies regarding GVCs, globalization, and economic interdependence. We apply the data to an IR/IPE study and investigate how GVC dependence affects political risk of FDI as an illustration.

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

1 Introduction

Global value chains 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 on how we look at globalization and how we quantify globalization and economic interdependence.[1] At the same time, GVCs provide a new perspective to investigate international political economy of globalization. Because GVCs are essentially about how values are generated and distributed in the global production network, mapping globalization from the perspective of GVCs can systemically reveal the distribution of gain and loss among participants in globalization, which is crucial for understanding politics of globalization.

This paper is intended to analyze the complex network of global production and measure globalization from the GVC perspective. We adopt a revised Leontief Decomposition method proposed and developed by Robert Koopman (2010), Robert Koopman and Wei (2014), and Zhi Wang and Zhu (2017) to trace original sources of value added in the dynamic system of global production and to calculate asymptotic connectivity between dyad pairs by incorporating direct and all indirect value added contributions of intermediates in n-step transitions as n goes to infinity. Based on the method and the ICIO database, we generate original data of value-added connectivity among dyad pairs formed by 35 sectors of 64 countries from 1995 to 2011, with the total sample size over 80 million. The data facilitate us to measure the structure and process of globalization from the global production perspective and quantify interdependence in the gain dimension. We construct several measures to summarize the structure and process of globalization, and find that globalization has been expanding from 1995 to 2011, reflected by the trend that national economies and country-sectors are increasingly integrated into the global production network. At the same time, globalization has been deepening with strengthened interdependence between participants. However, differentials of influence and bargaining power among GVC participants are also enlarged. At the structural level, the GVC system is found to be a hierarchical rather than a flat network, and structural influence is highly concentrated in a very small number of large economies. At the dyadic level, asymmetry of interdependence grows with the expansion of globalization, and bilateral production relations are unbalanced and power disparity increases over time. Not surprisingly, the system seems to be in a structural transition of "the decline of the West, and the rise of the Rest." The United States is the most influential and most powerful country in the system, and other western economies such as Germany, Japan, France, and the Great Britain are at

[1] http://www.oecd.org/sti/ind/global-value-chains.htm

the center of this hierarchical system. But their structural importance and dyadic bargaining power are in decline. Emerging economies, represented by the BRIC countries, rise very fast. China is the country whose influence in the system and bargaining power over its production partners grow most rapidly. Finally, our GVC measures and traditional measures of globalization such as openness and centrality measures of the trade network are positively but modestly correlated, and the correlation is getting weaker over time.

The data and measures generated in this research could have a wide range of potential applications in IPE/IR studies regarding GVCs, globalization, and economic interdependence. With GVCs as the most prominent feature of today's globalization, it is urgent to deepen our understandings of GVCs. Our data and measures can be used to describe and explain the changes of the structure and process of GVCs. At the same time, GVCs have profound impacts on almost all aspects of international political economy, and a wide range of IPE research questions have been re-investigated from the perceptive of GVCs. Examples include analyses of the impacts of GVCs on trade policies (In Song Kim, ming; 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; Vito Amendolagine and Seric, 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. In addition, the measures of asymmetric interdependence we proposed in this paper can be applied to empirically test theories regarding political implications of economic interdependence and help settle great debates such as the relationship between economic interdependence and military conflicts (Mansfield and Pollins, 2003; Maoz, 2009). In this paper, we illustrate how to apply the data and measures to an IPE study on GVC dependence and political risk of FDI as an empirical illustration.

2 Inter-Country Input-Output Tables 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 "value added" 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 to study the gain and loss of participation in GVCs (Amador and Cabral, 2014). In this section, we briefly review the literature on analyzing Inter-Country Input-Output tables, and introduce the Leontief Decomposition Method to analyze the complex network presented by ICIO tables.

2.1 Mapping GVCs with Inter-Country Input-Output Tables

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 a broader coverage and at more macro levels. Inter-Country Input-Output Tables (ICIOT) have been recently constructed to meet the urgency of analyzing the global structure and macro processes of GVCs. ICIOTs are among the four types of data that have been used in the literature to map GVCs. The other three types of data are trade statistics of products, customs statistics on processing trade, firm-level survey data. Amador and Cabral (2014) summarizes the main strands and timelines of empirical methods on GVC studies. Figure 2 shows that trade in value added derived from ICIOTs are the best in the sense that the data have a good balance between accuracy and coverage, though they are highly complex data. This is the reason that ICIO databases develop very rapidly to meet the increasing research demand to map GVCs. Recent ICIO data projects include the university-based Global Trade Analysis Project[2], 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), [3] the OECD Inter-Country Input-Output (ICIO) Tables [4], and the UNCTAD-Eora GVC Database[5]).

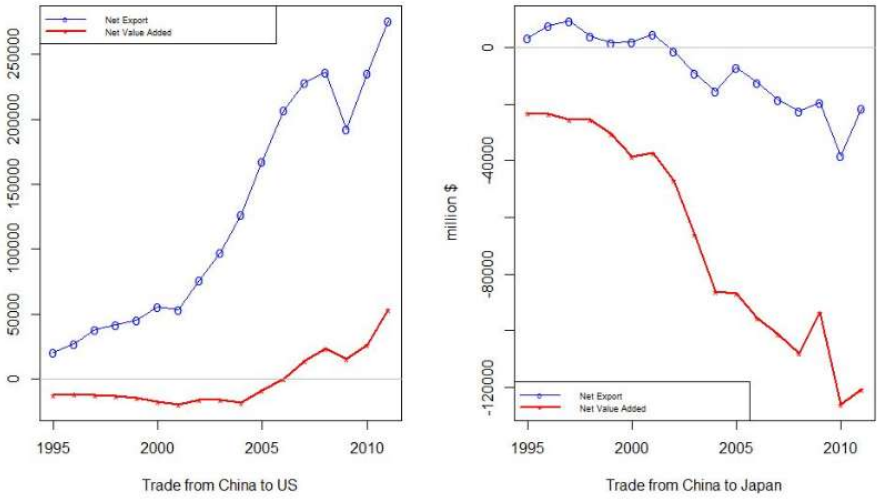
[2]https://www.gtap.agecon.purdue.edu/about/project.asp
[3]http://www.wiod.org/home
[4]http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm
[5]http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm

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 expanding and deepening GVCs, gross trade statistics are increasingly misleading due to the growing trade of intermediate inputs and their continuing flows in the complex and dynamic network (Robert Koopman, 2010; Robert Koopman and Wei, 2014). Quantities of exports may not imply 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 exchange and value-added relationship can be very larger, as the examples shown in Figure 1. For many years, the United States has a huge and increasing trade deficit with China, but in terms of the value added contribution embedded in their trade, China is the side that has a deficit rather than surplus for many years. And the difference between the two is also salient in the China-Japan example illustrated in the Figure. Secondly, value added is important for analyzing and explaining the effects and implications of GVCs. ICIOTs provide information about value added connectivities which are necessary 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 national governments to target to increase national competitiveness. Last but not least, value added between two actors is directly about the gain from interdependence. IR/IPE scholars have been long interested in interdependence, and the absolute and relative gain is essentially important to IPE/IR research questions involving the concept of interdependence (Keohane and Nye, 1977; Baldwin, 1980; Mansfield and Pollins, 2001, 2003).

All the ICIOT databases adopt similar data-generating process and methodology to gather and harmonize three original major data sources of national accounts statistics (NAS), supply-use tables (SUTs), and international trade statistics (ITS). The WIOD data project explains their methodology and procedure in great detail (refer to Abdul Azeez Erumbana (2011); Timmer (2012); OECD (2014)). Figure 3 is a graphical summary of the process in which the ICIOT data are normally generated.

Figure 4 presents a typical structure of an ICIOT. The matrix denoted by $\mathbf{Z}$ in the table is 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. The matrix $\mathbf{Y}$ records

Figure 1: Example of Difference Between Trade Deficits and "Value Added Contribution Deficits"

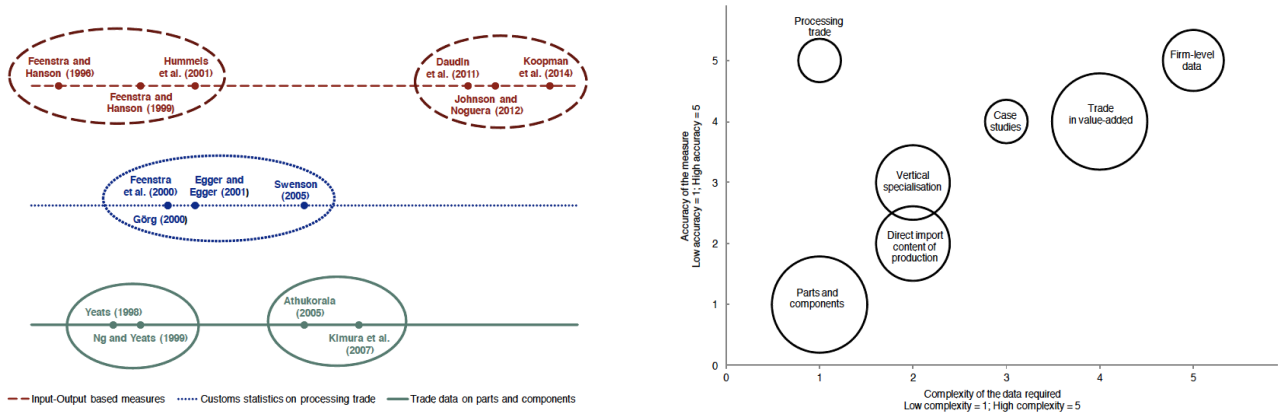


the output that is used to satisfy final demand rather than used as intermediates, and it is called final demand matrix. The last column of the ICIOT records the total output of each country-sectors, and the vector is denoted as $\mathbf{X}$. This is the total output viewed from the demand perspective; that is, $\mathbf{X} = \mathbf{Z} + \mathbf{Y}$, the total output is equal to the sum of how the output is used, either used for final consumption or as intermediates. The second last row in the ICIOT records the value added in each country-sectors. Value is added to products by using inputs besides intermediate goods, such as labor, capital, technology, management, taxes, etc. The value added vector is denoted by $\boldsymbol{Va}$. The last row is the total output of $\mathbf{X}$ from the supply perspective; that is, $\mathbf{X} = \mathbf{Z} + \boldsymbol{Va}$, and the total output is produced with intermediate inputs and value added inputs. The last column and last row should be equal, and the supply and demand are balanced. It is important because the ICIOT is based on the assumption of a global general equilibrium—demand is equal to supply at the country level and the global level.

In the matter of fact, an ICIOT is a numeric presentation of a complex network of the global production system. Federica Cerina and Riccaboni (2015) uses a hypothetical two-country-two-industry IO table to demonstrate that the ICIOT can be translated into a graphically-displayed network. The figure in the lower-left panel of Figure 5 is the network expression equivalent to the table in the upper panel. The network presented by an ICIOT is a complex network in the sense that the network has different types of nodes and ties and consists of multiple networks. In Figure 5, the network typology of ICIOT has three types of nodes,

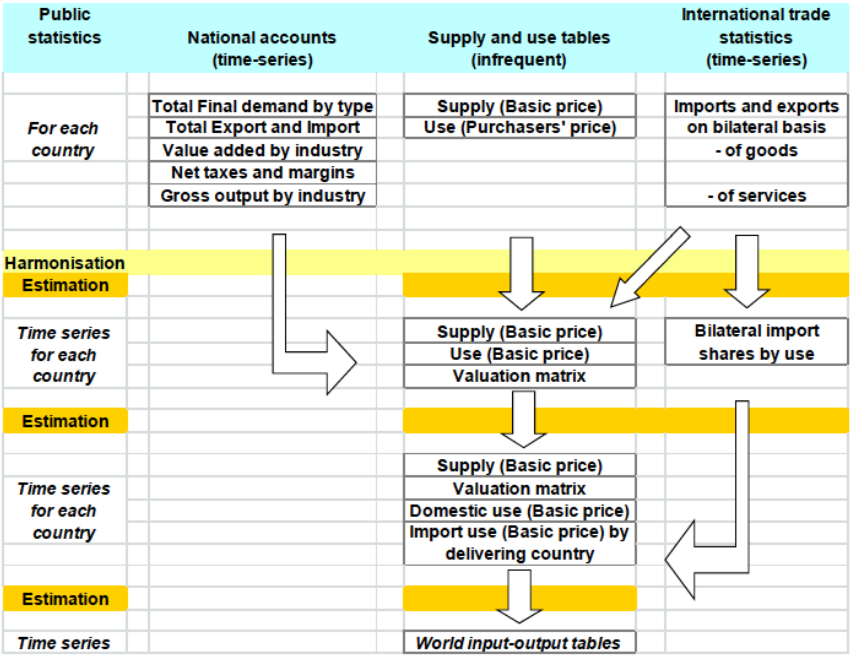
Figure 2: Approaches for Mapping GVCs

Measuring GVC—Timeline of Main Research Main Strands of Empirical Research on GVCs



Source: Amador and Cabral (2014)

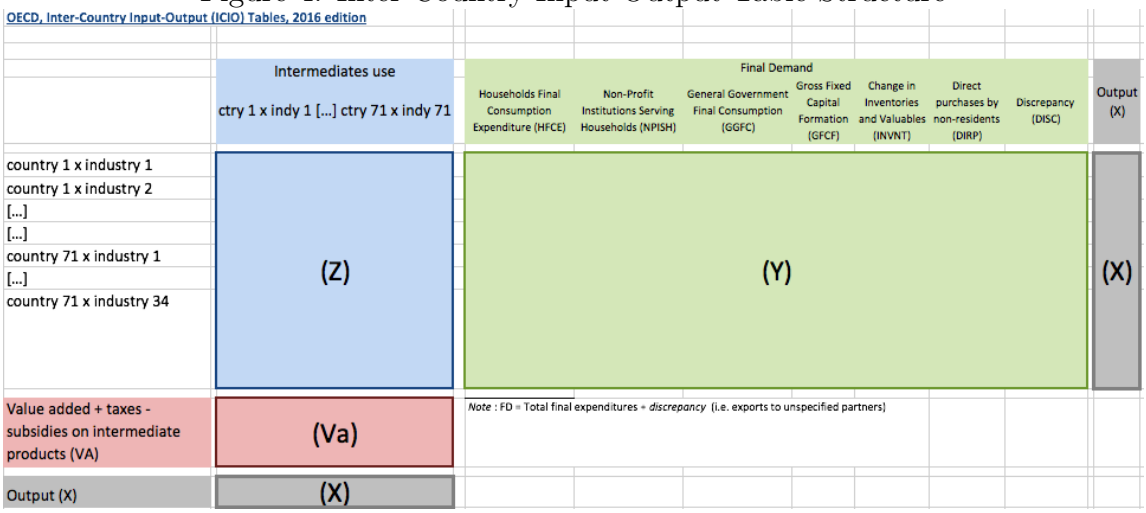
Figure 3: Typical Dataflows and construction steps in ICIOT



Source: (Timmer, 2012, p.65)

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

Figure 4: Inter-Country Input-Output Table Structure



Source: ICIO Database.

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 of value added. Each sub-network can be a dense and complex network in reality. The right-lower panel in Figure 5 shows an example of the network of $\mathbf{Z}$ matrix based on real ICIOT from the WIOD database, and nodes in the same color are industries residing in the same country.

How to analyze this complex network of GVCs represented by ICIOTs depends on the purposes of a specific research. For example, those who are interested in the pattern and structure of global trade of intermediate inputs may simply use the $\mathbf{Z}$ matrix of an ICIOT and apply network analysis tools to describe and summarize the network, as did in Federica Cerina and Riccaboni (2015). But if we are interested in the underlying structure of globalization and the interdependence in the gain dimension, we need to trace original sources of value added in the system. This cannot be done by applying standard tools of network analysis. One method that can help achieve this goal is the Leontief Decomposition method introduced below.

2.2 Underlying Production Structure and the Leontief Decomposition

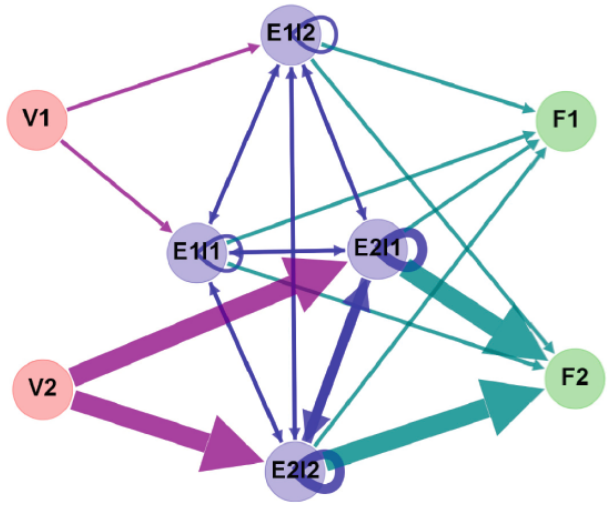
In this paper, we adopt the Input-Output model and the revised Leontief Decomposition method proposed and developed by Robert Koopman (2010), Robert Koopman and Wei (2014), and Zhi Wang and Zhu (2016) to trace original sources of value added and calculate value added contributions between participants in GVCs. The Leontief Decomposition based

Figure 5: ICIOT as a Complex Network

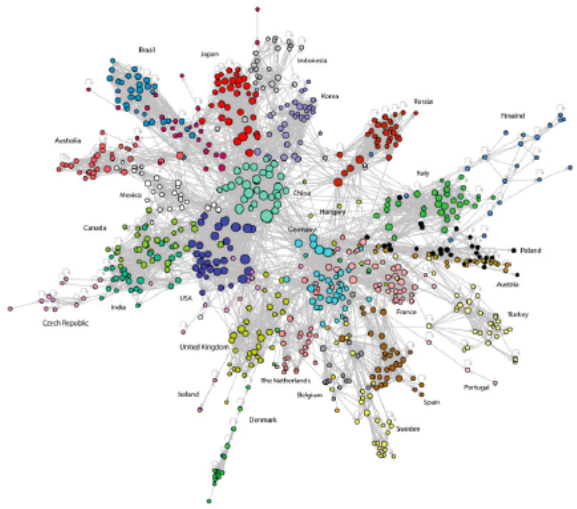
ICIOT in a 2-country-2-industry world

		Buyer Industry						
		Economy 1		Economy 2		Final Demand		
Seller Industry		Industry 1	Industry 2	Industry 1	Industry 2	Economy 1	Economy 2	Total Output
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 $\mathbf{Z}$ *in GIOT*



Source: Federica Cerina and Riccaboni (2015)

on the Input-Output table is able to decompose the domestic value added back to their original sources, and hence to reveals the fundamental structure of GVCs.

Suppose in the global production system there are 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, and

the input-output model can be written as follows:

$$\mathbf{X}_{NG\times 1} = \mathbf{A}_{NG\times NG}\mathbf{X}_{NG\times 1} + \mathbf{Y}_{NG\times 1}, \tag{1}$$

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

In vectors of $\mathbf{X}, \mathbf{Y}$, each row is a country-sector, and $\mathbf{A}$ is a transition matrix with columns and rows as country-sectors. The matrix $\mathbf{A}$ is defined as the proportion of output of a country-sector used in all country-sectors as intermediate input, and it 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} sets the share of the output of country-sector i flowing to country-sector j as intermediate input. Accordingly, the $\mathbf{Z} = \mathbf{AX}$ matrix is a flow network of trade of intermediate input[6]. It is easy to see that $\mathbf{A}$ is a one-step transition matrix, indicating of the strength of the direct connection of dyad pairs of country-sectors. Goods and services can keep flowing from one country-sector to another along channels set by the $\mathbf{A}$ matrix until they are finally consumed. 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 that can be traced back to the production of the other country-sector. To account for all the direct and indirect connectivity between country-sectors, we sum up all rounds of transition in the system as follows:

$$1 + \mathbf{A} + \mathbf{AA} + \mathbf{AAA} + ... + \underbrace{\mathbf{AA...A}}_{n} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + ...\mathbf{A}^n. \tag{3}$$

Then we define

$$\mathbf{B} \equiv \lim_{n\to\infty} \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + ...\mathbf{A}^n \tag{4}$$

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

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) and often called total requirement coefficients in input-output analysis. Re-arrange the equation $\mathbf{X} = \mathbf{AX} + \mathbf{Y}$, and we have $\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y} = \mathbf{BY}$, which is called the Leontief Insight. The

[6]Refer to Peiteng Shi (2014) for more details about flow networks.

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 dyad pairs in a complex network with intermediates constantly flowing therein. The dyadic relationships revealed by $\mathbf{B}$ matrix take into account of the first-order connectivity generated by the direct exchange and higher-order connectivity via 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 within the country. By definition, each element V_j^s is the ratio of value added to output in sector j:

$$V_j^s = Va_j^s / X_j^s, \tag{6}$$

and the subscript j refers to sector j. 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 source of production:

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

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

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

VB is sum up to 1:

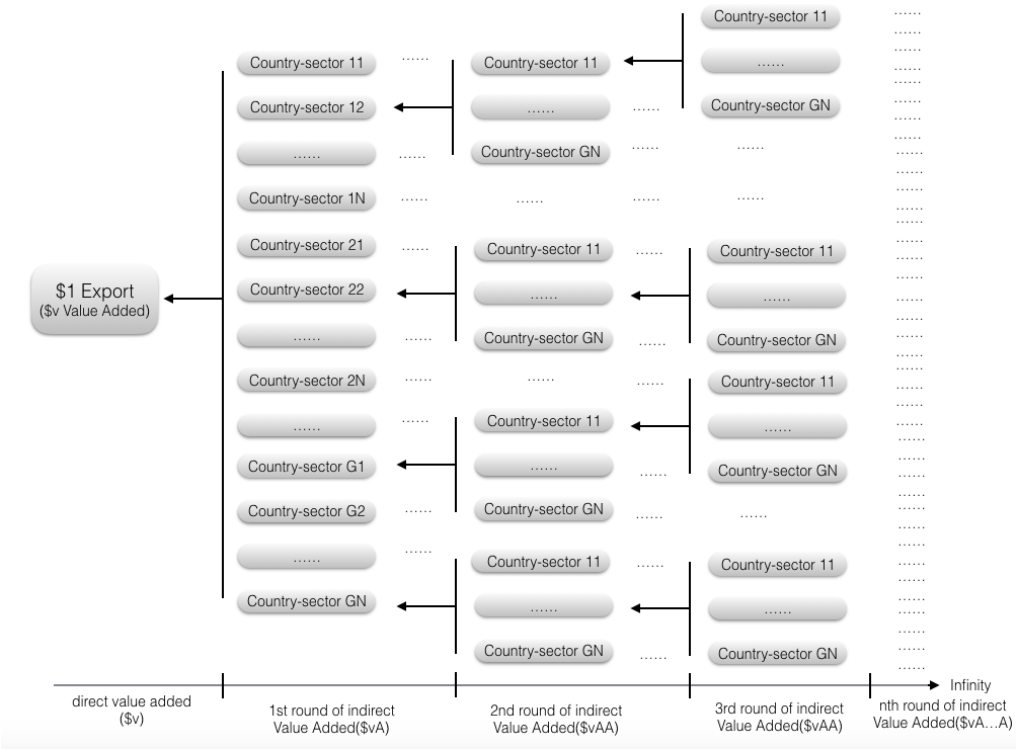
$$\mathbf{V}_1\mathbf{B}_{1s} + \mathbf{V}_2\mathbf{B}_{2s} + ... + \mathbf{V}_r\mathbf{B}_{rs} + ... + \mathbf{V}_G\mathbf{B}_{Gs} = \mathbf{j}, \tag{9}$$

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 Robert Koopman 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 6 graphically portraits the intuition of **VB** and how it relates to the one-step transition matrix **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 (tree) should be much thinner and more sparse than what is portrayed in Figure 6.

2.3 Differences Between Decomposition and Network Analysis

The ICIOT consists of a huge and complex network of the global production system, and network analysis seems a natural tool to analyze the ICIOT. In fact, network analysis has been increasingly applied to investigate the structural features of GVCs based on ICIOT data in the recent literature. For example, Zhen Zhu and Riccaboni (2015) builds a GVC network based on value-added exports, applies a breadth-first search algorithm to compute the global value trees, and calculates 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). The authors build similar value added networks using the WIOD, and try to identify the main drivers of structural

Figure 6: ICIO Production Structure: Global Value Added Chain (Tree)



change of GVCs from 1995 to 2011. They find that the size, strength, and connectivity of the networks increase significantly during the time period, and there are a few most influential country sectors around which other nodes of the network are highly clustered around. Some of those network analyses are based on the results of the Leontief Decomposition Method, but tend to neglect the fact that the Leontief Decomposition method itself is an approach to analyze the complex network and that the results generated by the Decomposition already take into account of all indirect connectivities and systemic interdependence.

The most important difference between network analysis and the Leontief Decomposition method lies in 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, in the Decomposition method, connectivity between a and b depends not only on the static paths between a and b but also on continuous flows throughout the system. Intermediate goods and services keep flowing in the channels defined by the matrix $\mathbf{A}$ as many rounds until they are finally consumed, and each round of transition would increase connectivity between dyad pairs. In such a dynamic system, the decomposition

method is a solution to the question of what is the asymptotic connectivity as flows continue to infinity. 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 dyad pairs. We should be very careful to apply network analysis to matrices containing the Leontief Inverse to avoid mis-counting and double-counting of indirect connectivity. Therefore, in this paper, we choose to construct measures directly based on data generated with the Leontief Decomposition rather than applying network techniques and using network metrics.

3 Mapping GVCs with ICIOT: Globalization and Interdependence

The availability of ICIOT databases and development of the decomposition methods have led to a burgeoning literature to empirically describe and analyze the structure of today's globalization (refer to Hernandeza and Pedersen (2015) and Frederick (2014) for more comprehensive reviews). The existing measures constructed based on ICIOT 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 Vito Amendolagine and Seric (2017) and Zhi Wang and Zhu (2017) apply more decomposed measures for GVC participation and positioning in GVCs. However, those existing measures are 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. The relative positioning implies different bargaining power (Sturgeon, 2009). As Mark Dallas and Sturgeon (2017) states, "power has been a foundational concept in examining global value chains and production networks (p.1)." 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). Following the earlier studies, the discussion of power in GVCs has been dominated by firm-level analyses. As an exception, Mahutga (2014) measures national-level power dif-

ferentials 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; Emilie Hafner-Burton and Montgomery, 2009; Hafner-Burton and Montgomery., 2009; Thomas Oatley and Danzman, 2013) and as a dyadic concept (Dahl, 1957; Keohane and Nye, 1977, 1987).

3.1 A Further Decomposition: Value Added International Trade of Intermediates

With the matrix of $\hat{\mathbf{V}}\mathbf{B}$ to reflect the underlying production structure, we now consider the actually flows of intermediates. The task is to decompose value added exports into export for consumption and for production. As in Zhi Wang and Zhu (2017), we decompose the ICIO model into four parts—output used domestically as intermediate goods, output used domestically as final goods, output used as input in foreign industries, and output used for foreign final demand:

$$\mathbf{X} = \mathbf{A}\mathbf{X} + \mathbf{Y} = \mathbf{A}^D\mathbf{X} + \mathbf{Y}^D + \mathbf{A}^F\mathbf{X} + \mathbf{Y}^F, \tag{10}$$

where $\mathbf{A}^D$ is an $NG \times NG$ domestic IO coefficient matrix by setting all off-diagonal block matrices of $\mathbf{A}$ as zero, $\mathbf{A}^F$ is an $NG \times NG$ foreign IO coefficient matrix by setting all diagonal block matrices of $\mathbf{A}$ as zero, and $\mathbf{A}^D + \mathbf{A}^F = \mathbf{A}$. Then the last two terms on the right-hand side of the equation are exports as intermediates $\mathbf{A}^F\mathbf{X}$ and exports for final use $\mathbf{Y}^F$, and they sum up to the total exports $\mathbf{A}^F\mathbf{X} + \mathbf{Y}^F = \mathbf{E}$. Re-arrange Equation 10 and we have

$$\mathbf{X} = (\mathbf{I} - \mathbf{A}^D)^{-1}(\mathbf{Y}^D + \mathbf{A}^F\mathbf{X} + \mathbf{Y}^F). \tag{11}$$

Denote $(\mathbf{I} - \mathbf{A}^D)^{-1} \equiv Ł$, which is the local Leontief inverse matrix, we have:

$$\mathbf{X} = Ł\mathbf{Y}^D + Ł\mathbf{Y}^F + Ł\mathbf{A}^F\mathbf{X}. \tag{12}$$

Then we convert the $\mathbf{X}, \mathbf{Y}^D, \mathbf{Y}^F, \mathbf{Y}$ into $GN \times GN$ diagonal block matrix $\hat{\mathbf{X}}, \hat{\mathbf{Y}}^D, \hat{\mathbf{Y}}^F, \hat{\mathbf{Y}}$, and $\hat{\mathbf{V}}$ is also a $GN \times GN$ diagonal matrix with $\mathbf{V}$ on the diagonal. Because $\mathbf{X} = \mathbf{BY}$, we have:

$$\hat{\mathbf{V}}\hat{\mathbf{X}} = \hat{\mathbf{V}}\mathbf{B}\hat{\mathbf{Y}} = \hat{\mathbf{V}}Ł\hat{\mathbf{Y}}^D + \hat{\mathbf{V}}Ł\hat{\mathbf{Y}}^F + \hat{\mathbf{V}}Ł\mathbf{A}^F\mathbf{B}\hat{\mathbf{Y}}. \tag{13}$$

In the equation, the first term on the right-hand side, $\hat{\mathbf{V}}Ł\hat{\mathbf{Y}}^D$, is the value added that is produced and consumed as final use domestically. The second term $\hat{\mathbf{V}}Ł\hat{\mathbf{Y}}^F$ is the value added export for foreign consumption, which is the traditional trade represented by "Portugal wine in exchange for England cloth". The third term, $\hat{\mathbf{V}}Ł\mathbf{A}^F\mathbf{B}\hat{\mathbf{Y}}$, is what is interested in this research, which is value-added exports for foreign intermediate use. "Because it is used in production activities outside the source country, it is part of the cross-country production sharing activities (Zhi Wang and Zhu, 2017, pp6-7)." This term can be further decomposed into many components, including whether the value added crosses national borders once or multiple times [7], but for our purpose we do not need any further decomposition in this research.

One important feature of $\hat{\mathbf{V}}\mathbf{B}\hat{\mathbf{Y}}$ is worthy of a special notice: the sum of each column j is equal to the final goods Y produced by the country-sector j, and the sum of each row i is equal to the GDP (value added) generated by country-sector i. When the rows are standardized with sector-level GDP and the columns are normalized with the sectoral final production, they are the share of value added to foreign country-sectors or the share of foreign value added to the final production. And the row is known as "forward linkage", showing the strength of value added linkages of the ith 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 jth country-sector as a downstream sector with its direct and indirect upstream partners around the world.

3.2 Measures of Globalization and Interdependence

As Keohane and Nye (1987) puts it, "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 unites 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. For all the measures, we start with the measures at the country-sectoral

[7] For example Zhi Wang and Zhu (2016) decomposes the value added exports into 15 terms.

level, and national-level measures can be generated by aggregating the country-sector-level measures.

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

We introduce three measures to describe the macro structure of globalization featured by GVCs. They are GVC participation, influence, and vulnerability. Each has two sub-measures from the supply and demand dimensions.

GVC Participation

Participation in GVCs is the degree of integration of an economy or country-section in globalization. The conventional measure of integration in globalization is openness as the ratio of trade to GDP. Because trade has been getting more and more complex and sophisticated, the theoretical and empirical implications of openness based on gross trade are getting ambiguous. This is the reason that the recent literature tries to use GVC measures to replace the traditional ones about integration in globalization (Vito Amendolagine and Seric, 2017; Zhi Wang and Zhu, 2017). For the measure of participation, we use the ratio of value added imports or exports of intermediates to GDP or final production. At the national level, GDP (Va) is equal to final goods (Y), but the two are not equal at the subnational levels.

For a sector p in country s, we denote the country-sector as sp, and its participation as supplier is the sum of its value added forward linkages in GVCs to the total value added generated in this country-sector, which reflects how much the country-sector produces for the production of foreign industries. This measure can be expressed as follows:

$$P_{sp}^{s} = \frac{\sum_{r \neq s} \sum_{q} (\hat{V} L A^{F} B Y)_{sp,rq}}{Va_{sp}}, \tag{14}$$

where the superscript s denotes "as supplier", and country-sector sp's participation as supplier in GVCs is the sum of its value added exports of intermediates to all the other foreign country-sectors rq, $\forall r \neq s$. Similarly, GVC participation as buyer is its value added imports of inputs in its production of final goods, which is essentially about how much the production of a country-section depends on the production of foreign sectors. It can be calculated as below

$$P_{sp}^{b} = \frac{\sum_{r \neq s} \sum_{q} (\hat{V} L A^{F} B Y)_{rq,sp}}{Y_{sp}}, \tag{15}$$

where the superscript b denotes "as buyer." Putting the forward and backward linkages to-

gether, the total participation of country-sector sp in GVCs is:

$$P_{sp} = \frac{\sum_{r \neq s} \sum_q (\hat{V} LA^F BY)_{sp,rq}}{Va_{sp}} + \frac{\sum_{r \neq s} \sum_q \hat{V} LA^F BY_{rq,sp}}{Y_{sp}}, \tag{16}$$

which is about how much a country-sector's production activities depend on the global market of intermediates. Country-level participation measures can be constructed by aggregating value added imports or exports at the country-sector level as ratio of national GDP:

$$P_s^s = \frac{\sum_p \sum_{r \neq s} \sum_q (\hat{V} LA^F BY)_{sp,rq}}{GDP_s}, \tag{17}$$

$$P_s^b = \frac{\sum_p \sum_{r \neq s} \sum_q (\hat{V} LA^F BY)_{rq,sp}}{GDP_s}, \tag{18}$$

$$P_s = \frac{\sum_p \sum_{r \neq s} \sum_q (\hat{V} LA^F BY)_{sp,rq} + \sum_p \sum_{r \neq s} \sum_q \hat{V} LA^F BY_{rq,sp}}{GDP_s}, \tag{19}$$

The denominators are all GDP_s in the above equations, because the value added is equal to final goods, and both are equal to national GDP.

GVC Influence

Based on gross trade data, the distribution of countries' influence in globalization is often measured by degree centrality or eigenvalue centrality. Not relying on networks, Mahutga (2014) uses a a modified version of Wallace, Griffin and Rubin's "logarithmic method" to construct a measure of GVC influence using trade data. Here we use the same logarithmic method but based on value added trade data of intermediates, which defines the influence of a country-sector sp as supplier in GVCs as the sum of the logarithm of the share made by its value added exports of intermediates to the final goods production of its partners around the world:

$$I_{sp}^s = \sum_{r \neq s} \sum_q log \left(\frac{(\hat{V} LA^F BY)_{sp,rq}}{Y_{rq}} + 1 \right). \tag{20}$$

We add 1 to the share for computational reasons. The logarithm is on the base of 10. The value of I_{sp}^s is bigger when a country-sector has more downstream partners and its value-added exports to its partners count a larger share of the partners' production of final goods, and *vice versa*. Similarly, influence as buyer in GVCs can be written as below:

$$I_{sp}^b = \sum_{r \neq s} \sum_q log \left(\frac{(\hat{V} LA^F BY)_{rq,sp}}{Va_{rq}} + 1 \right), \tag{21}$$

and the value of I_{sp}^b increases when a country-sector has more upstream partners and its value-

added imports from its partners count a larger share of their GDP, and *vice versa*. The total influence of a country-sector in GVCs is

$$I_{sp} = \sum_{r \neq s} \sum_{q} \left[log \left(\frac{(\hat{V} LA^F BY)_{sp,rq}}{Y_{rq}} + 1 \right) + \left(log \frac{(\hat{V} LA^F BY)_{rq,sp}}{Va_{rq}} + 1 \right) \right]. \tag{22}$$

The county-level measures of GVC influence is the sum-up of the influence of all sectors within a country:

$$I_s^s = \sum_{p} \sum_{r \neq s} \sum_{q} log \left(\frac{(\hat{V} LA^F BY)_{sp,rq}}{Y_{rq}} + 1 \right) \tag{23}$$

$$I_s^b = \sum_{p} \sum_{r \neq s} \sum_{q} log \left(\frac{(\hat{V} LA^F BY)_{rq,sp}}{Va_{rq}} + 1 \right), \tag{24}$$

$$I_s = \sum_{p} \sum_{r \neq s} \sum_{q} \left[log \left(\frac{(\hat{V} LA^F BY)_{sp,rq}}{Y_{rq}} + 1 \right) + log \left(\frac{(\hat{V} LA^F BY)_{rq,sp}}{Va_{rq}} + 1 \right) \right] \tag{25}$$

GVC Vulnerability

Globalization as general and GVCs as particular not only provide opportunities for economic development, but also induce challenges and risks. Systemic shocks and contagion are serious concerns for firms, sectors, and economies that are integrated in GVCs. GVCs are important channels of contagion, and shocks to local demand or supply can spread quickly to the entire system via GVC connections, as what was observed in the 2008 financial crisis and the 2011 Japaness earthquake (OECD, 2013). Daron Acemoglu and Tahbaz-Saleh (2012) finds that "higher-order interconnections capture the possibility of 'cascade effects' whereby productivity shocks to a sector propagate not only to its immediate downstream customers, but also to the rest of the economy."

To measure vulnerability, we use the widely-applied Herfindahl-Hirschman Index (HHI). HHI is a measure originally for market concentration. We apply HHI based on the assumption that diversification of a country-sector's forward or backward linkages in the global production network would reduce its vulnerability as supplier or buyer to external demand or supply shocks. Following the formula of HHI, we calculate vulnerability of a country-sector *sp* as supplier in GVCs is as follows:

$$V_{sp}^s = \sum_{s \neq r} \sum_{q} \left(\frac{(\hat{V} LA^F BY)_{sp,rq}}{Va_{sp}} \right)^2, \tag{26}$$

where $\frac{(\hat{V} LA^F BY)_{sp,rq}}{Va_{sp}}$ is the share of GDP produced by country-sector *sp* that is exported as

intermediate input to country-sector rq. The more diversified the buyers sp has, the smaller the HHI, and the less vulnerable the country-sector is as supplier in GVCs. Similarly, vulnerability of country sector sp as buyer depends on how concentrated its suppliers are:

$$V_{sp}^{b} = \sum_{s \neq r} \sum_{q} \left(\frac{(\hat{V} L A^{F} B Y)_{rq,sp}}{Y_{sp}} \right)^{2}, \tag{27}$$

where $\frac{(\hat{V} L A^{F} B Y)_{rq,sp}}{Y_{sp}}$ is the value added imports from a foreign country-sector as the share of the production of final demand of country-sector sp. And the total vulnerability is

$$V_{sp} = \sum_{s \neq r} \sum_{q} \left[\left(\frac{(\hat{V} L A^{F} B Y)_{sp,rq}}{Va_{sp}} \right)^{2} + \left(\frac{(\hat{V} L A^{F} B Y)_{rq,sp}}{Y_{sp}} \right)^{2} \right], \tag{28}$$

At the country level, the vulnerability measures are:

$$V_{s}^{s} = \frac{1}{Va_{s}^{2}} \sum_{s \neq r} \sum_{q} (\hat{V} L A^{F} B Y)_{sp,rq}^{2}, \tag{29}$$

$$V_{s}^{b} = \frac{1}{Y_{s}^{2}} \sum_{s \neq r} \sum_{q} (\hat{V} L A^{F} B Y)_{rq,sp}^{2}, \tag{30}$$

$$V_{s} = \frac{1}{Va_{s}^{2}} \sum_{s \neq r} \sum_{q} \left[(\hat{V} L A^{F} B Y)_{sp,rq}^{2} + (\hat{V} L A^{F} B Y)_{rq,sp}^{2} \right], \tag{31}$$

3.3 Measuring Process of Globalization: Dyadic Interdependence

The process of a system is mainly about interaction and how units are connected with each other. Interdependence between dyad pairs describes the process dimension of a system. In the GVC literature, not only the structure of GVCs but also dyadic linkages are at the center of research interests. Actually, dyadic 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 i on j (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)."

In this subsection, we construct measures of interdependence in two aspects, sensitivity and vulnerability. Baldwin (1980) explains the difference between the two types of interdependence as follows: "the distinction between 'sensitivity interdependence' defined in terms of mutual 'effects,' and 'vulnerability interdependence' defined in terms of the opportunity costs of disrupting the relationship, has become widely accepted [pp.489-490]." Mansfield and

Pollins (2003) further articulate the importance to differentiate the two aspects of interdependence:

> In the field of international relations, "economic interdependence" has two meanings. First, a group of countries is considered interdependent if economic conditions in one are contingent on those found in the others, for example, if inflation in France quickly places upward pressure on German prices. Second, countries are considered interdependent if it would be costly for them to rupture or forego their relationship, as would be the case if relations between the Organization of Petroleum Exporting Countries and the advanced industrial countries (which rely heavily on petroleum imports) were severed. The first of these is generally referred to as sensitivity interdependence; the second is typically referred to as vulnerability interdependence. The key difference between sensitivity and vulnerability interdependence hinges on the costs that countries would bear should relations between them be disrupted."[p.11]

Mansfield and Pollins (2003) urges that more research effort should be made to measure interdependence in the gain dimension. since "the microtheory underpinning the central liberal claim hinges not on trade flows, per se, but on the gains from trade (p.12)." AtHowever, the gain from dyadic interactions is difficult to trace, and the cost of disrupting the relationship requires the information on availability of substitutes, which makes the gain dimension of interdependence challenging to measure. Our data on value added contributions are directly about gains, and the interdependence measures we construct are the gain-dimension measures. In addition, Maoz (2009) criticizes the existing measures of interdependence to be marred by serious problems, including treating interdependence purely as dyadic relations and only considering first-order interdependence. The Decomposition method applied to the ICIOT incorporates direct and all indirect value added connectivities between dyadic pairs by tracing the value added process throughout the whole network, which nicely overcomes the problem of interdependence as dyadic relations and as first-order interdependence.

Sensitivity Interdependence

Sensitivity interdependence is essentially about correlation of changes of a dyad, and it is a relatively simple dimension of interdependence. We use the share of value added contributions

between country-sectors to measure sensitivity (inter)dependence:

$$SD^{s}_{sp\to rq} = \frac{(\hat{V}LA^{F}BY)_{sp,rq}}{Va_{sp}}, \tag{32}$$

$$SD^{b}_{sp\to rq} = \frac{(\hat{V}LA^{F}BY)_{rq,sp}}{Y_{sp}}. \tag{33}$$

The subscript of $sp \to rq$ denotes "country-sector sp depends on country-sector rq", and the superscribe indicates sensitivity dependence as supplier s or buyer b. The total sensitivity dependence of country-sector sp on rq is:

$$SD_{sp\to rq} = \frac{(\hat{V}LA^{F}BY)_{sp,rq}}{Va_{sp}} + \frac{(\hat{V}LA^{F}BY)_{rq,sp}}{Y_{sp}}, \tag{34}$$

and the asymmetry of sensitivity interdependence of country-sector sp on rq is:

$$AS_{sp\to rq} = SD_{sp\to rq} - SD_{rq\to sp}. \tag{35}$$

Asymmetric sensitivity interdependence means that one party could experience larger volatility than the other, which would be used as a leverage by the less volatile party in their relationship. This asymmetry may be a source of power, although the literature mainly focuses on vulnerability interdependence in power discussions. Asymmetric sensitivity interdependence is also important to investigate contagion, because the asymmetry would amplify a small shock to a significant fluctuation.

The country-level sensitivity interdependence is the aggregation of the sensitivity dependence at the sectoral level across all sectors for both countries:

$$SD^{s}_{s\to r} = \frac{\sum_p \sum_q (\hat{V}LA^{F}BY)_{sp,rq}}{Va_{s}} \tag{36}$$

$$SD^{b}_{s\to r} = \frac{\sum_p \sum_q \hat{V}LA^{F}BY)_{rq,sp}}{Va_{s}} \tag{37}$$

$$SD_{s\to r} = \frac{1}{Va_{s}}\left[\sum_{p}\sum_{q}(\hat{V}LA^{F}BY)_{sp,rq} + \hat{V}LA^{F}BY)_{rq,sp}\right] \tag{38}$$

$$AS_{s\to r} = SD_{s\to r} - SD_{r\to s} \tag{39}$$

Cross-level measures of sensitivity dependence between country s and country-sector rq can

be expressed as follows:

$$SD^{s}_{s\to rq} = \frac{\sum_p (\hat{V}LA^F BY)_{sp,rq}}{Va_s} \tag{40}$$

$$SD^{d}_{s\to rq} = \frac{\sum_p (\hat{V}LA^F BY)_{rq,sp}}{Va_s} \tag{41}$$

$$SD_{s\to rq} = \frac{\sum_p (\hat{V}LA^F BY)_{sp,rq}}{Va_s} + \frac{\sum_p (\hat{V}LA^F BY)_{rq,sp}}{Va_s} \tag{42}$$

We do not calculate the asymmetry of cross-level interdependence for the reason that only in very rare situations the dependency of a country-sector on a country is lower than that of the country on the sector.

Vulnerability Dependence

Measuring vulnerability interdependence should consider two factors: the direct of disrupting the relationship, and the opportunity cost as a function of the availability of substitutes. The first is measured as the share of GDP contributed by value added exports or imports of one party to the other, and the availability of substitutes is measured with the HHI. Then, the vulnerability dependence of country-sectors sp as supplier on country-sector rq is

$$VD^{s}_{sp\to rq} = HHI_{spb}\frac{(\hat{V}LA^F BY)_{sp,rq}}{Va_{sp}}, \tag{43}$$

$$\text{where, } HHI_{spb} = \sum_{r,q}\left(\frac{(\hat{V}LA^F BY)_{sp,rq}}{Va_{sp}}\right)^2, \tag{44}$$

where HHI_{spb} is the measure of concentration of buyers of country-sector sp's value-added exports of intermediates. The vulnerability dependence of country-sector sp on rq as buyer is calculated in a similar way:

$$VD^{b}_{sp\to rq} = HHI_{sps}\frac{(\hat{V}LA^F BY)_{rq,sp}}{Y_{sp}}, \tag{45}$$

$$\text{where, } HHI_{sps} = \sum_{r,q}\left(\frac{(\hat{V}LA^F BY)_{rq,sp}}{Y_{sp}}\right)^2, \tag{46}$$

where HHI_{spb} is the measure of concentration of suppliers of country-sector sp's imports of intermediates. And the total vulnerability dependence of country-sector sp on rq is

$$VD_{sp\to rq} = HHI_{spb}\frac{(\hat{V}LA^F BY)_{sp,rq}}{Va_{sp}} + HHI_{sps}\frac{(\hat{V}LA^F BY)_{rq,sp}}{Y_{sp}} \tag{47}$$

The asymmetry of interdependence between country-sector sp and rq is:

$$AV_{sp\to rq} = VD_{sp,rq} - VD_{rq,sp} \tag{48}$$

If $AV_{sp\to rq} > 0$, country-sector sp is more vulnerable than rq in their bilateral relationship, since the the potential cost is higher for sp than for rq when their relationship is disrupted. Therefore, rq enjoys more bargaining power over sp, originated from this asymmetric interdependence. The greater the value of $AV_{sp\to rq}$, the more asymmetric the interdependence, and the more power country-sector rq has over sp.

Measures of vulnerability dependence and asymmetry at the country level can be expressed as follows:

$$VD^s_{s\to r} = HHI_{sb}\frac{\sum_{q,p}(\hat{V}LA^FBY)_{sp,rq}}{Va_s}, \tag{49}$$

$$\text{where, } HHI_{sb} = \sum_r \left(\frac{\sum_{p,q}(\hat{V}LA^FBY)_{sp,rq}}{Va_s}\right)^2, \tag{50}$$

$$VD^b_{s\to r} = HHI_{ss}\frac{\sum_{p,q}(\hat{V}LA^FBY)_{rq,sp}}{Y_s}, \tag{51}$$

$$\text{where, } HHI_{ss} = \sum_r \left(\frac{\sum_{p,q}(\hat{V}LA^FBY)_{rq,sp}}{Y_s}\right)^2, \tag{52}$$

$$VD_{s\to r} = \frac{\sum_{q,p}(\hat{V}LA^FBY)_{sp,rq}}{Va_s} + HHI_{ss}\frac{\sum_{q,p}(\hat{V}LA^FBY)_{rq,sp}}{Y_s} \tag{53}$$

$$AD_{s\to r} = VD_{sr} - VD_{rs} \tag{54}$$

And cross-level measures of vulnerability dependence of country s on country-sector rq are as

below:

$$VD^{s}_{s\to rq} = HHI_{sb'}\frac{\sum_p(\hat{V}LA^{F}BY)_{sp,rq}}{Va_s}, \tag{55}$$

$$\text{where, } HHI_{sb'} = \sum_{r,q}\left(\frac{\sum_p(\hat{V}LA^{F}BY)_{sp,rq}}{Va_s}\right)^2, \tag{56}$$

$$VD^{b}_{s\to rq} = HHI_{ss'}\frac{\sum_p(\hat{V}LA^{F}BY)_{rq,sp}}{Y_s}, \tag{57}$$

$$\text{where, } HHI_{ss'} = \sum_{r,q}\left(\frac{(\sum_p\hat{V}LA^{F}BY)_{rq,sp}}{Y_s}\right)^2, \tag{58}$$

$$VD_{s\to rq} = HHI_{sb'}\frac{\sum_p(\hat{V}LA^{F}BY)_{sp,rq}}{Va_s} + HHI_{ss'}\frac{\sum_p(\hat{V}LA^{F}BY)_{rq,sp}}{Y_s} \tag{59}$$

4 Empirics of Globalization and Interdependence from the GVC Perspective

We use the ICIO database to calculate the proposed measures and summarize the empirical findings of globalization and interdependence in this section. The data we use are the OECD Inter-Country Input-Output (ICIO) data, which covers 64 countries and economies including 36 OECD countries and 28 emerging economies or developing countries. Table 6 and Table 7 in the appendix report the sample economies and sectors. Note that there is a "residual" unit of "the Rest of the Wold" (ROW) which includes all other economies besides the 64 economies to keep the global balance of supply and demand.[8]

4.1 The Basic Structure of GVCs

Based on the ICIO database and the decomposition methods, we generate an original database of global flows of value added goods and services. The dataset has four variables, including the flow of total value added goods and service ($\hat{\mathbf{V}}\mathbf{B}\hat{\mathbf{Y}}$), value added consumed domestically ($\hat{\mathbf{V}}\text{Ł}\hat{\mathbf{Y}}^{D}$), value added exports to foreign countries for consumption only ($\hat{\mathbf{V}}\text{Ł}\hat{\mathbf{Y}}^{F}$) , and value added exports to foreign countries as intermediates for production ($\hat{\mathbf{V}}\text{Ł}\mathbf{A}^{F}\mathbf{B}\hat{\mathbf{Y}}$). To measure globalization and interdependence, we will focus on the variable of value added exports of intermediates ($\hat{\mathbf{V}}\text{Ł}\mathbf{A}^{F}\mathbf{B}\hat{\mathbf{Y}}$). The unit of observation in the database is country-sector-year, and there are 80,494,592 observations in total, covering 65 economies and 34 sectors in 17

[8]We use the 2016 edition of the ICIO database, which is available for public access on http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm

years from 1995 to 2011. All the variables are skewed to the right, showing that the value added flow system is highly unbalanced.

The adjacency matrices of value added exports $\hat{\mathbf{V}}\mathbf{B}\mathbf{Y}$ and the value added share matrix $\hat{\mathbf{V}}\mathbf{B}$ reveal basic structures of the GVCs. Figure 7 shows the empirical realization of the added value flow matrix $\hat{\mathbf{V}}\mathbf{B}\mathbf{Y}$ and the value added share matrix $\hat{\mathbf{V}}\mathbf{B}$ at the country level in 1995 and 2011. The pattern of value-added exports does not change a lot from 1995 to 2011, though the scale increases over time. Interestingly, the pattern of value added exports is very different from that of the value added share.The system of total value added trade is quite dense, but the value added share of the global trade is sparse. For several economies, their total value added exports are large, but their value added shares of exports are very small, such as India, South Africa, Brazil and Taiwan. Comparison of value added share matrices over time shows economic upgrading of the national economies. For instance, value added shares of China, Russia, and the "Rest of World", rise rapidly from 1995 to 2011. The value added trade matrices demonstrates that most of the economies are active participators in GVCs, but the value added share matrices indicate that only a very few economies have large shares of value added in the system.

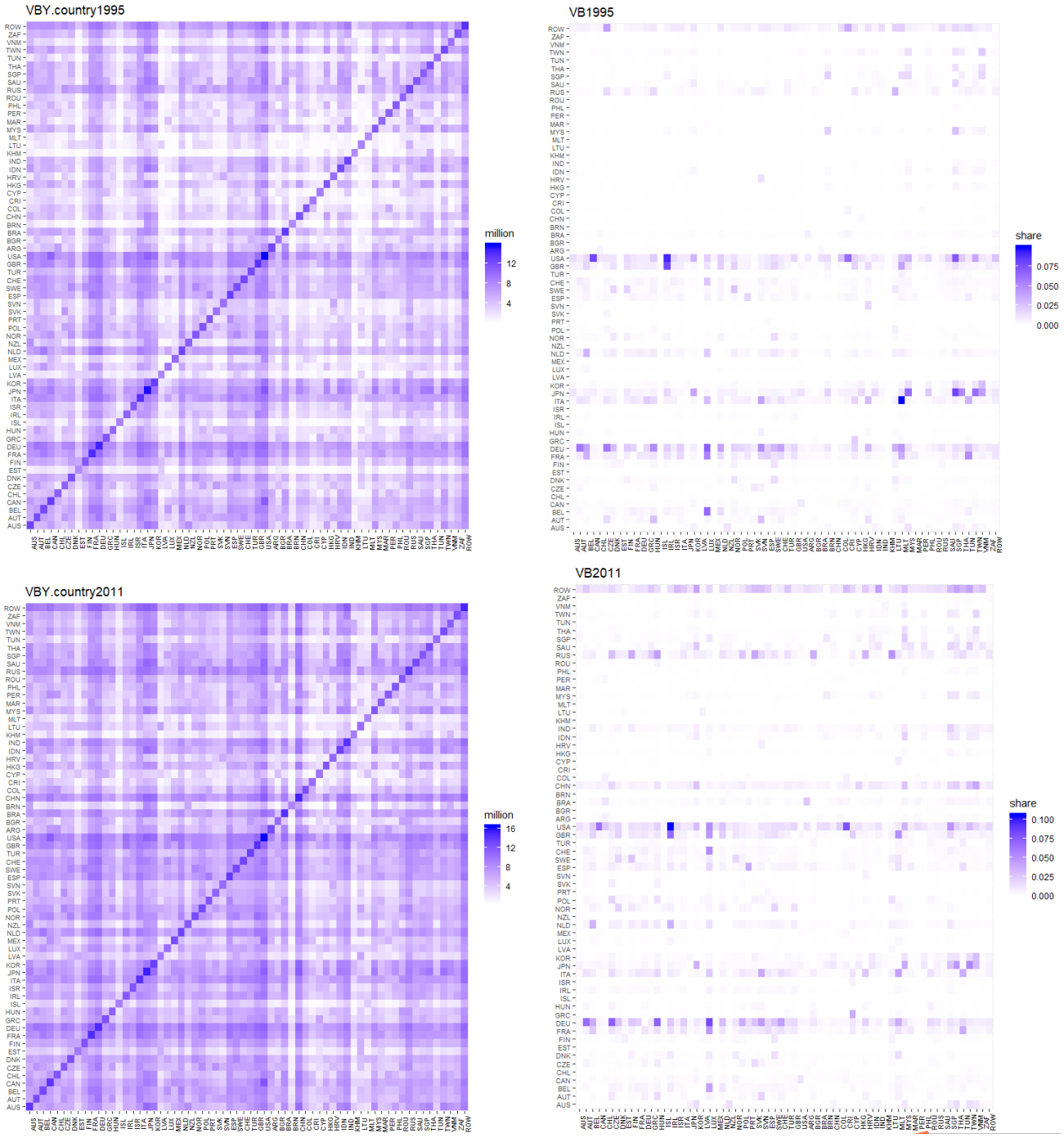
4.2 Globalization: Structure and Agents

4.2.1 Expansion of Globalization: GVC Participation

The GVC participation measures clearly demonstrate that GVCs have been expanding in both supply and demand dimensions and at both national and sub-national levels. As illustrated by Figure 8, the distributions of GVC participation at the country level has a bell curve with a long tail. The distributions at the country-sector level are more skewed to the right than those at the national level. In general, all the participation density curves move to the right from 1995 to 2011. Figure 9 are time series of the median-level GVC participation at the country and country-sector levels, and there are clear trends that GVC participation rate steadily increases during the sample years except the 2008 global financial criss. Supply participation and demand participation move closely together, and have very similar patterns at both the national and subnational levels. Interestingly, at the national level, the median levels of participation in supply and demand are very close, while at the country-sector level, participation as buyer in GVCs is generally higher than as supplier.

In addition, small economies have higher GVC participation than large economies. Figure 10 exhibits the average of participation rate of the sample countries over time. Countries above the dash line have relative GVC positioning as net supplier (in other words, they are

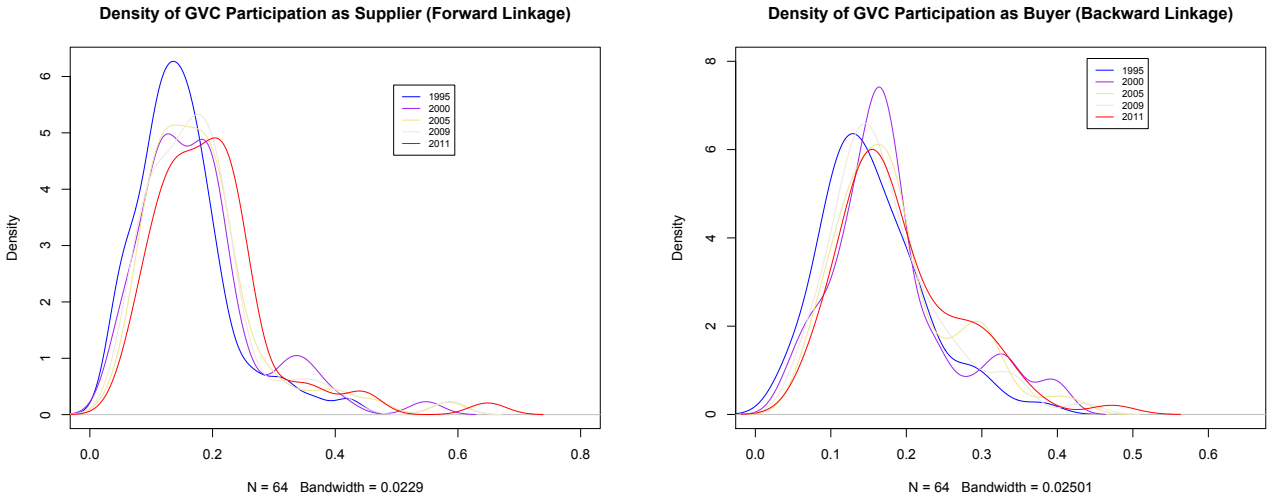
Figure 7: Empirical Illustrations of Value Added Share and Value added (1995)



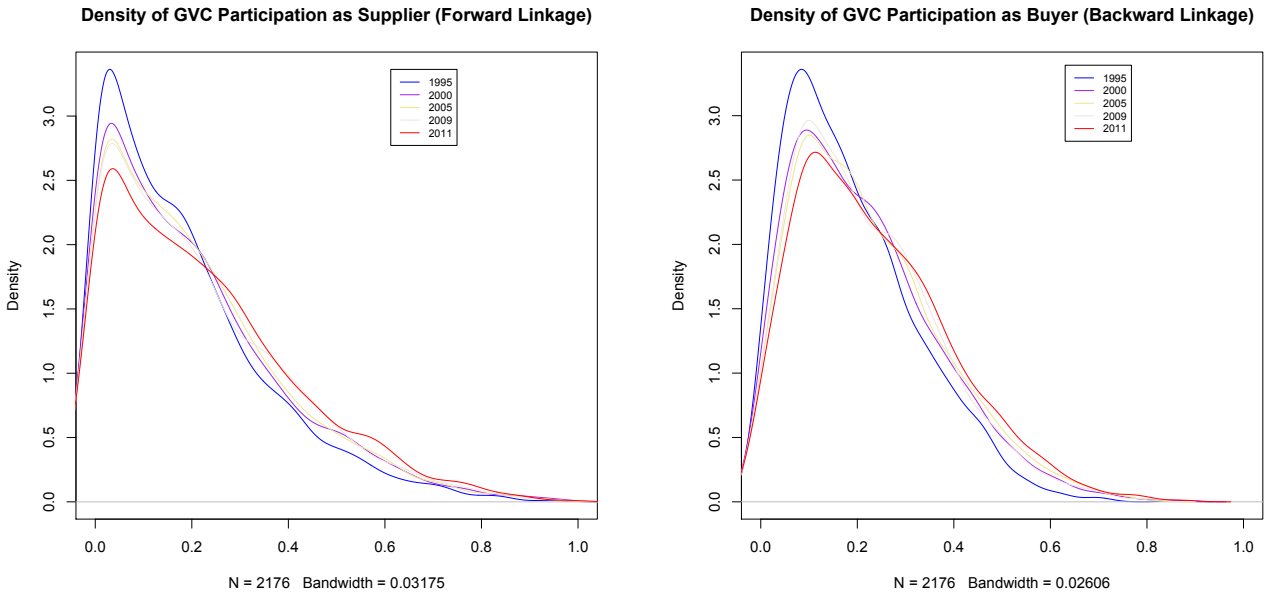
more forwardly linked in GVCs), and those below the line occupy relative GVC positioning as net buyer (they are more backwardly linked) (Vito Amendolagine and Seric, 2017; Zhi Wang and Zhu, 2017). Small countries such as Luxembourg (LUX), Singapore (SGP), and Mayotte

Figure 8: Distribution of GVC Participation of Countries and Country-Sectors (Selected Years)

Country-level GVC Participation



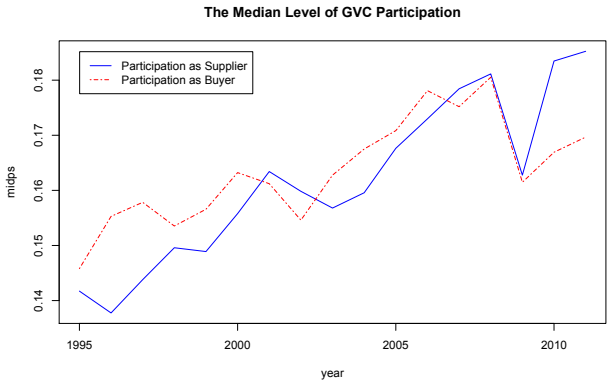
Country-Sector Level GVC Participation



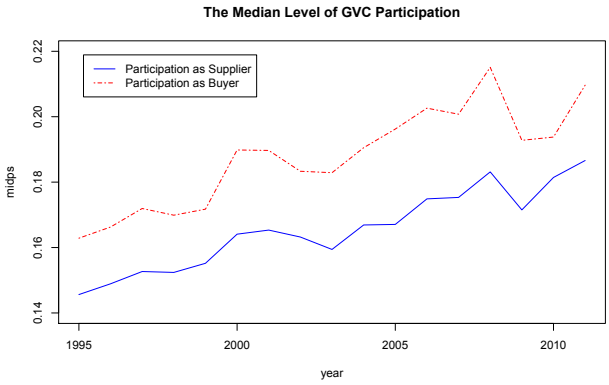
(MYT), have very high and balanced participation rates as supplier and buyer in GVCs. Those oil and gas exporter countries, such as Brunei Darussalam (BRN), Saudi Arabia (SAU), Norway (NOW), and Russia (RUS), are mainly forwardly linked in GVCs as supplier. Large economies, such as the United States, Japan, and France, have the lowest level of participation

Figure 9: Median Level of GVC Participation of Countries and Country-Sectors

Country-level GVC Participation

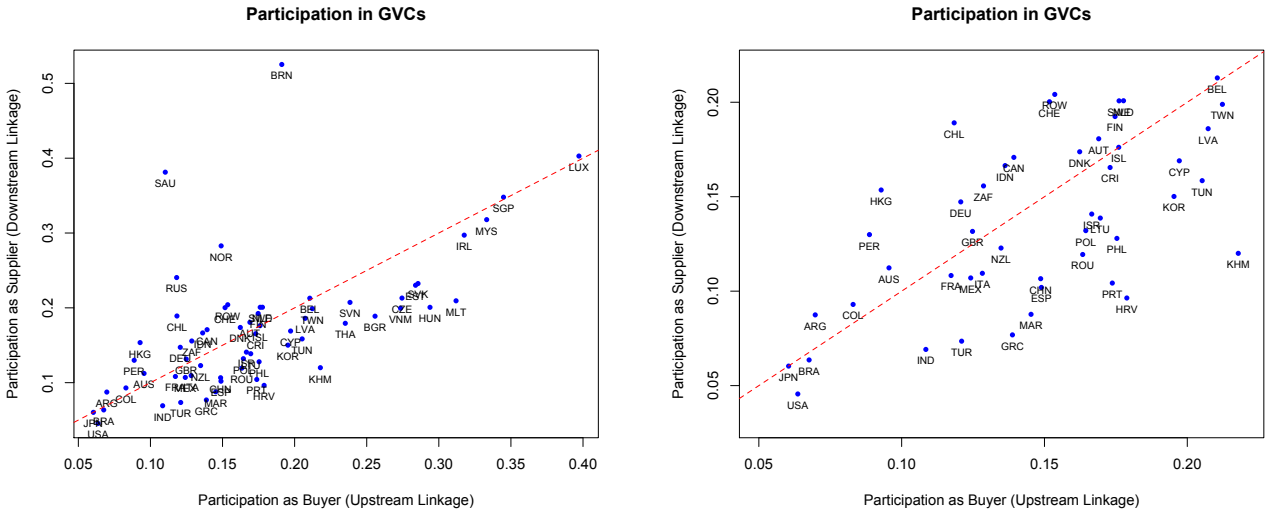


Country-Sector Level Participation



in both dimensions.

Figure 10: Average Participation Levels of Countries



Note: The figure on the right-hand side is a zoom-in of the left-lower part of the figure on the left-hand side.

At the country-sector level, Figure 11 reports the top 30 country-sectors with highest participation rate in GVCs as supplier or buyer. The most extreme value of GVC participation is 0.989, which is the participation rate as supplier of the sector "Basic Metals" in Iceland in 2008 (ISL_C27MET). This sector in Iceland produces almost entirely for supply to the global production. Not surprisingly, all the top 30 country-sectors participating in GVCs as

supplier are the sector "Basic Metals" in small economies, including Iceland, Peru, Estonia, and Luxembourg. On the demand dimension, the top 30 country-sectors are not necessarily in small economies (such as South Korea (KOR) and Portugal (PRT)), but dominated by two sectors, "Coke, Refined Petroleum Products and Nuclear Fuel" ($C23PET$) and "Computer Electronic and optical equipment" ($C30T33XCEQ$).

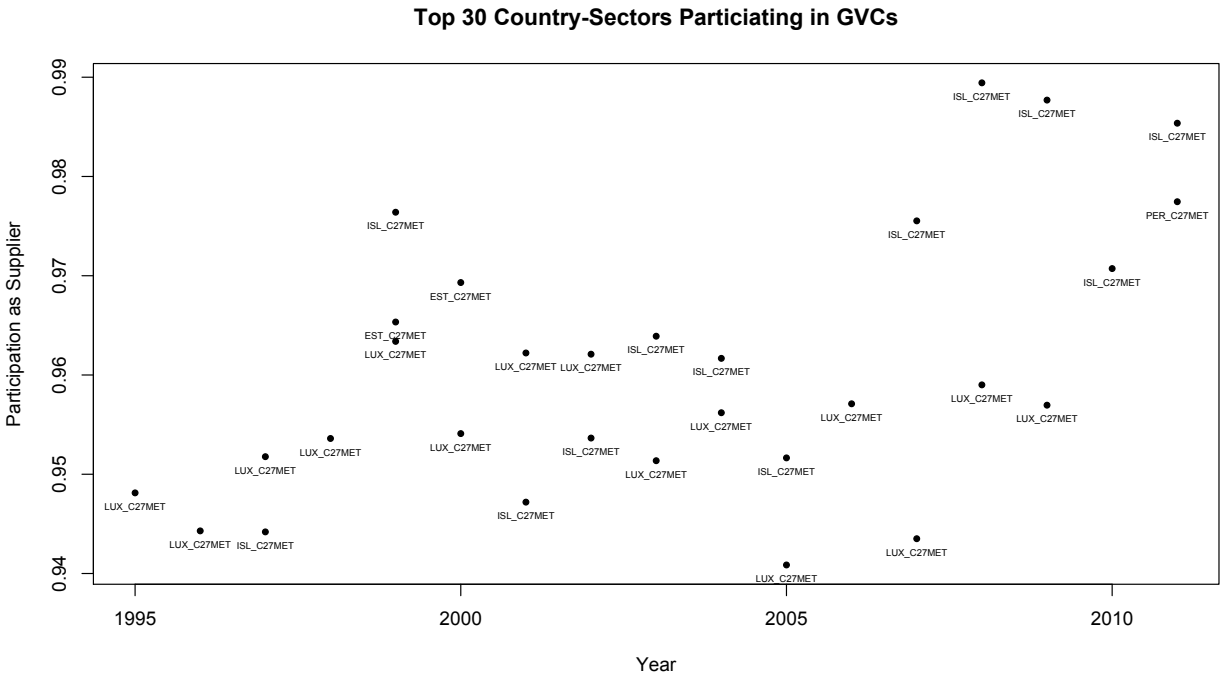
Table 1: Countries With Most Rapid Changes in GVCs

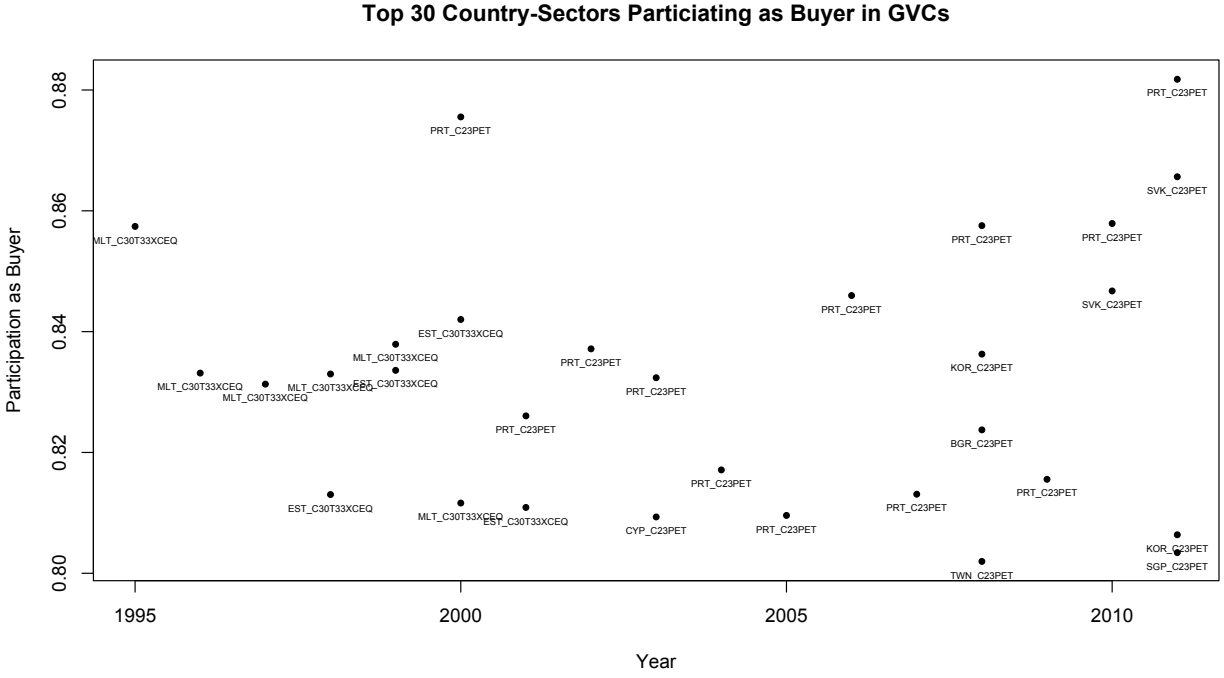
Rank	Part.S	Part. B	Infl. S	Infl. B	Vul. S	Vul.B
Most Rapidly Decreasing						
1	Canada	Estonia	Japan	Japan	Indiaia	Estonia
2	Bulgaria	Brunei	France	United States	Canada	Singapore
3	Indonesia	Singapore	United States	United Kingdom	Bulgaria	Brunei
4	Croatia	Norway	Italy	Netherlands	Costa Rica	Norway
5	Costa Rica	Canada	Finland	Taiwan	Croatia	Philippines
6	New Zealand	Philippines	Austria	Singapore	New Zealand	Canada
7	France	Australia	Taiwan	Austria	France	New Zealand
8	Finland	New Zealand	Belgium	Hong Kong	Finland	Australia
9	Cyprus	Netherlands	Sweden	Belgium	Turkey	Netherlands
10	Turkey	Mexico	Germany	Israel	United States	Mexico
Most Rapidly Increasing						
1	Brunei	Luxembourg	ROW	China	Brunei	Luxembourg
2	Saudi Arabia	Cambodia	China	ROW	Saudi Arabia	Thailand
3	Peru	Thailand	Russia	India	Singapore	Cambodia
4	Chile	South Korea	India	Indonesia	Luxembourg	Ireland
5	Hong Kong	India	Saudi Arabia	Spain	Chile	Malaysia
6	Taiwan	Taiwan	Brazil	Russia	Taiwan	Bulgaria
7	Malta	China	Spain	Poland	Malta	Viet Nam
8	Singapore	Bulgaria	Poland	South Korea	Ireland	South Korea
9	Germany	Poland	Norway	Turkey	Peru	Taiwan
10	Viet Nam	Turkey	Ireland	Brazil	Hong Kong	Hungary

4.2.2 Hierarhicality of the Structure: GVC Influence

The distributions of influence in GVCs are extremely skewed to the right, as shown in Figure 12. The median of the influence distribution as supplier is 0.080, the mean is 0.179, and the mean is roughly equal to the third quantile. For the distribution of influence as buyer, the median is 0.079, and mean is greater than the third quantile (0.161). The distributions have a very long tail, indicating that a very few countries have much higher influence than the majority in GVCs. Figure 13 reports those country-years that have ever been in the top 10% quantile of influence as buyer or supplier. In the top 10% quantile are only 8 countries, and

Figure 11: Country-Sectors With Highest Participation Rate





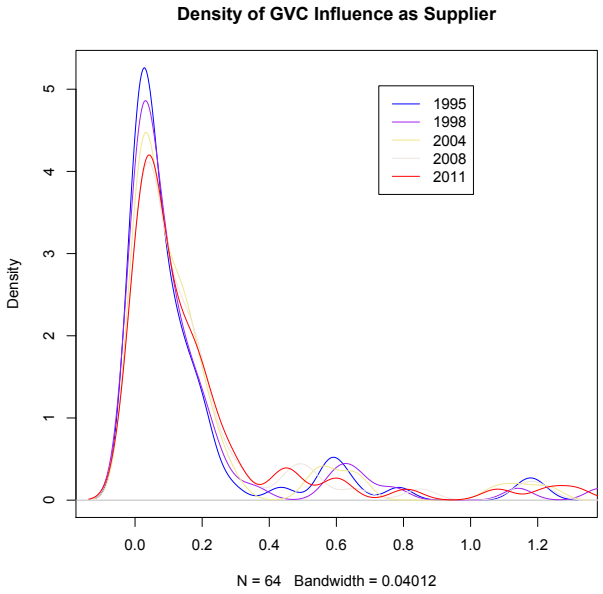
7 of them (except Russia) are the most influential ones both as supplier and buyer. Only two non-OECD countries, China and Russia, have ever been in the top 10% quantile of in the influence distribution—China's influence raises rapidly in the later years of the sample period, starting to appear in the pictures as supplier in 2010 and as buyer in 2007. The United States and Germany are the two "superpowers" in the GVCs. The United States is the most influential economy in GVCs and its influence as buyer is on the very top and far above other countries. The eight countries—the United States, Germany, the Great Britain Japan, Italy, Russia, France, and China—have about half of the total influence in the system, 49% as supplier and 51% as supplier. Among them, the United States has 14% of the total influence as buyer, and 11% as supplier. The second most influential country is Germany, which has 7% of the total influence as buyer and 10% as supplier. We calculate the GINI coefficient of influence in the system in each sample year. Figure 14 displays the time series of the GINI coefficient of influence. The distribution of influence has the GINI coefficient above 0.6 in all the sample years and in both the supply and demand dimensions. However, the inequality is in decrease over time, caused by the rise of China, the rest of the world, and other emerging countries in GVC influence.

The countries whose influence increase or decrease most rapidly are ranked in Table 1. China is the most impressive case, ranked as No.1 as the country with the most rapid increase of influence both as supplier and buyer (the ROW is not a single country). Besides China, the other BRIC countries —Russia, India, and Brazil–also have fast-growing influence in GVCs. The influence of the "Rest of World", consisting of all other developing countries in the world as a whole, is in a rapid rise. The economies whose influence in GVCs decrease in a relatively high speed are all developed economies. The influence of the United States and Japan diminish in the highest speed.

In general, the system of globalization characterized by GVCs is a hierarchical one, and influence is highly unevenly distributed in the system, with a few countries at the center leading by the United States. However, there seems not to have a single hegemon in the system. The United States is the most influential country and much more influential than the other countries, but Germany is not far behind the US, and the United States only has 27% of the influence of the core (consists of the eight countries) as supplier and 23% as buyer. At the same time, the rapid rise of China, the other emerging economies, and the rest of the world, as well as the decrease of the traditionally influential western economies, are gradually changing the structure.

Figure 12: Influence in GVCs (Selected Years)

Influence of Countries as Suppliers



Influence of Countries as Buyers

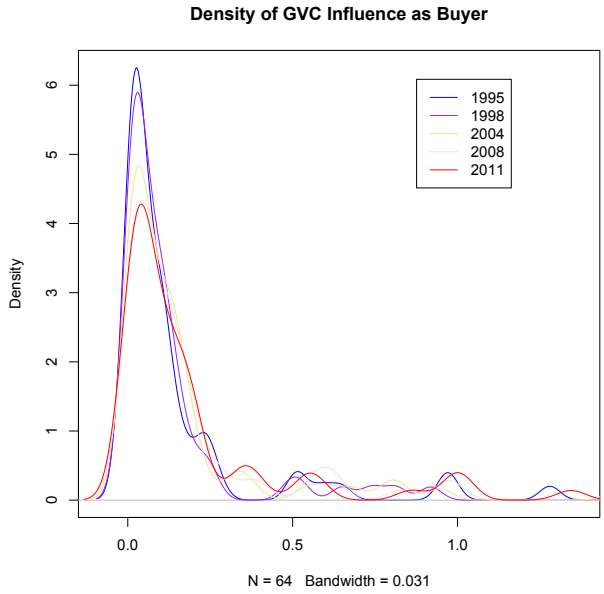
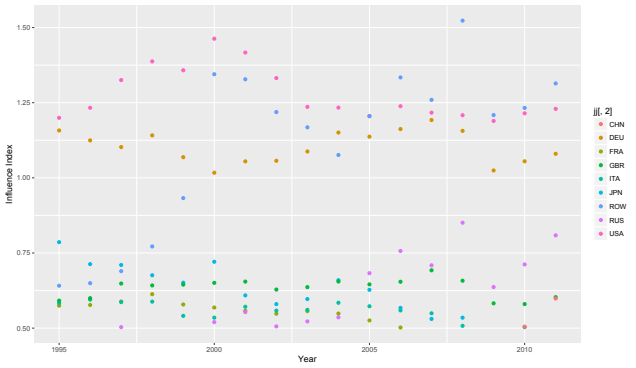
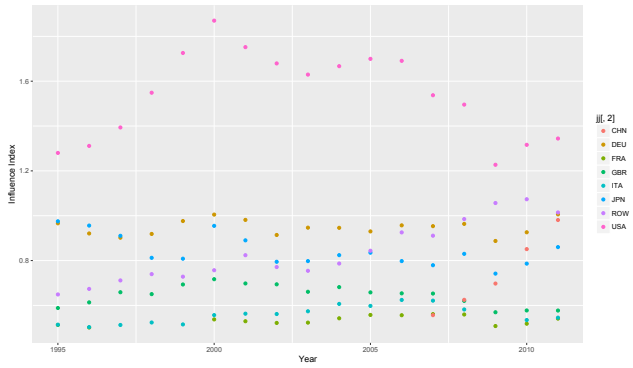


Figure 13: Most Influence Countries in GVCs (> 0.5)

as Suppliers



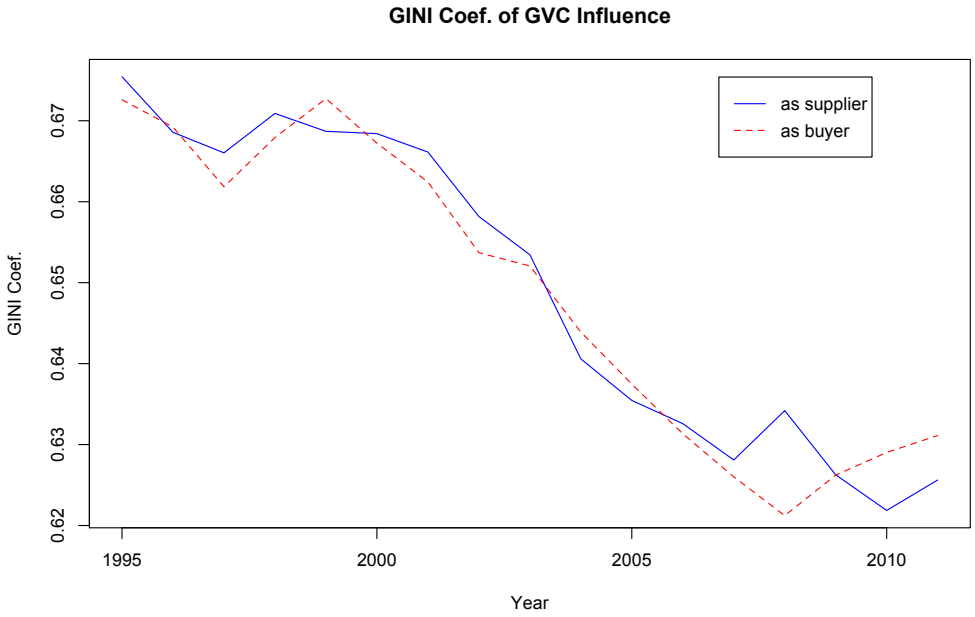
as Buyers



4.2.3 Stability and Contagion: GVC Vulnerability

During the sample years, the vulnerability of countries increases in general. Small economies normally have a high degree of GVC participation and are also more vulnerable in GVCs. The two measures of participation and vulnerability are highly correlated. As shown in Figure 20, the correlation coefficient between the two measures is greater than 0.9 at both the country and

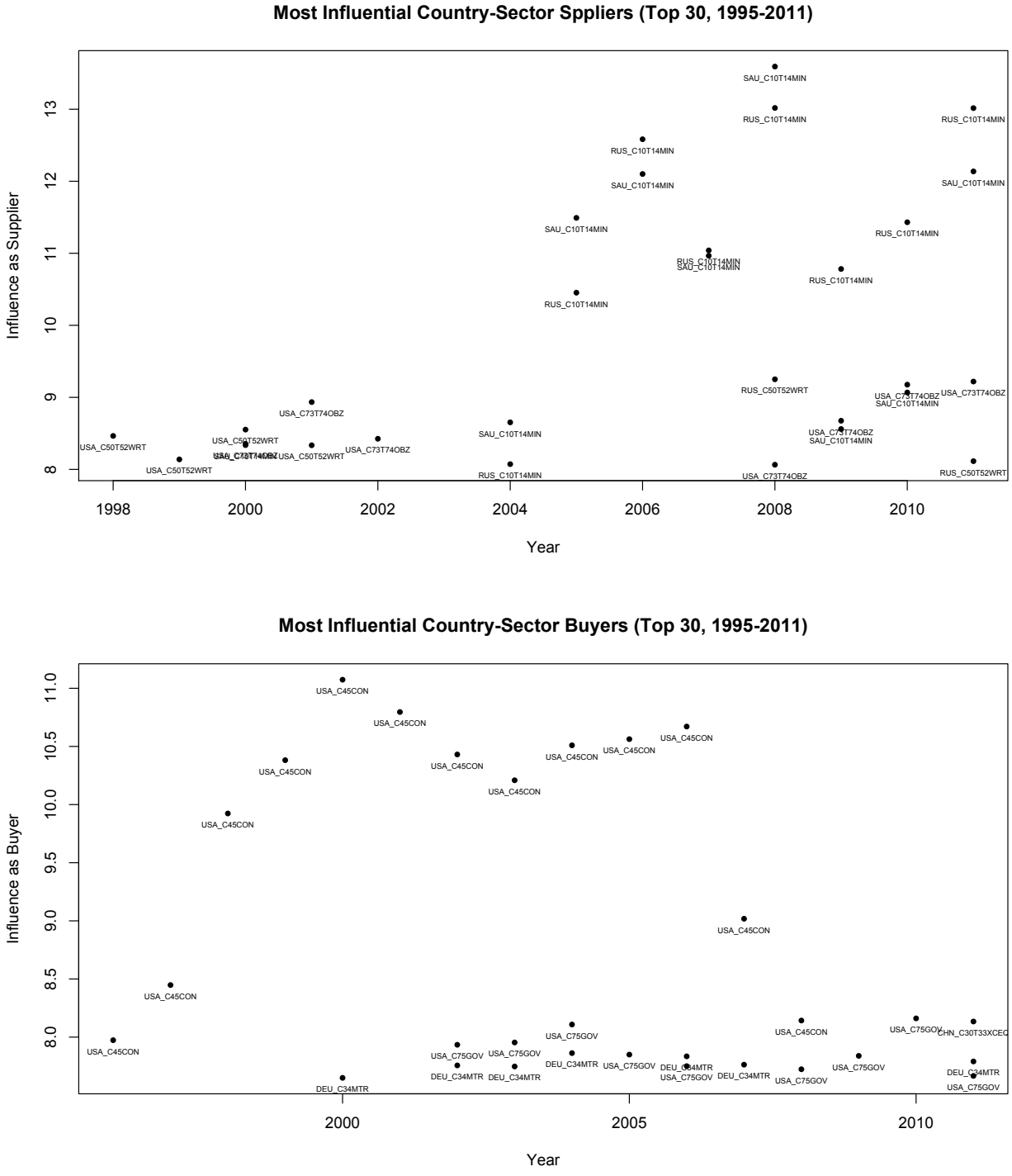
Figure 14: Gini Coefficient of GVC Influence Over Time



country-sector levels. Figure 17 reports the year-average vulnerability of the sample countries, and the pattern is very similar to Figure 10. Figure 18 shows how unbalanced the distribution of vulnerability in the system is. The GINI coefficient varies in the band between 0.4 and 0.55. In addition, the inequality of vulnerability fluctuates but does not have a substantial change over time.

Now we turn to analyze the correlation of the measures of participation, influence, and vulnerability and compare the GVC measures with some of their traditional counterparts. At the country level, influence is negatively correlated with participation and vulnerability, though the negative correlation is weak. This is because those that have more influence in GVCs are all big economies that have a relatively lower degree of GVC participation. Similar as at the country level, influence as buyer at the country-sector level is negatively correlated with all of the measures of participation and vulnerability, but influence as supplier is positively correlated with participation and vulnerability as supplier at the country-sector level. This may be partially explained by some of the characteristics of the industries. For example, sectors like Basic metals and Mining and quarrying mostly produce for meeting foreign production demand and have a concentrated buyer market; at the same time, their supply is important for global production and contribute a big share of value added directly or indirectly in final goods produced globally. Another interesting difference between the two

Figure 15: Most Influential Supplier (upper) or Buyers (lower) Country-Sectors



levels is that the correlation between influence as buyer and as supplier is very high (0.94) at the country level, but it is very weak at the country-sector level (0.19).

When comparing the GVC measures with some of the most-widely applied traditional measures of globalization based on the trade data, we find that the GVC measures are positively correlated with those traditional measures, but they are substantially different from the trade-data measures. Openness is the ratio of trade to GDP, and the data we use for comparison are from the World Bank. The two measures regarding integration in globalization are strongly correlated with the correlation coefficient as 0.79. Figure 21 shows the change of their correlation coefficient, and we can see that the difference between the two is enlarged over time. Figure 22 demonstrates the co-movement of participation and openness of the sample countries. For the majority of countries, their GVC participation moves almost in the same pace with their openness. There are two countries, Brunei Darussalam and Cyprus, whose GVC participation and openness move in the opposite directions.

Centrality in the global trade network is widely used as a measure of influence or importance in globalization (Benedictis et al., 2013). We use the data of centrality measures from CEPII for comparison, and the measures are based on a global trade network with countries as nodes and being among the top 3 trade partners as a tie. GVC Influence as buyer is highly correlated with GVC influence as supplier and the coefficient is 0.95. Similarly, in-degree centrality and out-degree centrality are highly correlated with the coefficient as 0.9. But GVC influence and degree centrality in trade network are only mildly correlated, and the correlation coefficient of supplier influence and out-degree centrality is only 0.36 and that of buyer influence and in-degree 0.44. The difference between the two measures are not surprising, since degree centrality is based on the volume of trade flows but the the GVC influence measures focus on value added to reflect the "importance" or "gain" of trade flows of intermediates. Finally, we compare the material capability indicated by using CINC from the COW database with GVC influence. We find that they are modestly correlated, and the coefficients of CINC with GVC influence as supplier, as buyer, and total influence are 0.62, 0.55, 0.59 respectively.

4.3 Interdependence and Power

In this subsection, we summarize the major findings of interdependence of participants in GVCs based on the measurement results of sensitivity dependence, vulnerability dependence and asymmetric interdependence. Note that power as a function of asymmetric interdependence is a dyadic and relational concept, different from the influence measure we discussed in the previous subsection. Power as asymmetric dependence is the power of actor i over

a specific actor j but not others in the system, but the influence of actor i is the power or importance of actor i in the GVC system, not necessarily over any specific actors.

Globalization has been deepening during the sample years, reflected by the steady increase of interdependence in both the sensitivity and vulnerability dimensions. The upper panel of Figure 23 demonstrates the upward trends of sensitivity and vulnerability interdependence over time. At the same time, asymmetry of interdependence is also enlarged with the increase of interdependence, as shown in the figures in the lower panel of Figure 23. Note that the scale of year-average asymmetry is larger than year-average interdependence simply because interdependence is averaged over directed dyads but asymmetry is averaged over undirected dyads in the same year.

Figure 24 visualizes the adjacency matrices of asymmetric interdependence. We rescale the data for better visualization by multiplying the variables with 10,000 and then taking the log of them. Each cell in the matrices is the degree of the asymmetry of interdependence between the row and the column countries. The darker the color, the more asymmetric the interdependence is. We define the legend as "power", simply meaning that the matrices are about whether and how much the row countries have power over the column countries. For any pair of countries, both parties can have power over each other, which can be represented by the sensitivity and vulnerability dependence measures. The asymmetry measures are about power differentials of the two parties. Therefore, the blank cells indicate that the row countries have no power over the column countries, but "no power" here only means that they are the relatively powerless in those dyadic relations.

Figure 24 presents two years (1995 and 2011) of the power distribution in the system as illustrations. We can see several interesting patterns in those adjacency matrices. First, the United States is the more powerful party in all of its dyadic relations in GVCs. The cells of the row of the United States are all colored (except the one in the diagonal), and the color of the cells is generally darker than other cells in the matrices. Secondly, there are a few countries that have absolutely no power over others. All blank are the rows representing Malta (MLT) and Cambodia (KHM) in the adjacency matrices of asymmetry of sensitivity interdependence in both 1995 and 2011, Brunei Darussalam (BRN) in the matrices of asymmetric vulnerability in 1995 and 2011. Thirdly, China is the country whose power over its production partner countries increases most impressively during the years. In 1995, it is the weaker party in most of its dyadic relations with OECD countries such as Australia, Austria, Belgium, Denmark, Israel, Italy and Spain. But in 2011, it becomes the powerful party in sensitivity and vulnerability interdependence over all the sample countries except the United States and Japan.

And the color of the cells also grows darker from 1995 to 2011. Fourthly, the structural power and the dyadic power are closely related, but they are substantially different. For example, Germany is the second most influential country in GVCs right after the United States, but its dyadic power is not so outstanding—it has less bargaining power when interacting with France, Japan, the United States, China, and India in 2011.

Figure 25 is a scatter plot of sensitivity and vulnerability dependence of directed country dyads on average. The upper panel is the complete plot, and in the lower panel we zoom in the lower-left cloud of country dyads in the upper panel. Among all the dyads, Brunei Darussalam most heavily depends on Japan in GVCs in both the sensitivity and vulnerability dimensions. Canada on the US is the directed relationship with the second highest sensitivity dependence, and it is vulnerability dependence on the US is also among the top ten. Besides Canada, countries like Mexico, Ireland, Singapore, and Costa Rica also highly depend on the US in the sensitivity dimension, which means that shocks to the US would cause large fluctuations to those countries. Small economies such as Luxembourg, Estonia, Czech Republic, and Ireland, are highly dependent on large European economies like Germany, the Great Britain, and France in the sensitivity dimension. In the vulnerability dimension, Brunei Darussalam is the country with highest dependence on its production partners. Norway, Luxembourg, and Saudi Arabia are among the top countries that are highly vulnerable in their interdependence with their partners. Most of the strong dependence occurs in dyads that are in the same geographical region, implying that regionalization of production activities is a driver of globalization. An exception is the United States whose production partners that are strongly depend on it are all over the world, which further highligts the status of the United States as the global superpower in GVCs.

We look more closely into the dyad of China and the United States. As shown in Figure 26, China's sensitivity dependence on the US increases from 1995 to 2007 and decreases afterwards. The supplier and buyer curves move almost in parallel, and the supplier curve globally dominates the buyer curve, demonstrating that China's sensitivity dependence on the US as supplier is stronger than as buyer. On the other hand, the sensitivity dependence of the US on China increases over time except between 2008-2009, and its sensitivity dependence on China as buyer is stronger than as supplier. Similar patterns can be observed in the time series of vulnerability interdependence between China and the US. The scales of the US graphs are much smaller than those of the China graphs, and the dependence of US on China is much lower than that of China on US. The graphs at the lower panel of Figure 26 are about asymmetry of interdependence between the two countries. For both types of interdependence,

the US is the less dependent party and has more bargaining power over China. The power of the US over China first increases from 1995 to 2007, and then rapidly declines since 2007. Over all, the economic interdependent relationship between the US and China reflected by GVCs , shows that the US is the more powerful party, but China's power over the US grows rapidly in recent years, and there seems to have a power shift between the two.

Table 2 reports the top 30 directed dyads whose dependence or asymmetry of interdependence changes most rapidly. For sensitivity dependence, we can see that countries become less dependent of the traditional GVC powers, such as the United States, Japan, and the Great Britain, but increasingly depend on emerging economies represented by China, Russia, and India. Thirteen out of thirty dyads with the fastest increasing sensitivity dependence are dyads involving China, compared to that 10 out of 30 dyads with the most rapidly decreasing sensitivity dependence involves the US. Many countries become less vulnerable in their interdependence with the United States, but more vulnerable to China. Table 3 records the top 30 dyads whose asymmetry of interdependence changes most rapidly. China enjoys the most stunning increase in its power over many other countries. The power of the "Rest of the World" as a whole, also increases in a fast speed. In addition, India's power rises fast over many other countries. The power of the US is in a rapid decline over many of its partner countries, and so is Japan.

5 An Empirical Application: GVC Dependence and Political Risk of FDI

This research generates original time-series cross-sectional data of value added trade of intermediates, which can have a wide range of potential applications in IPE/IR studies regarding GVCs, globalization, and economic interdependence. Because GVCs are the most prominent feature of today's globalization, it is urgent to deepen our understandings of GVCs. Our data and measures can be used to describe and explain changes of the structure and process of GVCs. We use part of the information contained in the data to construct measures to map GVCs, but there is much more could be done by fully exploring the data. At the same time, GVCs have profound impacts in almost all aspects of international political economy, and a wide range of IPE research questions have been re-investigated from the perceptive of GVCs. The data we generated on GVC participation, structural influence and vulnerability, and interdependence can be used to explain the political consequences of GVCs. Furthermore, our interdependence measures and the original data on $\mathbf{A}$, $\mathbf{B}$, $\hat{\mathbf{V}}\mathbf{B}$, $\hat{\mathbf{V}}\mathbf{B}\mathbf{Y}$ can be used to construct

Table 2: Most Rapidly Increasing or decreasing Dependence in GVCs

Rank	Sen. Dep.		Vul. Dep.	
	Decreasing	Increasing	Decreasing	Increasing
1	SGP→USA	TWN→CHN	BRN→THA	BRN→IDN
2	SGP→JPN	BRN→IDN	BRN→SGP	BRN→NZL
3	EST→FIN	MYS→CHN	CAN→USA	BRN→AUS
4	MYS→JPN	KOR→CHN	SGP→USA	BRN→CHN
5	CAN→USA	VNM→CHN	CRI→USA	BRN→IND
6	PHL→USA	KHM→CHN	MYS→USA	BRN→JPN
7	SVK→CZE	SGP→CHN	BRN→TWN	SAU→JPN
8	VNM→JPN	HKG→CHN	LUX→BEL	SAU→USA
9	IDN→JPN	THA→ROW	MYS→SGP	BRN→KOR
10	CYP→GBR	LUX→GBR	BRN→USA	SAU→IND
11	MYS→USA	THA→CHN	SVK→CZE	SAU→CHN
12	LUX→BEL	CHL→CHN	MYS→JPN	BRN→ROW
13	CRI→USA	SAU→CHN	SGP→JPN	TWN→CHN
14	MEX→USA	BRN→CHN	IRL→GBR	BRN→VNM
15	PHL→JPN	MYS→ROW	IDN→JPN	SAU→KOR
16	BRN→THA	BRN→NZL	VNM→SGP	SAU→ROW
17	MLT→FRA	SVN→ROW	LUX→NLD	MYS→CHN
18	TWN→USA	PHL→CHN	CYP→GBR	LUX→IRL
19	IRL→GBR	BRN→IND	MLT→SGP	SGP→CHN
20	CYP→USA	IND→ROW	SGP→MYS	NOR→GBR
21	IDN→USA	HRV→RUS	CAN→JPN	SAU→TWN
22	EST→ROW	SVK→ROW	LUX→FRA	KOR→CHN
23	MLT→USA	SAU→ROW	BRN→HKG	BRN→MYS
24	RUS→ROW	SAU→IND	EST→FIN	BRN→ESP
25	LTU→DEU	TUN→ROW	IDN→USA	SAU→IDN
26	KHM→THA	TWN→ROW	CRI→ROW	CHL→CHN
27	BRN→JPN	KOR→ROW	PHL→USA	SAU→THA
28	IRL→JPN	BRN→AUS	MYS→GBR	HKG→CHN
29	NZL→JPN	PER→CHN	RUS→ROW	VNM→CHN
30	LUX→NLD	MYS→IDN	IDN→SGP	LUX→GBR

Table 3: Most Rapidly Increasing or decreasing Dependence in GVCs

Rank	Asymmetry of Sen. Dep.		Asymmetry of Vul. Dep.	
	Increasing	Decreasing	Increasing	Decreasing
1	CHN-KOR	USA-SGP	IDN-BRN	THA-BRN
2	CHN-TWN	JPN-SGP	NZL-BRN	SGP-BRN
3	IDN-BRN	FIN-EST	AUS-BRN	USA-CAN
4	CHN-MYS	USA-CAN	CHN-BRN	SAU-IDN
5	CHN-VNM	JPN-MYS	IND-BRN	USA-SGP
6	CHN-HKG	USA-PHL	JPN-BRN	USA-CRI
7	CHN-KHM	JPN-IDN	JPN-SAU	USA-MYS
8	CHN-SGP	JPN-VNM	CHN-TWN	BEL-LUX
9	CHN-THA	GBR-CYP	USA-SAU	TWN-BRN
10	CHN-DEU	USA-MYS	KOR-BRN	USA-BRN
11	GBR-LUX	BEL-LUX	CHN-SAU	GBR-IRL
12	ROW-THA	USA-MEX	IND-SAU	CZE-SVK
13	CHN-AUS	USA-CRI	SAU-TWN	JPN-MYS
14	CHN-CHL	CZE-SVK	ROW-BRN	SGP-IRL
15	CHN-BRN	JPN-PHL	VNM-BRN	JPN-IDN
16	ROW-MYS	THA-BRN	CHN-KOR	JPN-SGP
17	ROW-SVN	FRA-MLT	ROW-SAU	SGP-VNM
18	IND-BRN	GBR-IRL	KOR-SAU	SAU-THA
19	ROW-SVK	USA-TWN	CHN-MYS	NLD-LUX
20	RUS-HRV	JPN-CHN	CHN-SGP	ZAF-SAU
21	CHN-PHL	ROW-RUS	TWN-SAU	GBR-CYP
22	NZL-BRN	USA-CYP	IRL-LUX	SGP-MLT
23	CHN-SAU	USA-IDN	GBR-NOR	FRA-LUX
24	ROW-TUN	ROW-EST	IDN-SAU	JPN-CAN
25	ROW-TWN	JPN-ROW	KHM-BRN	SAU-PHL
26	AUS-BRN	USA-MLT	MYS-BRN	HKG-BRN
27	ROW-SAU	DEU-LTU	ESP-BRN	USA-IDN
28	CHN-PER	JPN-BRN	CHN-CHL	SAU-ZAF
29	CHN-GBR	THA-KHM	TUR-RUS	FIN-EST
30	CHN-FRA	JPN-IRL	CHN-HKG	SAU-BEL

Note: The country on the left-hand side is the one that depends less in the dyad.

adjacency matrices for spatial regressions to explain or control for spatial dependence and contagion in globalization. In addition, the measures of asymmetric interdependence we propose in this paper may be applied to empirically test theories regarding political implications of economic interdependence and help settle great debates such as economic interdependence and military conflicts (Mansfield and Pollins, 2003; Maoz, 2009).

In this section, we apply the data to study how GVCs affect political risk of FDI as an empirical illustration. [We will add another example of economic interdependence and military conflict later.]

Global value chains and foreign direct investment are intrinsically linked together, and the recent literature on FDI demonstrates strong research interest in GVCs. In a seminal study, Johns and Wellhausen (2016) proposes an "under a common roof" theory and argues that the connections between foreign and domestic firms in production networks create an informal insurance against contract breach by states. However, the "under a common roof" theory is insufficient to explain why some common roofs are more risk-proof than others, given the fact that almost all multinationals have their local partner firms and common roofs are too common to foreign firms. GVC dependence in the "under a common roof" theory should be conceptualized and operationalized by focusing on the gain dimension of interdependence, since the key in the logic of the theory is the opportunity cost of disrupting a relationship. At the firm level, whether domestic firms under a common roof would fight for their foreign partners depends on their vulnerability dependence on the foreign firms. If substitutes are ease to find, the domestic firms would prefer to flee the common roof rather than standing with their foreign partners against the host government. At the macro level, vulnerability dependence of the host country on a foreign sector in GVCs is important to analyze the incentive of the host government to protect property rights of foreign firms. In the era of globalization featured by GVCs, there is a tension faced by the host government "between the need for promotion of foreign investment on one hand and the appropriate regulatory powers of the state to protect society on the other [p.6]."(Moehlecke, 2017) What kind of FDI is particularly protected partially depends on the national gain of the host country. As Mayer and Phillips (2017) points out, "the core complexity of state agency and state power needs to be much more carefully understood in GVC and related debates, as a basis on which the governance of the evolving GVC world can be properly theorised as revolving around the inseparability of economic and political power."

We construct a GVC measure of asymmetry of sensitivity and vulnerability dependence of countries on country-sectors as GVC supplier to re-investigate the impact of GVCs to political

risk of foreign direct investment by focusing on the causal mechanism of the opportunity cost of disrupting the investment relationship. Figure 27 shows the asymmetry of vulnerability interdependence between the host country and two selected foreign country-sectors.

As for the dependence variable of political risk of FDI, we use ISDS filings as a proxy of the risk of contract breach. ISDS is a costly method for firms to settle disputes with host governments, and is often recommended to be used as the last resort. The cost for firms to file ISDS cases includes the litigation cost, time, retaliations by the sued government, risk of losing the market, and fail to get a sufficient compensation, and so on (Wellhausen, 2016a, pp.2-3). Then ISDS filings indicate high risk of expropriation, including that the host government has a high propensity to take expropriatory actions and that it is difficult for the firm to solve a dispute in a less costly way. Our theory suggests that vulnerability dependence of the host country on a foreign country-sector would offer advantages for firms to prevent expropriation from occurring and to settle disputes with the host government in a less costly way than filing ISDS cases. The ISDS database records ISDS cases involving 73 home country, 124 host country, and 9 industries. The database uses a more aggregate criterion to define industries than ICIO. Therefore, we use additional firm-level information to match industries in ISDS database with ICIO database. The number of fillings varies widely across industries.

The data are time-series cross-sectional, and observations would be clustered in many different ways. We use multilevel modeling to control for possible heterogeneities in multiple dimensions. There are several control variables that we include in the regression analysis, and whose variables are reported in the Appendix. Table 4 reports the four models we estimate. `Model 1` is the simplest model including GVC Vulnerability Dependence and random intercepts. In `Model 2`, we add variables of macro institutional arrangements set by host-home country negotiations, represented by `BIT` and `PTA`. Then we further increase the number of control variables by adding host-country time-varying control variables into `Model 3`. And `Model 4` further adds control variables of economic and political gaps between host and home countries. The effect of GVC Vulnerability Dependence on ISDS filing is negative and statistically significant at the 5% significance level, which confirms the theory that GVC dependence of the host country reduces political risk of FDI. Table 5 reposts models with asymmetry of sensitivity interdependence as the primary explanatory variable. And the regression results show that the more bargaining power the country-sector from which the foreign firm comes from, the less likely the firm will be in a situation that it has to choose ISDS to settle disputes with the host government.

This application illustrates that the data can be used to construct cross-level economic

Table 4: Empirical Results Based on Vulnerability Asymmetry Dependence

	Dependent Variable: ISDS Filing			
	Model1	Model 2	Model 3	Model 4
Vuln. AD	−0.029***	−0.029***	−0.032***	−0.044***
	(0.005)	(0.005)	(0.006)	(0.007)
BIT		0.00000	−0.00002	0.00002
		(0.00002)	(0.00002)	(0.00002)
PTA		0.00000	0.00004	−0.00002
		(0.00002)	(0.00002)	(0.00003)
Political Stability			−0.0002***	−0.0002***
			(0.00003)	(0.00004)
Regime Type			0.00002***	0.00002***
			(0.00000)	(0.00000)
Rule of Law			−0.0001***	−0.0001*
			(0.00002)	(0.00004)
Corruption			0.00002	0.0003**
			(0.0001)	(0.0001)
Population			0.00004***	0.0001***
			(0.00001)	(0.00001)
GDPpc			−0.00004	0.0003***
			(0.00002)	(0.00003)
Democracy Gap				−0.00000
				(0.00000)
Rule of Law Gap				−0.00004
				(0.00003)
Corruption Gap				−0.0003***
				(0.0001)
Economic Gap				−0.00000***
				(0.000)
Constant	0.0001***	0.0001***	0.0004	−0.002***
	(0.00003)	(0.00003)	(0.0003)	(0.0003)
Industry Effect	*Yes*	*Yes*	*Yes*	*Yes*
Year Effect	*Yes*	*Yes*	*Yes*	*Yes*
Observations	2,627,612	2,627,612	1,829,900	1,421,485
Log Likelihood	8,211,693.000	8,211,673.000	5,538,035.000	4,315,844.000
Akaike Inf. Crit.	-16,423,377.000	-16,423,333.000	-11,076,043.000	-8,631,655.000
Bayesian Inf. Crit.	-16,423,313.000	-16,423,243.000	-11,075,882.000	-8,631,448.000

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5: Empirical Results Based on Sensitivity Asymmetry Dependence

	Dependent Variable: ISDS Filing			
	Model 1	Model 2	Model 3	Model 4
Sens. AD	−0.003***	−0.003***	−0.004***	−0.005***
	(0.0003)	(0.0003)	(0.0005)	(0.001)
BIT		0.00000	−0.00002	0.00002
		(0.00002)	(0.00002)	(0.00002)
PTA		−0.00001	0.00002	−0.00005*
		(0.00002)	(0.00002)	(0.00003)
Political Instability			−0.0001***	−0.0002***
			(0.00003)	(0.00004)
Regime Type			0.00002***	0.00002***
			(0.00000)	(0.00000)
Rule of Law			−0.0001***	−0.0001**
			(0.00002)	(0.00004)
Corruption			0.00003	0.0003**
			(0.0001)	(0.0001)
Population			0.00002***	0.00003***
			(0.00001)	(0.00001)
GDPpc			−0.0001**	0.0002***
			(0.00002)	(0.00003)
Democracy Gap				−0.00000
				(0.00000)
Rule of Law Gap				−0.00004
				(0.00003)
Corruption Gap				−0.0004***
				(0.0001)
Economic Gap				−0.00000***
				(0.000)
Constant	0.0001***	0.0001***	0.001**	−0.002***
	(0.00003)	(0.00003)	(0.0003)	(0.0003)
Industry Effect	*Yes*	*Yes*	*Yes*	*Yes*
Year Effect	*Yes*	*Yes*	*Yes*	*Yes*
Observations	2,627,612	2,627,612	1,829,900	1,421,485
Log Likelihood	8,211,706.000	8,211,686.000	5,538,048.000	4,315,869.000
Akaike Inf. Crit.	-16,423,402.000	-16,423,358.000	-11,076,070.000	-8,631,704.000
Bayesian Inf. Crit.	-16,423,338.000	-16,423,268.000	-11,075,908.000	-8,631,497.000

Note: *p<0.1; **p<0.05; ***p<0.01

interdependence. Multinationals are important actors in globalization, and it is important to measure the bargaining power of multinationals over the host countries to understand firms' decisions and behaviors of investment and national policies of FDI. But bargaining power in dyadic relationships between a state and a non-state actors is challenging to measure, and theories and hypotheses regarding FDI in IPE studies can only be indirectly tested without good measures of relative bargaining power based on asymmetric interdependence. The data of value added trade of intermediates and the measures of interdependence we generate can be used to improve our understanding of globalization in a more pluralist way.

6 Conclusion

This paper generates an original dataset of value-added connectivity at the country-sector and national levels by analyzing the complex data of Inter-Country Input-Output Tables, and constructs new measures of the structure and process of globalization. We apply the revised Leontief Decomposition method to trace original sources of value added in the global production network, and treat the GVC system as a dynamic network with value added continuously generated and distributed with flows of intermediate inputs throughout the system. The measures based on the value added data reveal that globalization has been expanding and deepening over the sample years, but the system of globalization is highly hierarchical and interdependence is unbalanced. Most of the structural influence is concentrated in a very few large economies, and the inequality of influence is extremely high. At the same time, asymmetric interdependence grows with the level of interdependence. Partners in the global production network are in increasingly unequal relations, in the sense that one party in the dyadic relationship is more sensitive and vulnerable than the other. it is worth mentioning that China is the country whose structural and dyadic power increases most rapidly over the sample years. And there is a noticeable trend of "the decline of the West, and the rise of the Rest" during the years from 1995 to 2011. The data and measures could have a wide range of potential applications in IR/IPE studies regarding GVCs, globalization, and economic interdependence. As an example, we show in this paper that the data and measures can be used to tackle the challenging problem of measuring bargaining power of non-state actors (multinationals) over the state and test hypothesis about cross-level interdependence and political risk of FDI. With the prospect that ICIO databases will be quickly expanded in their coverage and improved in their quality, we will update and expand our data and measures in a timely manner for empirical applications.

A Sample Countries and Sectors in ICIO Database

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Table 6: Sample Countries

OECD Countries		Non-OECD Economies	
ISO Code	Country	ISO Code	Country
AUS	Australia	ARG	Argentina
AUT	Austria	BRA	Brazil
BEL	Belgium	BRN	Brunei Darussalam
CAN	Canada	BGR	Bulgaria
CHL	Chile	KHM	Cambodia
CZE	Czech Republic	CHN	China
DNK	Denmark	TWN	Chinese Taipei
EST	Estonia	COL	Colombia
FIN	Finland	CRI	Costa Rica
FRA	France	HRV	Croatia
DEU	Germany	CYP	Cyprus
GRC	Greece	HKG	Hong Kong SAR
HUN	Hungary	IND	India
ISL	Iceland	IDN	Indonesia
IRL	Ireland	LTU	Lithuania
ISR	Israel	MYS	Malaysia
ITA	Italy	MLT	Malta
JPN	Japan	MAR	Morocco
KOR	Korea	PER	Peru
LVA	Latvia	PHL	Philippines
LUX	Luxembourg	ROU	Romania
MEX	Mexico	RUS	Russian Federation
NLD	Netherlands	SAU	Saudi Arabia
NZL	New Zealand	SGP	Singapore
NOR	Norway	ZAF	South Africa
POL	Poland	THA	Thailand
PRT	Portugal	TUN	Tunisia
SVK	Slovak Republic	VNM	Viet Nam
SVN	Slovenia	ROW	Rest of the world
ESP	Spain		
SWE	Sweden		
CHE	Switzerland		
TUR	Turkey		
GBR	United Kingdom		
USA	United States		

Note: In the original ICIO database, data for China and Mexico are further split into several subsets. The China table is split into four—Domestic sales only, Processing goods exporters, Non processing goods exporters, and Services (including utilities & construction), and the Mexico table is split into three—Non-Global Manufacturing, Global Manufacturing, and Services (including utilities & construction). For the purpose of our analysis, we merge those split data and only look at the total IOTs of China and Mexico.

Table 7: Sample Sectors

ISIC Rev.2 Code	Sector
C01T05AGR	Agriculture, hunting, forestry and fishing
C10T14MIN	Mining and quarrying
C15T16FOD	Food products, beverages and tobacco
C17T19TEX	Textiles, textile products, leather and footwear
C20WOD	Wood and products of wood and cork
C21T22PAP	Pulp, paper, paper products, printing and publishing
C23PET	Coke, refined petroleum products and nuclear fuel
C24CHM	Chemicals and chemical products
C25RBP	Rubber and plastics products
C26NMM	Other non-metallic mineral products
C27MET	Basic metals
C28FBM	Fabricated metal products
C29MEQ	Machinery and equipment, nec
C30T33XCEQ	Computer, Electronic and optical equipment
C31ELQ	Electrical machinery and apparatus, nec
C34MTR	Motor vehicles, trailers and semi-trailers
C35TRQ	Other transport equipment
C36T37OTM	Manufacturing nec; recycling
C40T41EGW	Electricity, gas and water supply
C45CON	Construction
C50T52WRT	Wholesale and retail trade; repairs
C55HTR	Hotels and restaurants
C60T63TRN	Transport and storage
C64PTL	Post and telecommunications
C65T67FIN	Financial intermediation
C70REA	Real estate activities
C71RMQ	Renting of machinery and equipment
C72ITS	Computer and related activities
C73T74OBZ	R&D and other business activities
C75GOV	Public admin. and defence; compulsory social security
C80EDU	Education
C85HTH	Health and social work
C90T93OTS	Other community, social and personal services
C95PVH	Private households with employed persons

Table 8: Variables,Measures and Data Sources

Variable	Definition	Measure	Data Source
Vulnerability AD	Asymmetric Value Added Dependence based on Vulnerability	Percentage	Inter-Country Input Output table(ICIO)
Sensitivity AD	Asymmetric Value Added Dependence based on Sensitivity	Percentage	Inter-Country Input Output table(ICIO)
ISDS Finding	Whether a country-sector from which a foreign firm files an ISDS again a host government	1 for Yes; 0 for No	Wellhausen (2016b)
BIT	Is there a bilateral investment treaty signed between the host and home countries	1 for Yes; 0 for No	Database of Bilateral Investment Treaties(ICSID)
PTA	Is there a preferential trade agreement signed between the host and home countries	1 for Yes; 0 for No	Design of Trade Agreements (DESTA) Database
Population	Population of the host country	Million	International Monetary Fund(IMF) Database
GDPpc	GDP per capita of the host country	Current US dollar	International Monetary Fund(IMF) Database
Rule of Law	Judiciary independence of the host country	From 0 (lowest) to 16 (highest)	Freedom Houses Annual Report
Corruption	How corrupt is the host government	From 0(not corrupt) to 100 (highly corrupt)	Corruption Perceptions Index (CPI)Database
Political Instability	Political Instability of the host country	From 0(least unstable) to 10(most unstable)	Bertelsmann Stiftungs Transformation Index (BTI)Database
Regime Type	How democratic is the host government	From -10(least democratic) to 10(most democratic)	Integrated Network for Societal Conflict Research (INSCR)Database
Economic Gap	Difference of GDP per capita between the host and home countries	GDP per capita of the host country minus that of the home country	
Gap of Rule of Law	Difference of Rule of Law between the host and home countries	Rule of law score of the host country minus that of the home country	
Corruption Gap	Difference of corruption between the host and home countries	Corruption index of the host country minus that of the home country	
Democracy Gap	Difference of Regime Types Between the host and home countries	the host country minus that of the home country	

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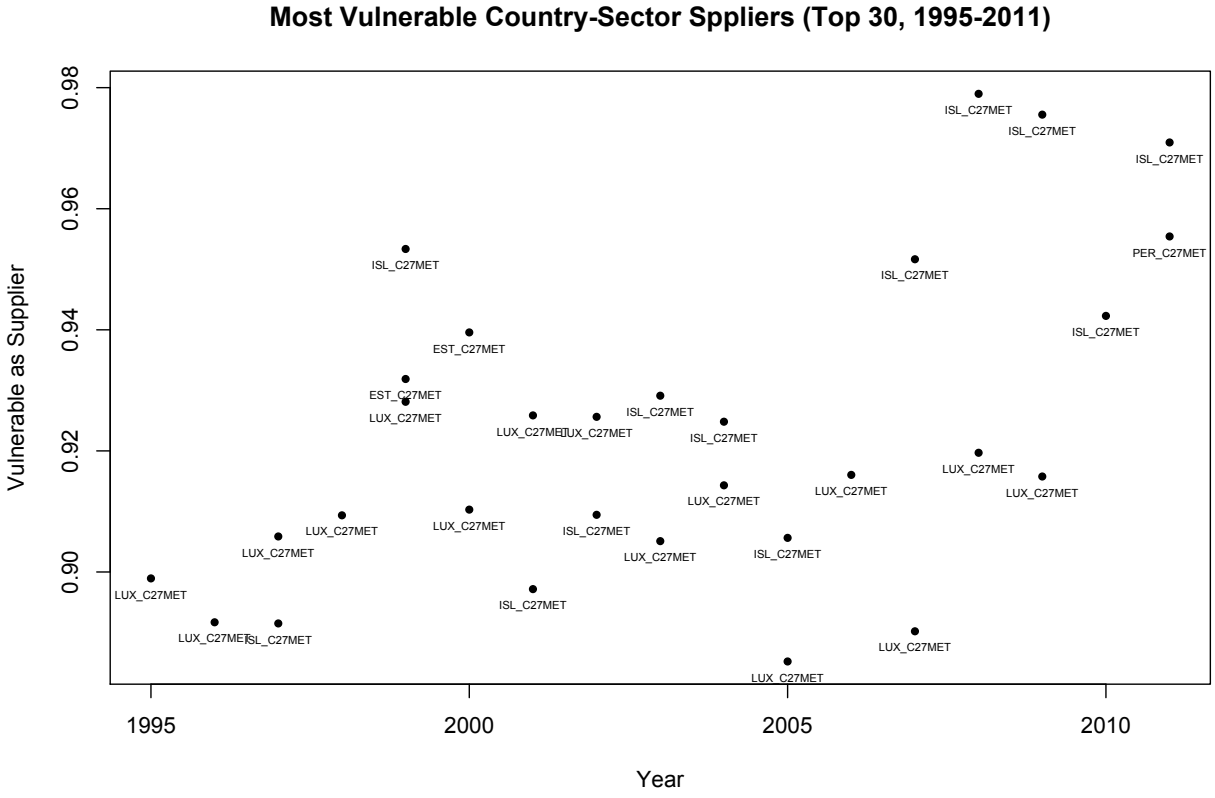
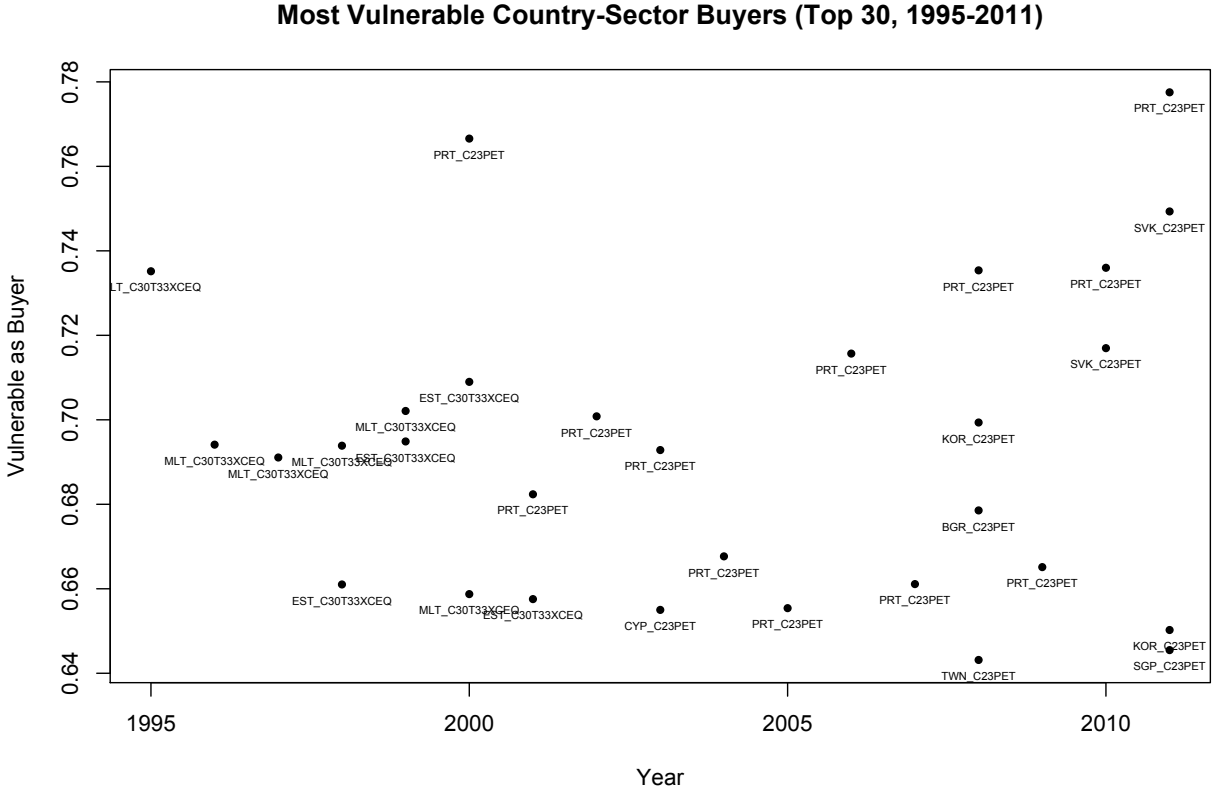
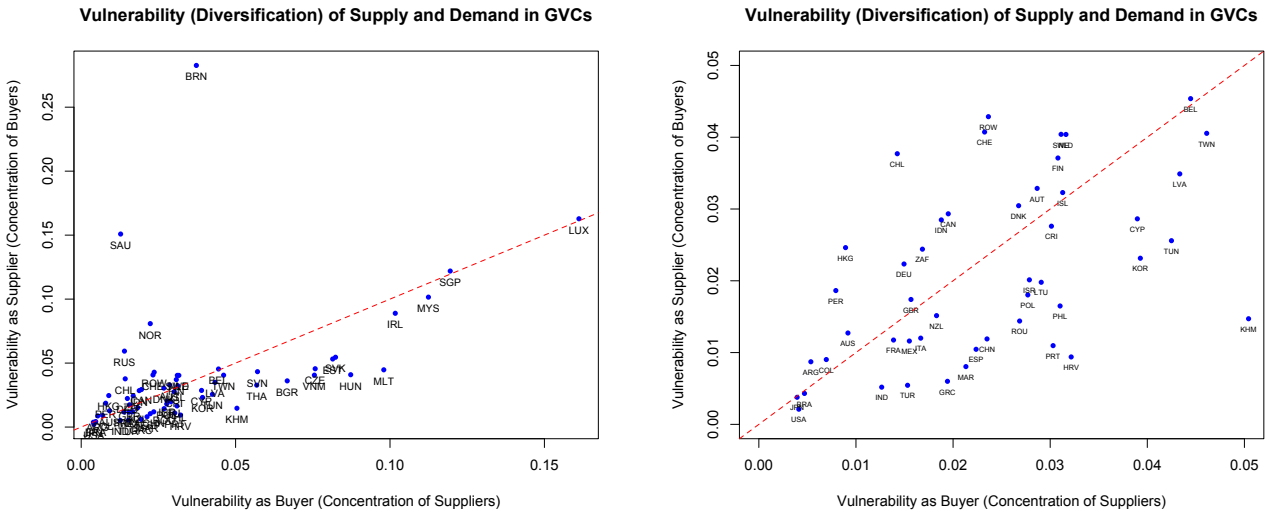
Figure 16: Most Vulnerable Supplier (upper) or Buyers (lower) Country-Sectors





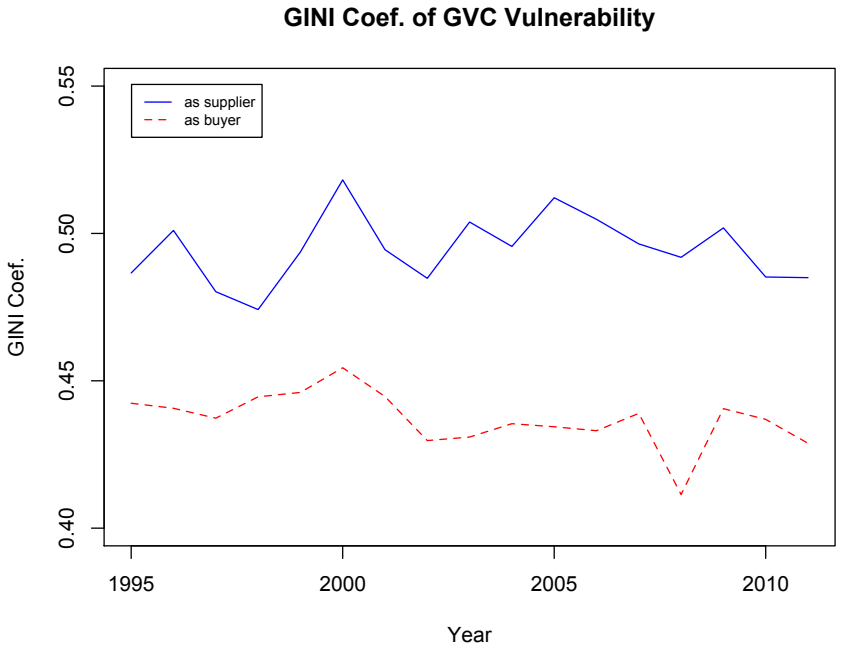
Note:

Figure 17: Vulnerability (Year Average)



Note:

Figure 18: Vulnerability (Year Average)



Note:

Figure 19: Correlation of Participation, Influence, and Vulnerability

Coutry Level

Country-Sector Level

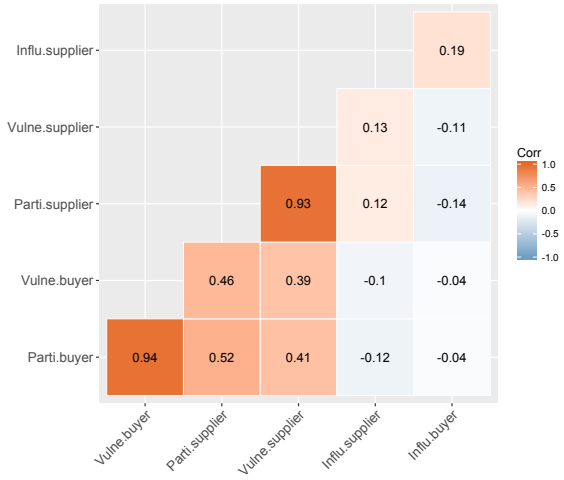


Figure 20: Correlation of Participation, Influence, and Vulnerability

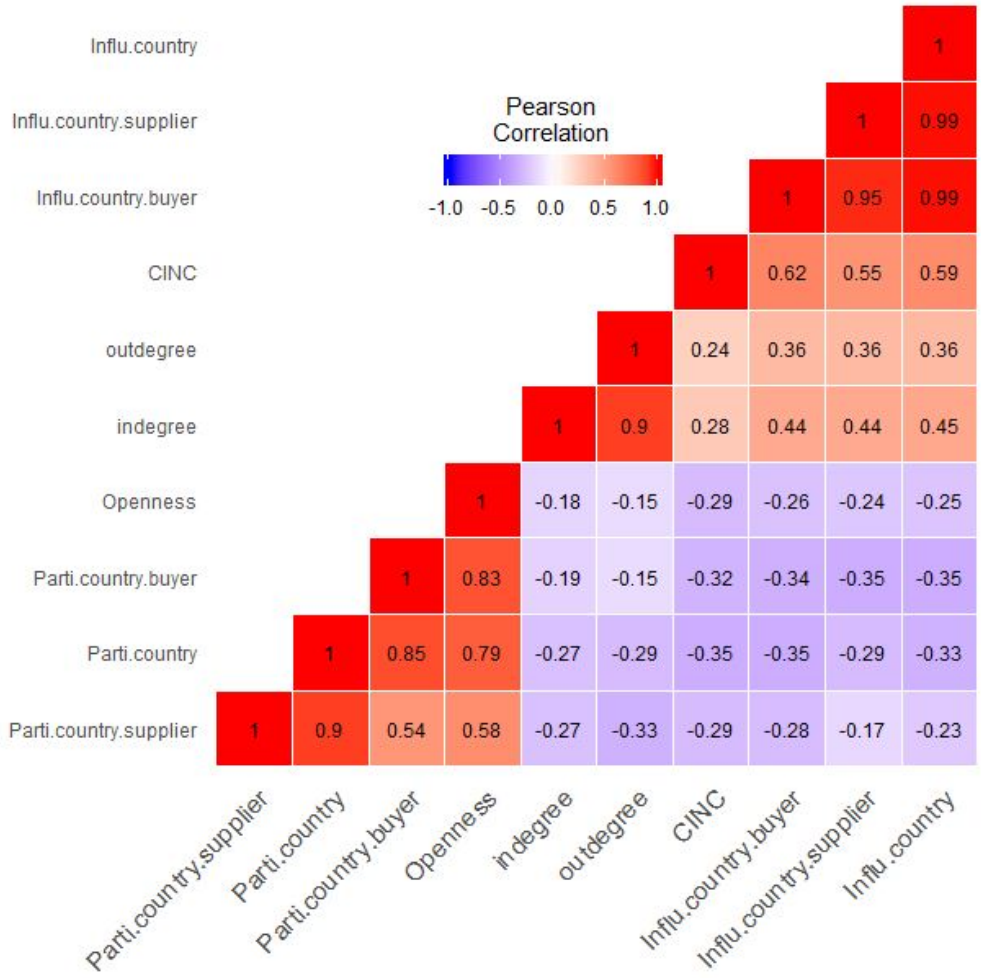


Figure 21: Correlation of Participation and Openness

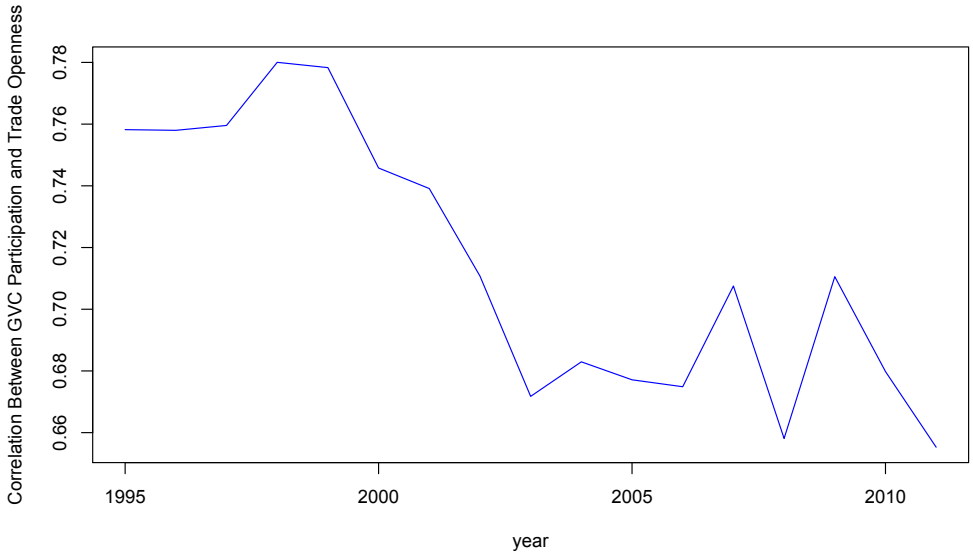


Figure 22: Correlation of Participation and Openness

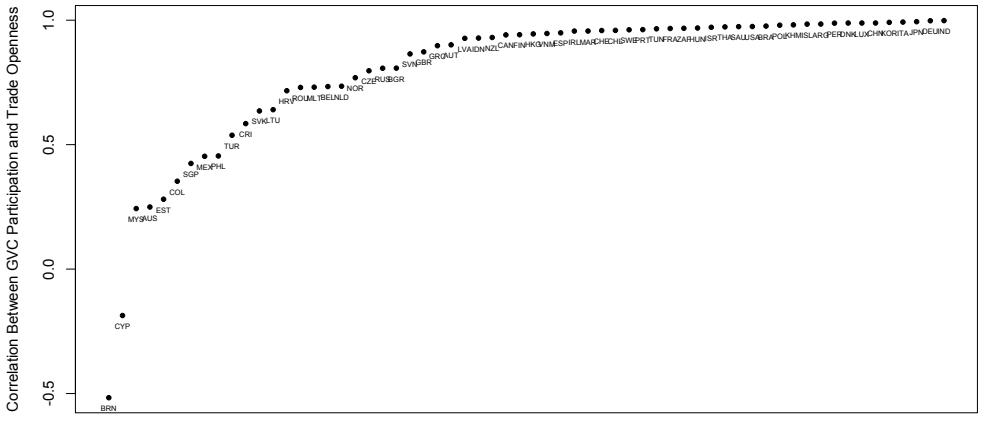
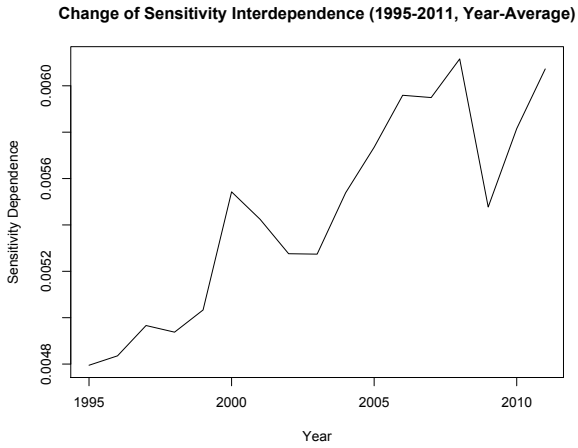
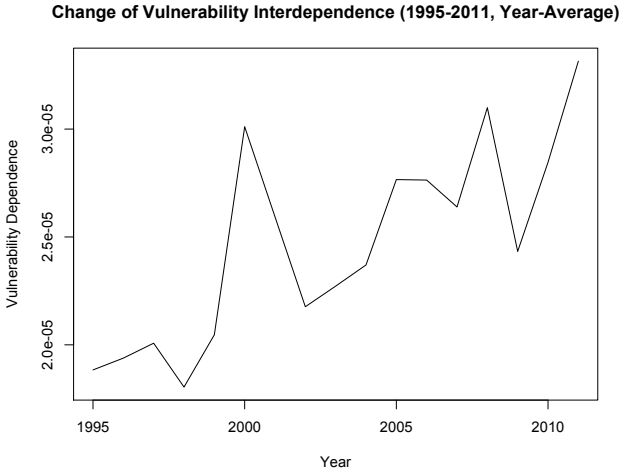
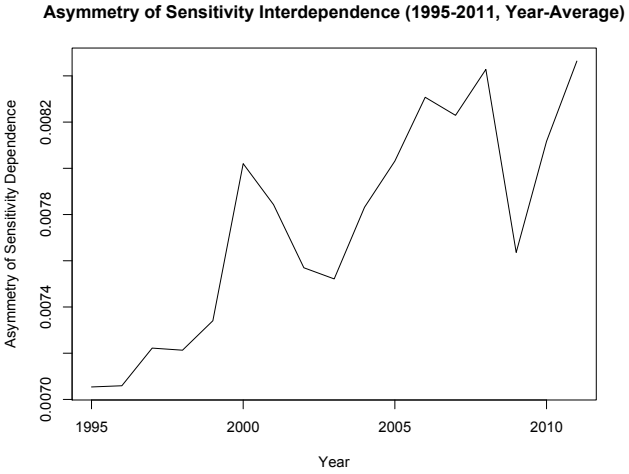


Figure 23: Asymmetry of Sensitivity and Vulnerability Interdependence







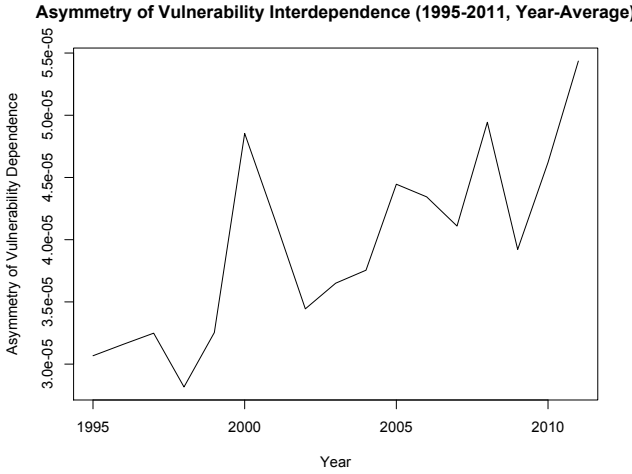
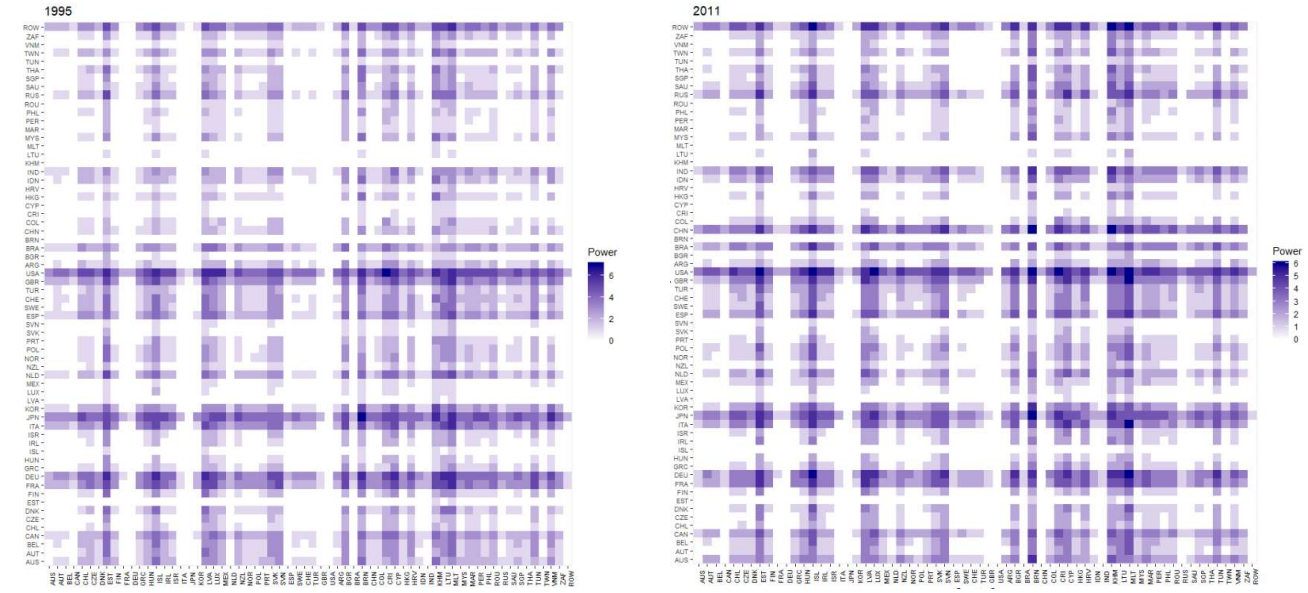


Figure 24: Asymmetry of Sensitivity and Vulnerability Interdependence

Asymmetric Sensitivity Interdependence



Asymmetric Vulnerability Interdependence

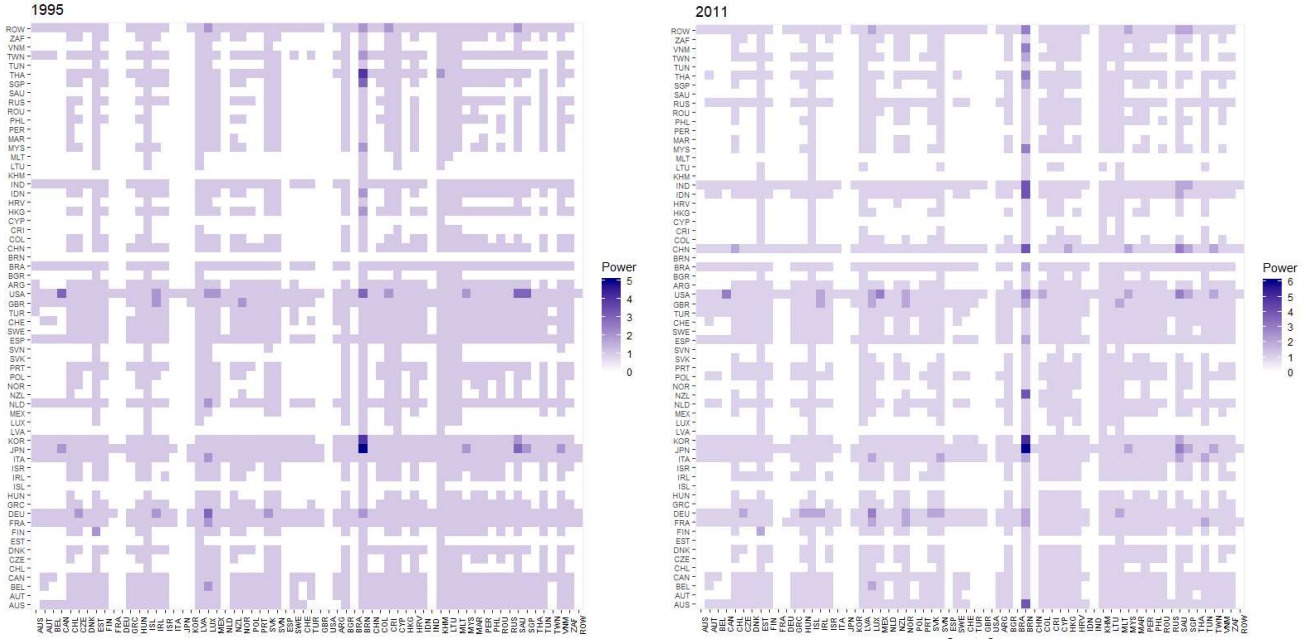
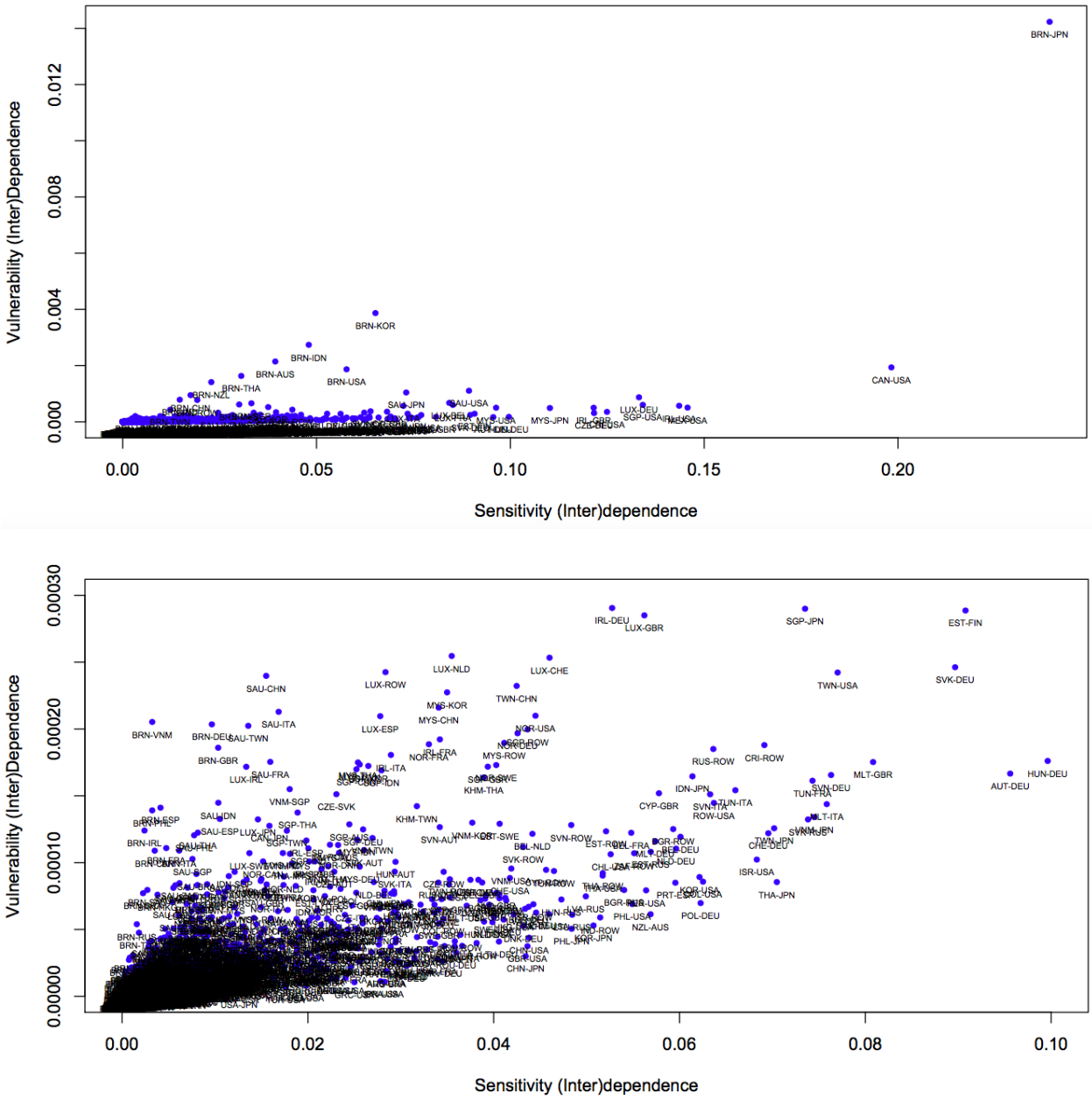
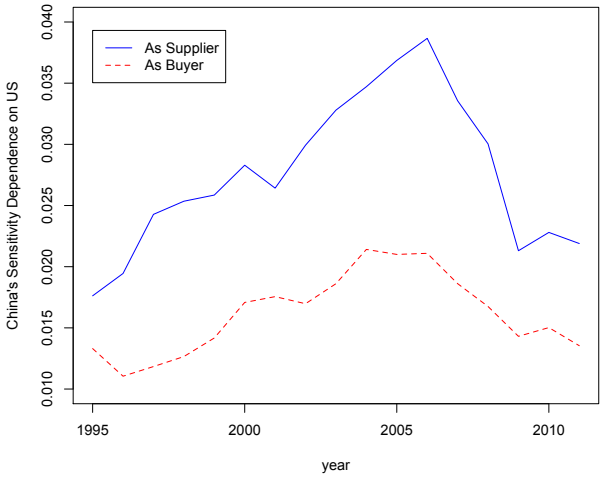


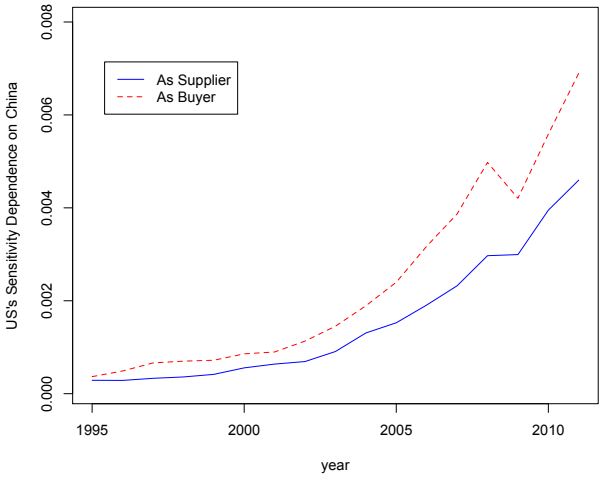
Figure 25: Interdependence (Year Average)

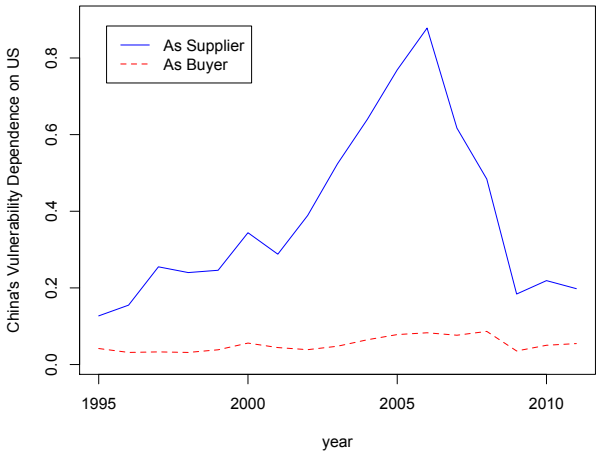


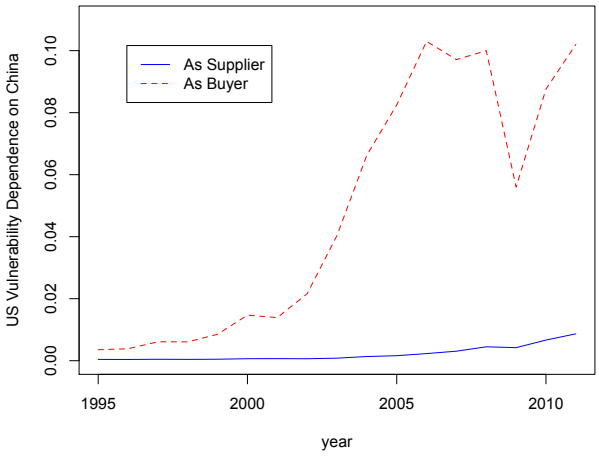
Note:

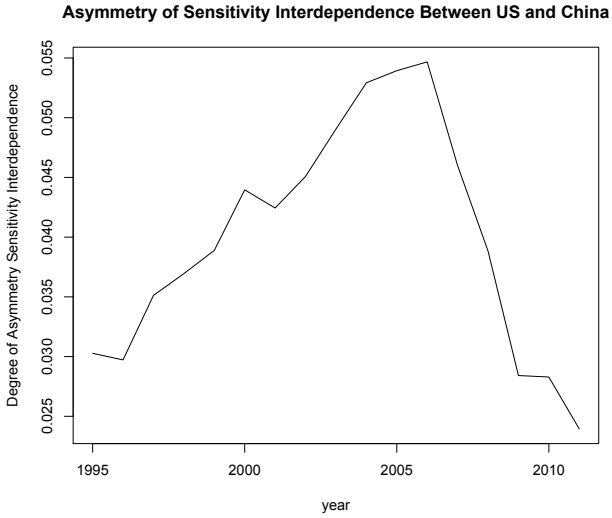
Figure 26: US-China











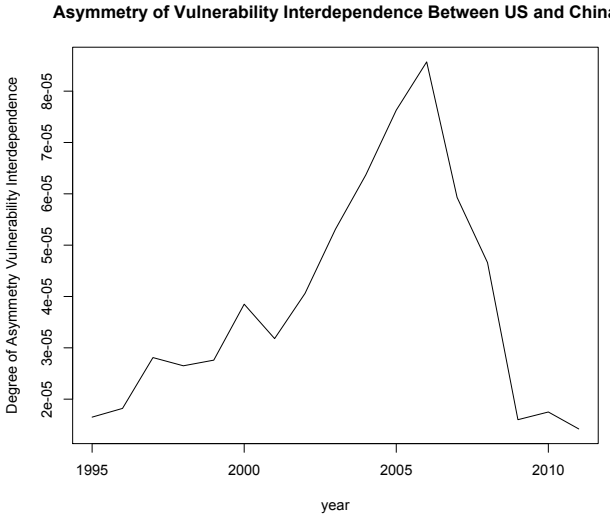


Figure 27: Asymmetry of Interdependence Between Host Country and Two Selected Foreign Country-Sectors

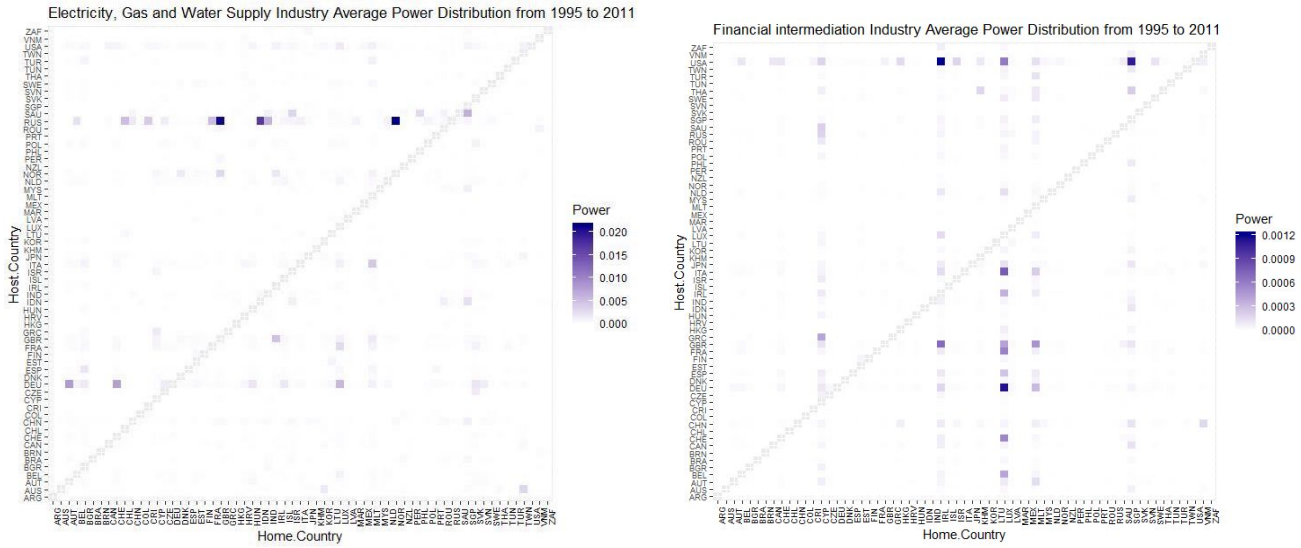


Figure 28: ISDS Filling by Industry