THE GRADUATE INSTITUTE | GENEVA
CENTRE FOR TRADE
AND ECONOMIC INTEGRATION

CTEI PAPERS

CTEI-2012-3

CTEI Working Papers

International Production Sharing: Insights from Exploratory Network Analysis[a]

Yose Rizal Damuri[b]

Abstract

The phenomenon of international production sharing, in which production is broken up into smaller bits of tasks and locate them in separate places, has been widely observed globally in the last several decades. While it has been getting a lot of attention, it is still not clear how to define and examine the trend. In this paper, some statistical methods borrowed from network analysis and graph theory provide an alternative way to see the pattern and structure of global production network. The availability of new input-output data complements the analysis by providing information on international production link beyond what trade data could reveal.

[a] This paper is part of research under the ProDoc Trade Programme. It was presented at Geneva Trade and Development Workshop on 5th April 2011 at the World Trade Organization..

[b] Graduate Institute of International and Development Studies for Trade and Economic Integration

ProDoc Trade Programme

The ProDoc Trade is a research and training programme that brings together PhD students and professors from the University of Geneva, the University of Lausanne and the Graduate Institute of International and Development studies, as well as economists working in the Geneva-based International Organisations devoted to trade (mainly the WTO, ITC and UNCTAD). This networking aims at an agglomeration of excellence in research and making the Lémanique area the heart of international trade economics attractive to trade scholars world wide and to first-rate students from around the globe.

www.graduateinstitute.ch/ctei

Centre for Trade and Economic Integration (CTEI)

The Centre for Trade and Economic Integration fosters world-class multidisciplinary scholarship aimed at developing solutions to problems facing the international trade system and economic integration more generally. It works in association with public sector and private sector actors, giving special prominence to Geneva-based International Organisations such as the WTO and UNCTAD. The Centre also bridges gaps between the scholarly and policymaking communities through outreach and training activities in Geneva.

www.graduateinstitute.ch/ctei

INSTITUT DE HAUTES ÉTUDES
INTERNATIONALES
ET DU DÉVELOPPEMENT

GRADUATE INSTITUTE
OF INTERNATIONAL
AND DEVELOPMENT STUDIES

CP 136 – CH-1211 GENÈVE 21
TÉL +41 22 908 57 00
http://graduateinstitute.ch

International Production Sharing: Insights from Exploratory Network Analysis

1 Introduction

1.1 Background of Study

For the last couple of decades, a new international business model has been sharpening the development of global manufacturing industry. This emerging trend, know as production sharing, defines production process at a finer level of tasks than the conventional model[1]. The core of this evolving business model is to break up production process into smaller bits of tasks and to place them in separate places, usually cross-border locations. These segmented activities can then be reintegrated again through a system of international value chains and international production networks.

The main goal of placing smaller fragments of production process on different location is to take advantage of economic differences among different locations and countries. Different stages of production may be located at places where costs of production are the lowest. That would be done by matching different factor intensities for each production stage to factor abundance of locations. By allowing production process to flow across border, firms could exploit differences in international factor endowments more comprehensively.

As a growing business and production model, this international fragmentation of production has been discussed in many studies and analysis. The next sub-section of this introduction discusses in more detail several theoretical and empirical attempts to examine the trend. However, despite a lot of academic and scholarly attention, there is no clear method to examine the prevalence of global production sharing. Even some very basic questions remain unanswered: What is the magnitude of this practice? Which countries play more important role? On what position?

This paper proposes new approach to examine international production sharing, particularly with regard to measurement issues in order to address numerous basic questions on the extents of this recent practice. Some statistical and mathematical methods borrowed from network analysis and graph theory provide an alternative way to see the pattern and

---

[1] This division of production into stages is known in many other designations, such as vertical specialization (Hummels et al. 2001), product fragmentation (Jones and Kierzkowski 2001), the 2nd production unbundling (Baldwin, 2006), or simply production network. In this paper, those terms are used interchangeably with the term production sharing.

structure of global production network. The availability of new data on input-output table enables us to see product fragmentation as a network flow of production across countries. The main contribution of this paper into the literature is to provide better methodology to measure the extent of product fragmentation, as well as proposing new concept in examining the phenomena by putting it into network perspective. This approach provides clearer insights on structure and pattern of the developing production network. Better understanding on its structure and pattern is important for further examination of international production sharing network.

After this introduction and review on related literatures and existing method, the paper examines the change in trade pattern with relation to the development of global production network. In particular we are interested in exploring whether there are tendency towards regionalization and globalization of production sharing. The next section explores proposed alternative measurement of production network by manipulating information from newly available input-output table, based on some stochastic principles and features. Markov-process type of random walk is introduced in an attempt to track the path of international production flow and value added in a particular sector, allowing us to get various characteristics of this international production network. The paper is concluded by summarizing discussion in the final section.

1.2 International Production Sharing: Literature and Methods

The trend of international production unbundling has attracted scholarly attention from various perspectives. Earliest appraisals come from business and management point of view, with the emphasis on management of supply and value chain. While most of these literatures come up as part of study in multinational companies, some also discuss more general aspects of international production and management. For example, OLI framework of international business presents location as one factor that firms need to chose in order to optimize their operation (Dunning 1989).

Literatures on supply and value chain remain an important contributor to the discussion on international production sharing by providing illustrations and case studies on the operation of particular firms or industries. Linden et al. (2007), for example, presents the case of globalized value chain in the well known Apple's product iPod.

From trade perspective, fragmentation of production has introduced a new line of thinking that somewhat different than traditional Ricardian trade model (Baldwin 2006).

International exchange of final goods as proposed by traditional model become less important as technological advance and reduction of transport cost have opened "the black-boxes" of production entity, which are previously organized within a single firm located in one site or in close proximity.

Important references on the theoretical framework of production fragmentation comes from Jones and Kierzkowski, which explore the underlying motivations and reasons for firms to choose their production centers fragmented in several locations (1990, 2001), as well as the impacts of such activities (1998), although some works on trade in intermediate inputs can be found in earlier literatures (for example Batra and Casas 1973, or Dixit and Grossman 1982). These papers suggest that variation in factor intensity of production stages and differences in relative endowments across countries, together with technical progress in related service links, make cross-border production sharing feasible and profitable.

Other theoretical works focus on the implications of this practice on structure of production, prices, and wages to both recipient and sending countries[2]. Production sharing is also commonly attributed to liberalization of trade, in particular with regard to regional integration. Since cross-border relocation of different stages of production can happen through international trade in intermediate inputs, trade liberalization among countries in the same region might enhance production sharing in the region[3].

Empirical literatures on international production sharing focus on looking at patterns of the network; how they evolve over time; and the impacts of such development onto other aspects. Some studies present the importance of international production unbundling and intermediate goods into productivity at micro (firm) level, such as Amity and Konings (2007), which describes the positive impact of liberalization in intermediate goods in Indonesia to the firm productivity. Others try to identify the characteristics of firms involve in such network, such as competition in the industry where production sharing usually takes place (Paul and Wooster, 2008).

At aggregate level, Egger and Egger (2001), using outward processing data of EU countries, find that outward processing, as a measure of production unbundling activities, is more

---

[2] See for example Venables (1999), Markusen (2005), Grossman and Rossi-Hansberg (2006) and Baldwin and Robert-Nicoud (2007). Most of these papers work on a general equilibrium setting in the style of H-O model where price equalization does not occur as a result of international trade.

[3] The link between regional integration and production fragmentation is usually examined descriptively. Some exceptions include the works from Arndt (2002), which employ mathematical modelling to address the issue.

prevalent in import competing industries, and negatively affects skill intensity in net-exporting industries. On the effect to economic growth, Baldone et al. (2007) estimates international production sharing contribute more to economic activities than the traditional trade activities in final products.

Another type of empirical literatures on international production sharing concerns more on the measurement and pattern of this practice in relation to international trade. These works attempts to give meaningful description on the prevalence of international product fragmentation by considering various different aspects and complexity of the phenomena. Since this type of study is more related to discussion in this paper, we take a look at the literature in more detail by putting the associated works into categories based on their methodologies.

Current Methods of Assessment

There are three main methodologies and data sources that have been used in measuring the prevalence of international production unbundling: customs statistics based on special scheme of trade; international trade statistics in parts and components; and input output table of production.

The first method relies on the availability of customs statistics that record trade activities under special schemes of tariff reduction or exemption. Many countries, in order to give incentives for domestic industrial development provide tariff exemption for imported inputs that are used further for exporting goods (this is mostly the case of developing countries), or for domestic input content of imported final products (the case of developed countries). The special scheme usually makes the customs official to record the trade activities under a special heading. This special heading allows trade scholars to obtain a narrow measure of international production network. Swenson (2005), for example, examines the US offshore assembly program (OAP), which record input contents of import originated fro the US, and find that offshoring activities grew significantly during the period of 1980-2000. Egger and Egger (2005) also present similar result for the outward processing trade (OPT) program of EU, particularly with Central Eastern European countries.

The problem with this method is the availability of data. Besides EU's OPT and US's OAP statistics, only a handful of countries make this statistics available. To our knowledge only China among other major trade player which make this statistics available. Lemoine and Ünal-Kesenci (2004) assess China's assembly trade statistics and shows that China's outstanding performance can be linked to its integration in the international production network. Another difficulty with the method is related to the general trend of tariff reduction. As tariff rate on parts and components becomes lower, firms' incentives to use such special schemes is decreasing, resulting to poorer coverage of the international use of intermediate goods.

Certain categorization of trade statistics can also be used to indicate the occurrence of international production unbundling. Standard International Trade Classification (SITC) version 2 and 3 classify trade statistics into category loosely based on stage of production. These classifications allow trade scholars to identify certain products related to the incidence of production unbundling, especially with the case of manufacturing and machinery production[4]. This type of work is initiated by Yeats (1998), which finds that trade in parts of components of machinery accounts for more than 30% of total OECD countries exports. Other works used this method extensively, particularly in looking at production fragmentation with focus on several specific regions. The extensive use of the method is understandable as the data can be easily collected and offer intensive coverage in terms of regions, period, and also products[5].

Despite its popularity due to easily accessible data and wide coverage of analysis, this method suffers from several important problems. The most important one is double recording in trade statistics, especially in machinery products. Car windshield produced in country A exported to country B for assembly process, would be counted again as B's exports, although there is no production transformation on that product. High prevalence of cross border shipping of the same product makes this problem worse. Another problem is related to the use of imported inputs. When import of a particular intermediate input takes place, it is not clear of the use of this product, whether it would be used directly by consumer as a replacement for broken product, or used by a producer for further production process.

To deal with that problem, Hummels et al. (2001) proposes the calculation of vertical specialization index (VS), which is based on the import content of exports using information from input output (IO) table. The study finds that VS activities of ten OECD members grew

---

[4] With machinery, this paper refers to the classification of SITC heading 7 (version 2 and 3), which covers general machinery, electrical and electronics, and motor vehicle and other transportation.

[5] Many studies on regional importance of production network, such as studies on the so called "Factory Asia", use this particular method. See for example Kimura and Ando (2004),

almost 30% since 1970 and account for more than 20% of the exports. Other studies extend the coverage of the method and offer modifications from the original formulation to look at other specific aspects of international production sharing, such as the work from Chen et al. (2005) which uses more recent data and cover more regions; or the work from Johnson and Noguera (2009) which extends the use of information from IO to compute bilateral trade in value added; or Inomata (2008) that tries to capture the entire structure of production chain using international input output table.

The accuracy of this method depends largely on the breakdown of production sector in IO table. More detail breakdown provides better information on how production process identified and tracked in the economy. This is the important problem of using IO table, as there is no international standard classification of production in the table, making it difficult to use it for international comparison. Moreover, most countries only provide less detail breakdown of production, which often not enough to see the importance of international production network. Another problem is related to the frequency of publication of such data, which is usually produced every five years, making it difficult to be combined with international trade statistics.

The most important limitation of this method, however, comes from the fact that input-output tables are constructed basically at national level, having no or little information on the international aspects. In order to examine the prevalence of international product fragmentations, the information from IO should be combined by trade data, along with certain assumptions in mind. Nevertheless, this method offers clearer measurements and understanding of the international production unbundling.

This paper adopts the second and third methods in looking at global production networks using the information from trade data and IO table. The methods proposed in this paper differ from the existing literature on the measurements of international production sharing in at least two aspects: the analysis is based on methods developed in exploratory network analysis that takes into account not only bilateral relations, but also capturing the whole structure of the network; in addition, the framework proposed in this study allows inference of various features and characteristics of the cross-border flow of production and value added at the aggregate level.

2 Global Production Unbundling: What Trade Data Reveals?

As mentioned in the previous section, the method of analyzing international production sharing by looking at trade data has some notable drawbacks. However, it also offers widest coverage in looking at the network of production. This section explores the global patterns of international production unbundling by looking at trade in parts and components of machinery products. The purpose of this section is to examine the development of trade in parts and components, as one of the most important aspect of production unbundling, and to analyze certain patterns in the development of trade network.

Specifically, this section examines whether the growing production unbundling phenomena tend to be regionally concentrated as many observers presented[6]. While stories of international production network can be observed strongly in the East Asia region, the globalization of production and trade in manufacturing products has also taken place in other parts of the world. However, whether those countries are integrated regionally would require more careful examination. In this section, we explore the structure of the international production unbundling network that can be observed from data of international trade in parts and components.

2.1 Global Network of Trade in Parts and Components

A majority of studies in global trade and production unbundling is either to look at the basic trend and structure of trade flows at the total level (see Fenstra 1998 and Yeats 2001), to focus on regional structure of the trade (see Kimura and Ando 2005), or case studies of several countries. Rarely analysis has been done on bilateral trade patterns in parts and components, particularly involving global patterns of trade[7]. Analyzing bilateral trade matrices reveals patterns of triangular and multilateral links between countries, which is usually unseen in total trade flow. It becomes more important in the case of parts and components as the products are often imported from one country to which they are later passed downstream of the value chain in other countries.

One obstacle in doing that analysis is obvious: the structure is too big to be analyzed descriptively. With over 100 countries with considerable value of trade, the matrix of global trade consists of thousands of possible trade flows that make it difficult to handle with

---

[6] See the literature review in the previous section

[7] Some authors, such as Athukorala and Yamashita (2006) examines international production network being developed in East Asia in a global context. But only looks at the pattern of trade aggregated at regional or global level, instead of on bilateral basis.

conventional methods. Network Analysis (NA) provides some useful tools in analyzing global bilateral trade flow. In the network analysis, structure of global bilateral trade can be seen as a network of relation, in which countries are symbolized as the nodes or actors of the network and the amount of bilateral trade represents strength of a directed (export or import) relations between them.

The application of NA in analyzing global trade network can be traced back to the early 1990s with the publication of a paper from Smith and White (1992) which tries to identify the roles of countries played in the global trading network and its evolution. Some later papers concern more on the technical aspects of the global trade network, such as its topological features and relational characteristics (see for example Kali and Reyes 2007).

While some methods of network analysis fit the needs in examining international trade network, the application of NA's techniques to trade statistics needs careful consideration. Many methods in network analysis see pair-wise relations more than just relation between two parties involved. In fact, network analysis is developed to examine relations beyond direct bilateral connections. In friendship relation, for example, not only direct friends that matter, but also friends of friends affect the network of friendship relation. Application of network analysis to friendship connection, e.g. online social network, normally explores the extents of these "higher orders" relations.

This nature of NA's methods would be beneficial in looking at international production sharing, in which production moves among many countries before being consumed, and not only bilateral trade connection that matters. Unfortunately, bilateral trade statistic is built on the assumption that trade involves only two countries; it is the flow of final goods from one country to another, where it would be directly consumed in the destination country. The extents of higher order relations in trade network can not be appropriately derived from this bilateral direct relation, particularly not from the value of trade.

There are two ways to deal with this problem. One way is to choose methods of network analysis dealing with this type of bilateral connection. Several methods in network analysis and graph theory consider direct bilateral relation as similarity or distance between objects. These methods are suitable for the application of network analysis on the structure and pattern of bilateral trade relations in parts and components. We will apply relevant techniques by assuming that bilateral trade relations are in line with proximity between countries.

Alternatively is to reconstruct trade statistics to suit the nature of network analysis. This can be done by looking at relations in production sharing as a network flow of production or value added, streaming from one country to others until the production flows out of the network, consumed as a final good. With this reconstructed data of international production flow, many techniques of network analysis can be employed to examine properties of global network of production sharing. This section mainly discusses the application of the first procedure, while the latter part of this paper introduces to the alternative.

2.2 Structure of Trade Network

Before going into more detail analysis of global trade network of parts and components, it is worthwhile to say something about the data being used. A dataset of bilateral trade of parts and components has been constructed using data from the UN Comtrade Database. The classification of parts and components in this study follows the classification used in Kimura (2007) as described in Appendix A[8]. In assessing changes over time, it is also important to note that the dataset is not a balanced panel and the number of countries changes over time. This occurs mainly due to the creation of new countries and the abolishment of the old ones, as well as additional data from a large number of unreported countries in the past.

In order to reduce the number of missing value from the dataset, but at the same time cover a substantial number of countries, only countries with total exports of more than one billion US dollar in 2005 are included in the sample. In the end the sample covers 100 countries for the period of 1985 and 113 countries for 2005.

Table 1 presents some basic features of the dataset. From the table we can see that the number of countries involve in parts and components trade increase over the period of observation. Of all countries with reported data in mid 1980’s, only less than 60% recorded some amount of exports of parts and components products, while the percentage increases to 87% in 2008. Trade in parts and components has also gain importance in the last three decades, with an increase of more than 3 percentage point over its share in the world total trade within 20 years of time. Note that the share of parts and components trade slightly falls in the wake of 2008 crisis, while the number of exporters and countries being involved in the trade activities has also declined.

[8] There are other attempts to classify intermediate inputs (see Yeats 1998, for example). The classification used in this study is based on SITC version 2, comprising intermediate inputs used in machinery production.

Table 1. Trade in Parts and Components

	1985		1995		2005		2008	
	Value / No.	%	Value / No.	%	Value / No.	%	Value / No.	%
World Exports of Parts and Components[1]	163	9.99	594	12.24	1,320	13.00	1,760	11.56
Number of Country Pairs with the non zero trade[2]								
- Manufacture	4,760	61.25	7,637	72.35	10,283	77.76	9,779	82.97
- Machinery	4,212	54.19	6,873	65.11	9,549	72.21	9,264	78.60
- Parts and Components	3224	41.48	5631	53.34	8254	62.42	8202	69.59
Exporters of Parts and Components[3]	58	58.59	88	84.62	113	99.12	102	87.18

1) Value in US$ billions; percentage of total world exports; 2) Percentage of non-missing country pairs
3) Percentage of non-missing exporters

One characteristic of trade in parts and components presented in Table 1 is that only a relatively small number of countries are involved in the network. While more than 60% of possible country pairs exchange manufacture goods in the mid 1980's, only around 40% engage in parts and components trade. A more detail observation also reveals that the biggest ten exporters of parts and components contribute to more than 88% of the world market in 1985, and remain concentrated in 2005, although the figure declines to around 67%.

Table 2 provides more information on how trade in this type of product spreads out. The USA and Japan dominate the market of parts and components in most of the period of observation, while Germany overtakes the second place in 2005. Looking at the mean and the standard deviation of each country in the table raises a suspicion that the destinations of these countries' exports are also rather concentrated. Relatively large values of standard deviations compare to the means indicate that some destinations are more important to these exporters than others. In order to give more insights on the structure of parts and components trade network, we will turn to network analysis.

Table 2. Ten Biggests Exporters of Parts and Components

1985					2005				
Country	Exports	Share (%)	Mean	Standard Deviation	Country	Exports	Share (%)	Mean	Standard Deviation
USA	49,200	30.18	424.5	1,306.3	USA	163,000	12.35	1,404.2	4,515.7
JPN	22,700	13.93	195.3	875.4	DEU	143,000	10.83	1,231.3	2,611.5
DEU	20,200	12.39	174.2	407.9	CHN	124,000	9.39	1,073.3	3,947.0
GBR	13,500	8.28	116.4	299.5	JPN	112,000	8.48	963.2	3,266.6
CAN	10,900	6.69	93.9	908.5	HKG	76,500	5.80	659.6	4,130.6
FRA	10,000	6.13	86.4	225.9	GBR	60,200	4.56	518.8	1,276.3
ITA	6,803	4.17	58.6	160.0	KOR	59,400	4.50	511.9	1,691.3
SWE	4,514	2.77	38.9	85.0	FRA	53,100	4.02	457.9	1,200.9
NLD	3,595	2.21	31.0	98.7	SGP	50,400	3.82	434.3	1,291.6
HKG	2,876	1.76	24.8	139.4	ITA	45,200	3.42	389.3	998.5

Some Basic Measures of Network

To facilitate the analysis, trade data is constructed in a graph form. Let $G = (V,E,w)$ be a connected, weighted, and directed graph of trade relations, consisting of a set of nodes, or vertices *V,* which represents the set of countries in our sample, and a set of edges $E \subset V \times V$. Each edge represents $E(r,s)$ trade relation between two countries r and s with trade values assigned as non-negative real weight w_{rs}. The graph can be written in a matrix $\mathbf{W}=\{w_{rs}\}$ where *rs-th* element is represented by the corresponding weight w_{rs}. In some cases it is also useful to define the graph in its binary form by having it as $v \times v$ adjacency matrix $\mathbf{A}=\{a_{rs}\}$ where $a_{rs} \in \{0,1\}$ by letting $a_{rs}=1$ if $w_{rs}>0$, and zero otherwise.

The most simple but useful measure in examining the structure of a network is the *vertex degree*, which is defined as the number of links that a given node has established; it simply means how many partners that a particular country has trade relations with. Another concept is *vertex strength* defined as the sum of weights associated to the links held by any given vertex, or country. It is the sum of trade volume to all partners for each country. Vertex degree (VD) and vertex strength (VS) of country r is then defined as follow.

$$VD_r = \sum_s a_{rs} = \mathbf{A}\ \boldsymbol{\iota}_V$$

$$VS_r = \sum_s w_{rs} = \mathbf{W}\ \boldsymbol{\iota}_V \quad \textit{where } \boldsymbol{\iota}_V \textit{ is a } v \times 1 \textit{ vector}$$

Both are important since the distribution of those indicators hint at certain topological characteristics of the network structure. In a *random network*, i.e. a network consists of nodes with randomly placed connections, the distribution of vertex linkages follows a bell-shaped curve. In a *scale-free network*, where most nodes only have few connections and few have many connections – the network normally takes form as hub and spoke -, the distribution of VD and VS tends to follow power law (Barabási and Bonabeu 2003).

Figure 1.a Kernel density of VD

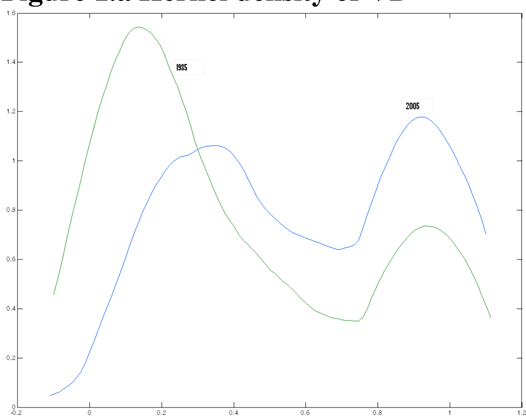


Figure 1.b Kernel Density of VS

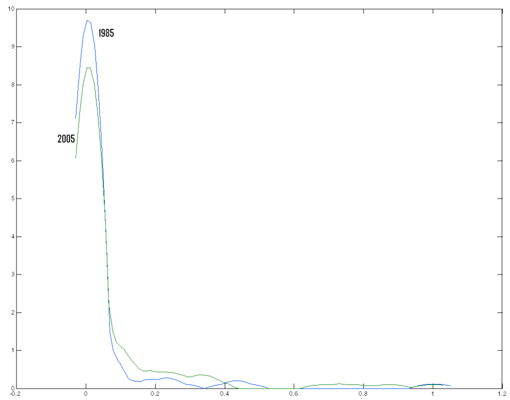


Figure 1.a and 1.b provide the kernel estimation of VD and VS trade network in parts and components for 1985 and 2005. The noticeable feature of the degree distribution is bimodality that appears both in 1985 and 2005. Most countries either trade with less than 50% of total countries, i.e. poorly connected to the network, or have extremely well trade relations with almost all countries. However, the bimodality of the two distributions is somewhat different. In 1985, low connected countries were more abundant than the well connected ones. But the opposite situation can be observed in 2005.

From the distribution of vertex degree, it is difficult to conclude topological characteristic of the network structure, as the distribution hardly follows certain parametrical distributions. But for trade relations, looking at the volume of bilateral trade might be more insightful than just to see whether there is a bilateral connection or not. That is why distribution of VS might give better information than just the distribution of VD. Kernel density distributions of countries' trade value both for 1985 and 2005 follow the power law feature, at least asymptotically.

This shape of distribution suggests some characteristics of scale-free network, in which hub and spoke relations are found. From this simple analysis we can suspect that hub and spoke trade connections, where few countries have many important connections and many countries have few important connections, can be observed from trade relation in parts and components. We will analyze this characteristic in more detail later in this section by applying other technique from graph theory.

Another network characteristic worth mentioning with regards to our further analysis is the network symmetry. One way to measure for the network symmetry is by applying an index developed by Fagiolo (2006) based on the norm of the adjacency and weight matrix. The index can be expressed in a formula below.

$$\tilde{S} = \frac{\|\mathbf{Q}-\mathbf{Q}'\|_F^2}{2\,\|\mathbf{Q}\|_F^2}\frac{n+1}{n-1} \text{ where } \mathbf{Q} = \mathbf{W} - (1-w_{ii})\mathbf{I}\,;$$

$$\|\mathbf{Q}\|_F^2 = \sqrt{\sum_s \sum_r a_{rs}^2} \text{ is the Frobenius norm of the matrix } \mathbf{Q}$$

The index ranges from 0 (full symmetry) to 1 (full asymmetry). The application of the formula to trade network matrix **W** reveals that the symmetry index is 0.28 and 0.31 for 1985 and 2005 respectively. These indicate certain level of symmetry for the network although far from perfect symmetry. This result gives support to our treatment of trade data in the next analysis: dealing with trade data as proximity data between countries. In other words, we treat bilateral trade relations as symmetric assuming that countries pursue bilateral balance trade regime. This enables us to apply appropriate network analysis techniques as discussed previously.

Treating bilateral trade relations as symmetric may result to the loss of some useful information. It is possible that trade between two countries is very much skewed towards one partner, making the balance trade assumption affects validity of the results. However, relatively low index of symmetry suggests that the loss may not be that severe, particularly compare to the advantages from the application of appropriate network methods. Keeping this in mind, the next analysis looks at trade relations as proximity between countries and treats the network as an undirected one.

Maximum Spanning Tree

One powerful method offered by network analysis is the visualization of a network by drawing the relationships between nodes as lines or arcs. Despite that visualization can provide numerous useful insights, a graph of a network becomes more difficult to interpret when the number of nodes is large, particularly for a very dense network like global trade network, where many countries are connected to almost all other nations. To overcome that limitation, numerous methods have been developed to provide clearer interpretation of network visualization. We look at the application of some of those methods to the network of trade in parts and components.

As explained earlier, the analysis conducted in this section considers bilateral trade relation as similarity or distance. Therefore it is important to make the matrix **W** symmetric, or to create an un-directed graph $G=(V,E,w)$ where $w_{rs}= w_{sr}$. It is equivalent to the assumption that bilateral trade is balance. A geometric mean of bilateral trade relations is used in place of the original trade data.

$$w_{rs} = w_{sr} = (w_{rs}\ w_{sr})^{1/2}$$

One simple but useful technique in network visualization to explore the structure of relations between nodes is *maximum spanning tree* (MST) technique. Given a connected graph $G = (V,E,w)$, the MST is a sub-graph (V,T) such that T is a *spanning tree* with the maximum total weight. A spanning tree T is a *tree* which links all vertices in the graph together, while the trees in graph G refers to the sub-graph T in which any two vertices are connected by exactly one edge.

A spanning tree of trade network is a connected graph which links a set of countries together in such a way that there is only one connection between any pair. Therefore the maximum spanning tree of trade network only presents the most important trade relation between two countries, which maximizes the total trade relation in the network. By only focusing to the most important bilateral connection, the structure of the network is more noticeable and easy to see.

The technique used in this analysis is known as Kruskal's algorithm (Kruskal 1956). Kruskal's algorithm works iteratively by selecting and adding an edge $E(r,s)$ in decreasing order of their weights w_{rs}. If the edge connects two different trees then it is added to the set of edges that is part of the MST, and the two different trees are merged into a single tree for the next iteration. If the edge connects two vertices belong to the same tree, then it would be discarded.

Figure 2a, and 2b present the maximum spanning tree graph for trade in parts and components in 1985 and 2005 respectively. Value of the MST, which means the value of trade covered by the most important bilateral trade link of these countries, is as high as 91% and 96% of the total export in parts and components, for 1985 and 2005 respectively. Only less than 9% and 4% of trade in those products take place, respectively for 1985 and 2005, as non-MST bilateral relations – bilateral trade connections that are dropped and not shown in the graphs. From technical point of view, these numbers suggest that the graphs successfully cover important bilateral trade links. From economic point of view, the value indicates high concentration of parts and components trade in the most important relations only.

Both structures of trade relation in 1985 and 2005 expose a tendency of hub and spoke relations between countries. This is in line with previous suggestions from the distribution of degree and strength of vertices (VD and VS). There are several countries which serve as hubs of the trade network, through which other countries are connected to the entire network. USA and Germany are among the most important countries in the trade network both for 1985 and 2005. Other countries include Japan, which serve as a hub for many East Asian countries in 1985, France, which connect many Middle East and African countries, and also UK.

Figure 2.a. MST Graph of Trade in Parts and Components 1985

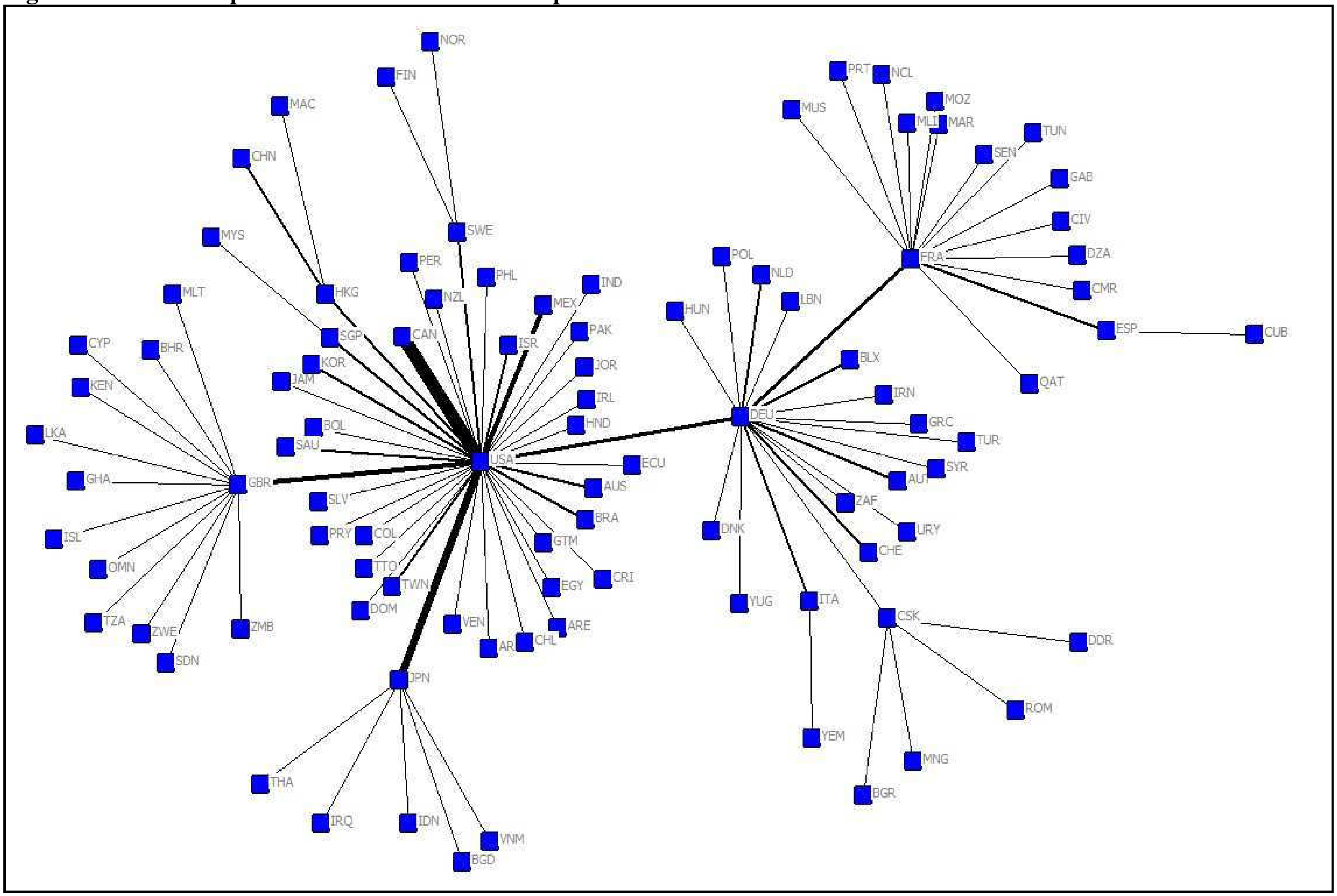
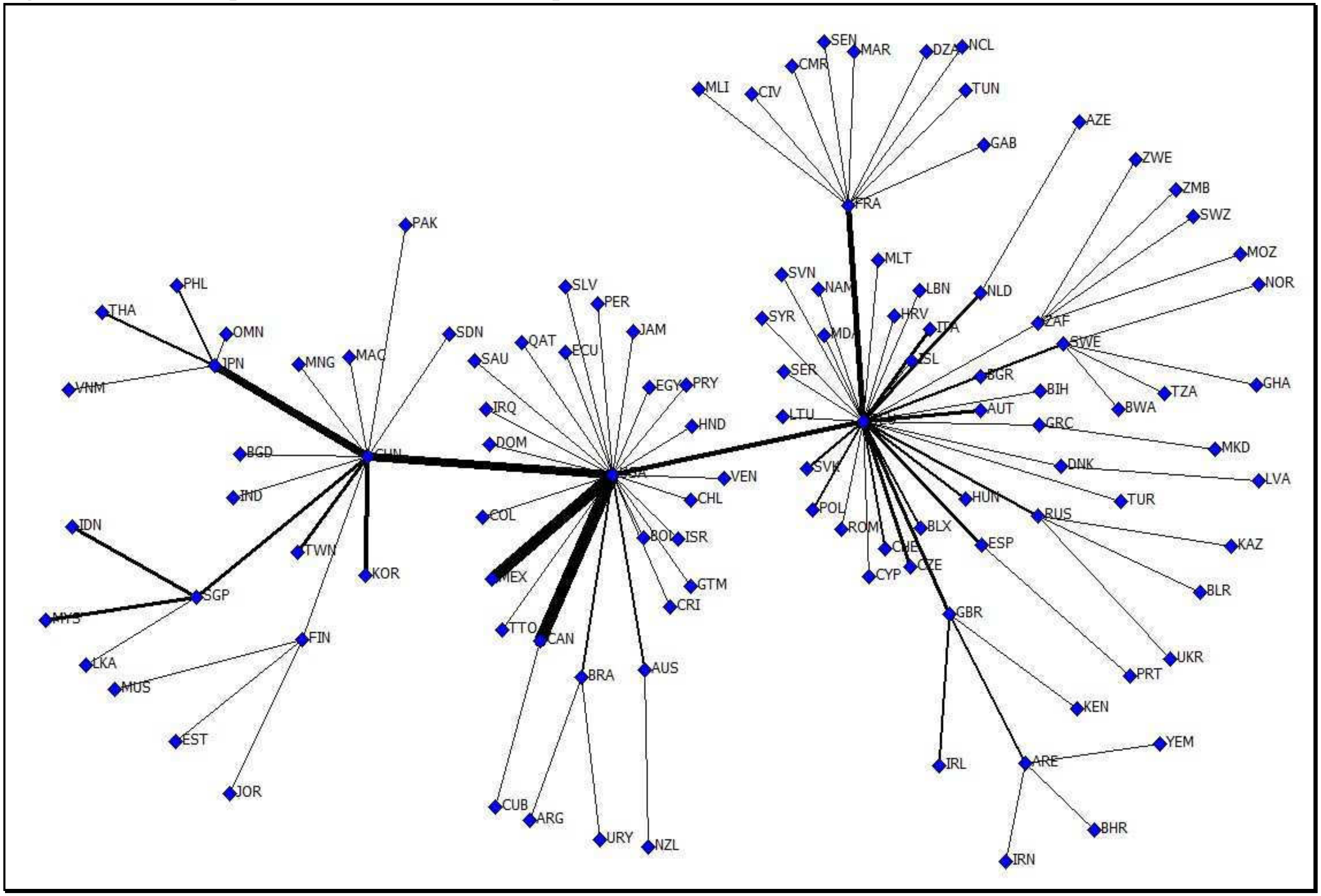


Figure 2.b. MST Graph of Trade in Parts and Components 2005



The position and role of some other countries also change during the period of observation. While United Kingdom maintain its position as a hub for 2005, the importance of this country as a bridge to the network diminishes as less country partners become connected directly. Brazil has also emerged as a sub-hub to connect several other countries to the network in 2005. Table 3 provide more detail description on the structure of MST for 1985 and 2005 by presenting 10 most important countries as hubs of the network, along with the number of direct partners and the trade value. It is clear from the table that not only some countries have become more important in the last two decades in the network of trade in parts and components, but also some countries have lost their importance.

Table 3. MST of Trade in Parts and Components: A Comparison

1985			2005		
Country	**No. of Partners**	**Value of Trade**	**Country**	**No. of Partners**	**Value of Trade**
USA	37	31,168,432	Germany	33	81,632,456
UK	18	3,234,154	USA	29	106,901,954
Germany	15	9,160,420	France	11	13,111,647
France	9	2,655,493	China	8	59,813,866
CSK	5	115,789	UK	8	10,118,576
Japan	3	5,589,308	Japan	5	24,197,890
Sweden	3	1,027,320	South Africa	5	1,192,589
Hong Kong	3	680,804	UAE	5	991,596
Yugoslavia	3	187,205	Singapore	4	17,546,223
Mexico	2	2,790,095	Rusia	4	1,242,980

With regard to East Asian countries the two MST graphs also show that connections among countries in the region have become stronger during the last two decades. While for 1985, the graph shows heavy dependence of the regions to the US, where 6 out of 12 countries place the US as their important partner, the graph for 2005 display stronger role and position of some big East Asian countries to serve as hub in parts and components trade for other countries in the region.

High value of global trade's MST and evidence of hub and spoke structure of the network suggest highly concentration of production sharing activities in several countries. The result indicates that those countries serving as hubs play the most important role in shaping up the global network of production. Moreover, with only less than 4% of global trade in parts and components takes place between those spoke nations and their non-hubs partners, the practice of production fragmentation tends to happen between countries belong to the same group. These groups consist of one country as a hub and many other countries as spokes. We take a look at this grouping tendency in more detail in the next sub-section. In the meantime we explore more the non-MST relations of the global trade network.

More on the Structure and Pattern of Trade

Despite its clarity and simplicity, our MST graphs, by focusing only on the most important connection between pair of countries, basically throw away some other information that might be useful. Therefore it is quite informative to complement the MST graph with other less important trade relation between countries. Figure 2.c present MST graph for 2005 complemented with four largest bilateral trade relations of each country.

The graph clearly indicates that beside the MST relation, there are many other important bilateral trade links dropped by focusing only on the most important ones. The most noticeable one is the connection between US, Japan and China, which form a triangle trade relation. Another structural characteristic that can be observed is the tendency of countries which share the same hub to connect intensively to each other.

Although trade relations between countries belong to different hub are not rare, these are less prevalent than trade link between country pairs sharing the same hub. In fact if the bilateral trade relations in the graph are reduced to the two largest, instead of the four largest, most visible links belong only to countries sharing the same hub. This confirms our previous notion about the prevalence of production sharing between countries in the same group.

Given the description on the structure and pattern of trade using the MST diagram, one might ask whether such structure and pattern are uniquely observed in the trade network of parts and components or if they also apply to trade network in general. Figure 2.d presents maximum spanning tree graph for the network of total trade in 2005. The structure of hub and spoke is also observed for this network, with USA and Germany as two important countries.

However, there are several differences in the structure and pattern of total trade network and trade in parts and components that can be observed from the MST graph, particularly in the position of countries in the network. The most obvious one is the position of China which in the total trade network ranks as the 9th most important country by having only five other countries directly links their largest trade relation with this country, compare to being the third most important ones in parts and components. China's position is lower than Japan, which serves as a hub for 10 countries. Other countries that do not serve as important hubs in the network of parts and components, such as Italy and Brazil, turn out to become more important in total trade network.

Figure 2.c. MST Graph of 2005 plus the Second Largest Bilateral Trade Relations

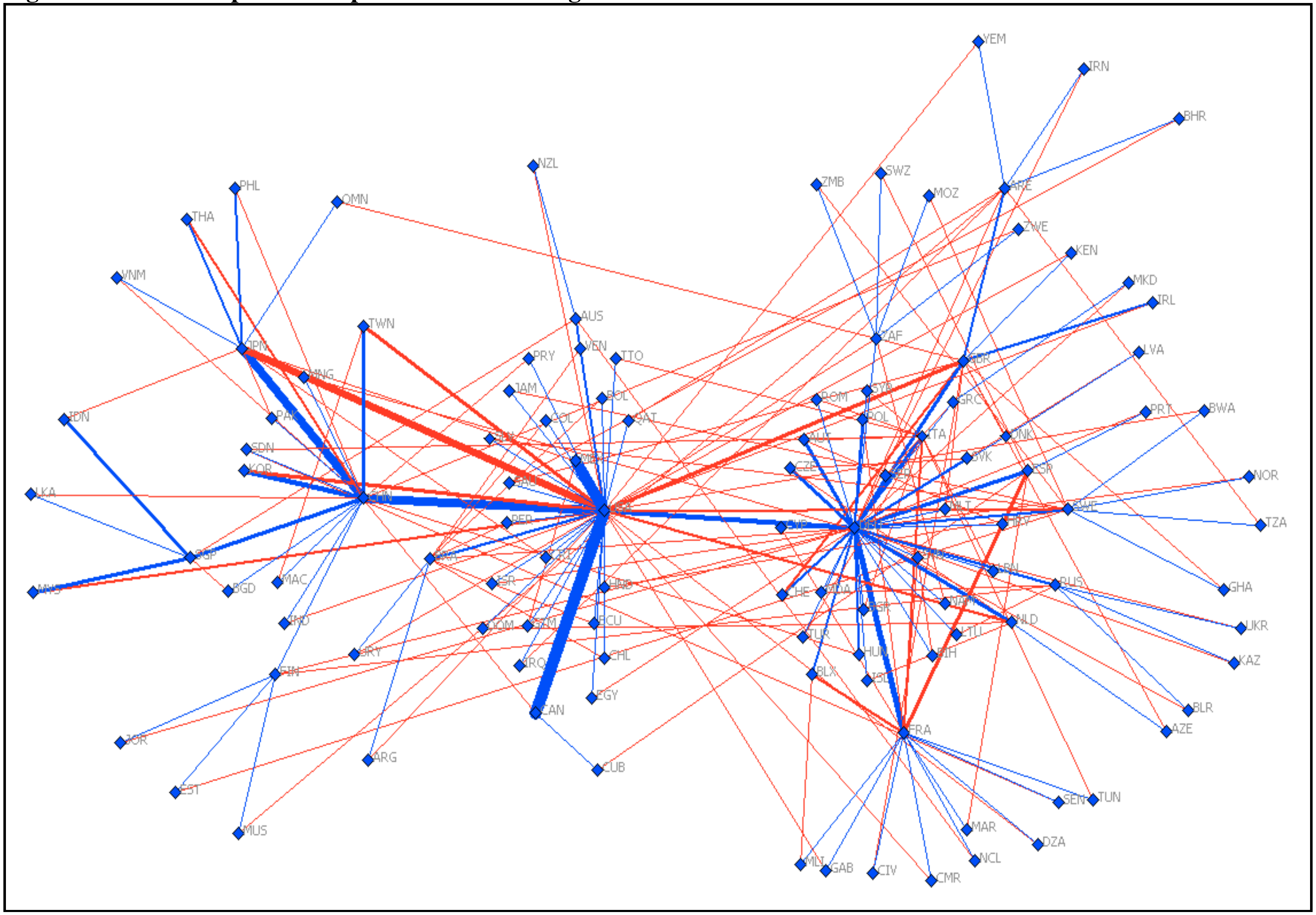
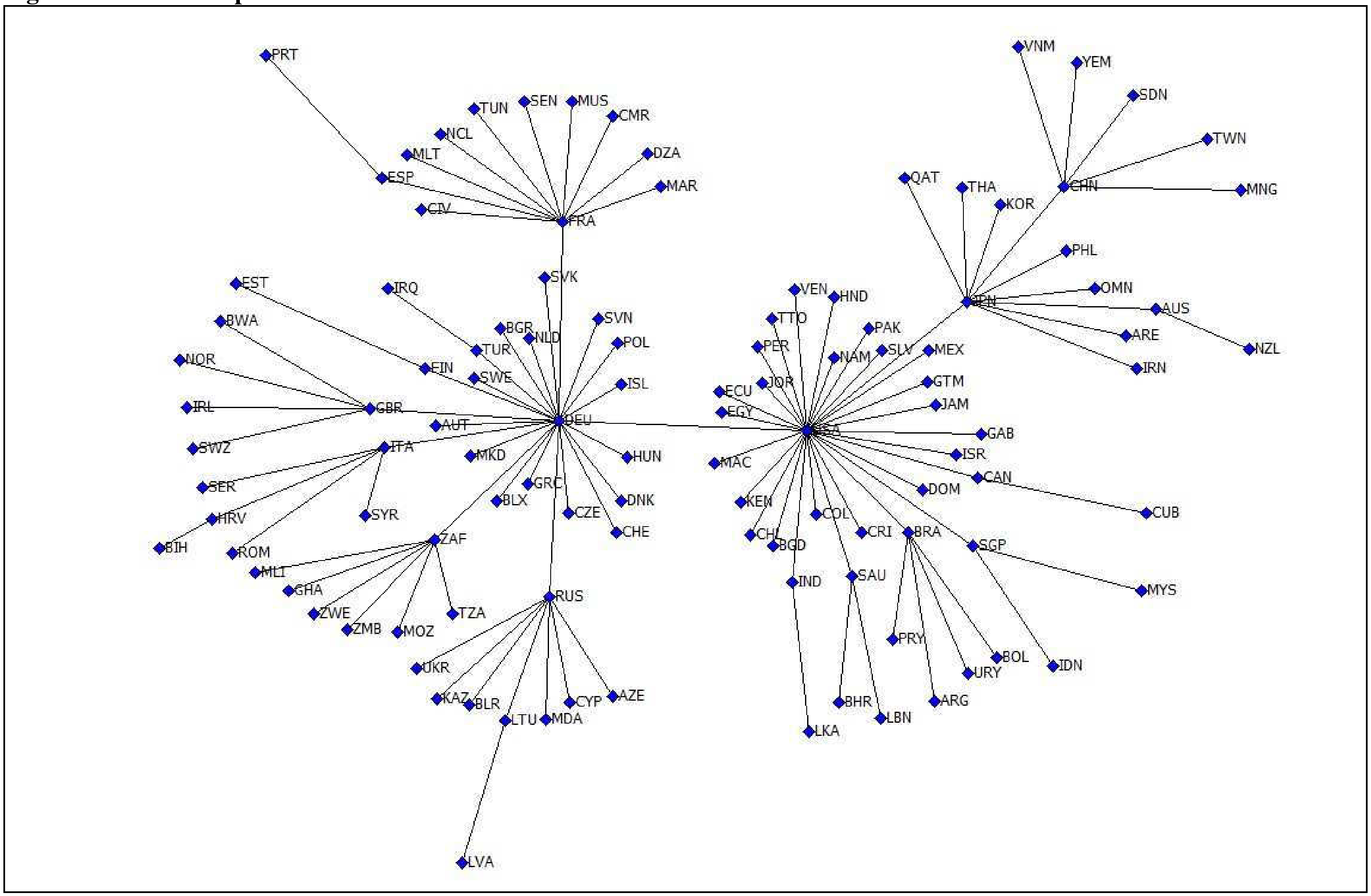


Figure 2.d. MST Graph of Total Trade Network in 2005



In short, the MST graphs of trade network in parts and components employed in this section identify clearly the hub and spokes structure of network with only several countries play important role. However, the structure is less clear in East Asia where trade relations outside the hub and spokes links are also quite important. The importance of hub and spoke type of relations indicates that trade and production activities spread across countries within the same group. Furthermore, the graphs suggest that this grouping may follow geographical location of the countries. In order to see further the pattern of bilateral trade in parts and components with regards to this grouping, we will use other network analysis and statistical techniques in the next sub-section.

2.3 Pattern of Trade: Mapping the Network

The proposition that international production network is a regional phenomena has been widely accepted[9]. Many studies in fact examine the so-called vertical fragmentation of production by focusing intensively on the regional tendency of the phenomena and accept the regionalization as a factual characteristic of the network. But rarely this tendency is examined without a-priory assumption about the countries grouping. Here using some statistical methods commonly employed in network analysis, we examine whether the pattern of global trade in parts and component follows geographical distinction of economic regions. We try to visualize the network of trade based on the consideration explained earlier that the bilateral trade relations between countries is seen equivalent to proximity. After that we use the results of the analysis to see the pattern of integration.

Multidimensional Scaling

One common approach for visualization of network is known as the multidimensional scaling (MDS). This method is part of a larger statistical technique loosely known as dimensional reduction or ordination. The basic idea of this analysis is to "reduce" dimensions of the data in order to provide clearer view on its pattern, usually in two dimensions (Scott 2007). By mapping the connection profiles between countries in two dimensional data, MDS provides coordinate of each node, in our case is the country of origins, which can be plotted in a normal Cartesian system. Unlike other methods of dimensional reduction, such as *principal component analysis*, techniques developed in MDS do not require the linearity of data.

---

[9] Arndt (2002) provides conceptual explanation on the regionalization of production sharing by arguing that lower trade barrier allow producers to exploit the difference in factor endowment. Many empirical and descriptive studies are also based on this consideration (see the next footnote)

Let the vertices of graph $G(V,E,w)$ are seen as objects **V** and the symmetric weight w_{rs} become the dissimilarity measure between object r and s, δ_{rs}=- w_{rs}. With this definition, the greater the weight the closer the distance is between the two nodes. An arbitrary mapping of ϕ from **V** to **X**, a set of points in a Euclidean space, is also defined. The distance between points of x_r and x_s is given by d_{rs}. The aim of multidimensional scaling analysis, in general, is to find a mapping ϕ for which d_{rs} is approximately equal to a monotonic transformation of dissimilarity between the vertices $f(\delta_{rs})$ following the minimization of certain objective function also known as *stress function*.

So, in the implementation of an MDS technique, there are two important choices need to make: the transformation of $f(\delta_{rs})$ and the stress function. In the so-called *metric* or *scale* MDS, $f(\delta_{rs})$ is the dissimilarity measure itself; therefore distance between points in Euclidean space is associated with the original data of dissimilarity. In the *non-metric* or *interval* MDS, the disparities measure $\hat{d}_{rs}=f(\delta_{rs})$ is a monotonic transformation such that it follows either

$\delta_{rs} < \delta_{pq} \Rightarrow \hat{d}_{rs} \leq \hat{d}_{rs}$ (weak monotonicity) or $\delta_{rs} < \delta_{pq} \Rightarrow \hat{d}_{rs} < \hat{d}_{rs}$ (strong monotonicity).

Here, what matters is not the original measure of dissimilarity δ_{rs}, but rather the rank of the objects **V** based on their dissimilarity measure.

The stress function is the measure of fitness of the estimation. By minimising the function, which is basically variant of the difference between d_{rs} and $f(\delta_{rs})$, the best configuration of **X** representing the vertices is attained. One of the most commonly used stress function is

$$S = \sqrt{\frac{\sum_{r,s}\left(d_{rs} - \hat{d}_{rs}\right)^2}{d_{rs}^2}}$$

which is minimized with respect to d_{rs}, and also with respect to $\hat{d}_{rs}$ using an isotonic regression. The minimization of S is a complex operation that can be achieved only by using computing algorithm (Cox and Cox 2001). Numerous algorithms have been developed to find better result of MDS. The analysis that follows makes use of an algorithm called MiniSSA, which is based on non-metric MDS with the above description of stress function.

Map of Trade Relations and Regionalization

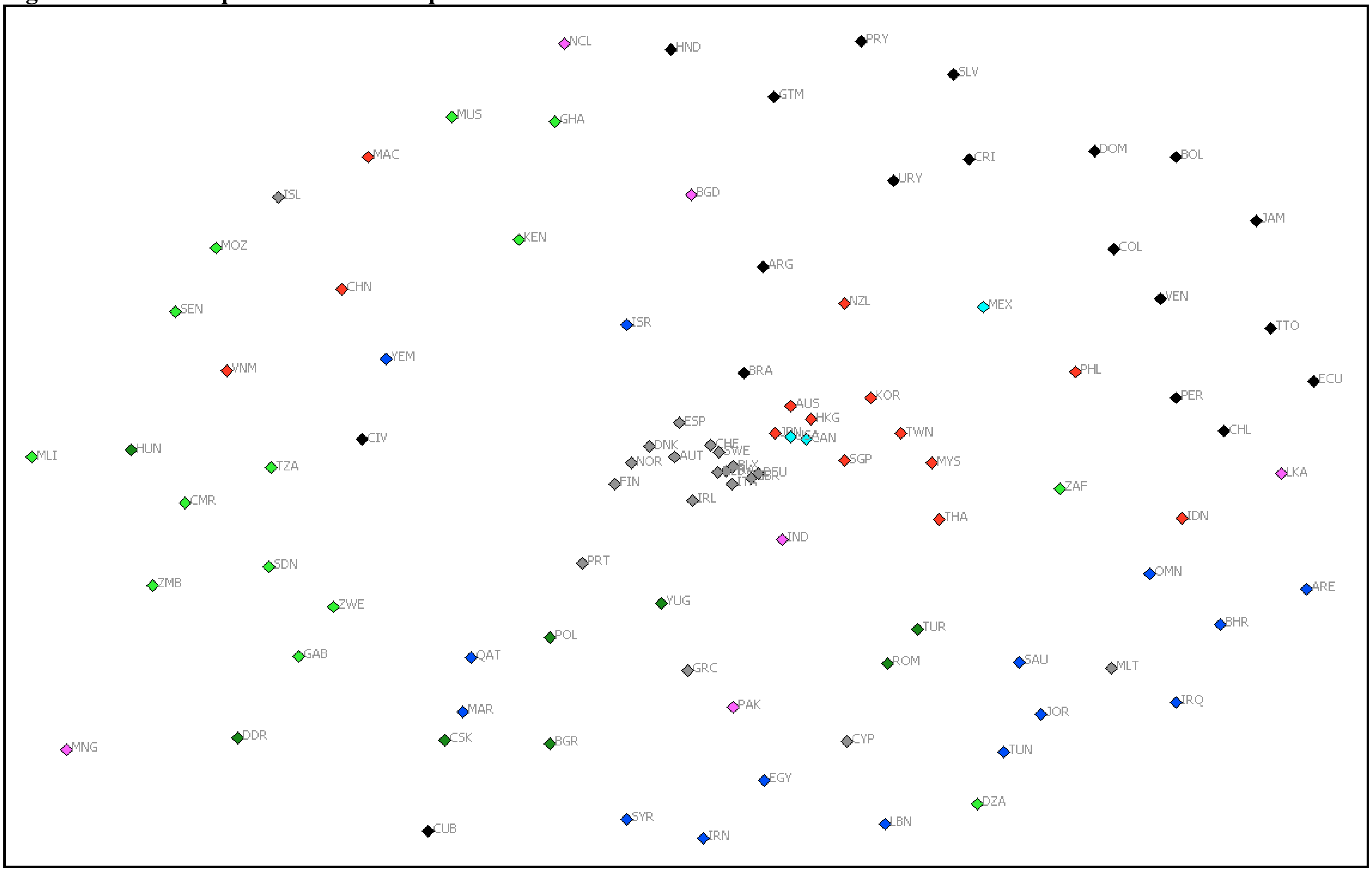
The result of MDS analysis of trade in parts and components for the period of 1985 and 2005 are represented in Figure 3a and Figure 3b. In both graphs the position of each country in our dataset relative to others corresponds to the representative point. Bear in mind that while in a MDS graph, location of a particular node relative to others represents the distance between nodes, the dimensions itself (horizontal and vertical axes) bears less significance. What matters is the relative position. Our MDS mappings of trade in parts and components come with the stress function of 0.200 and 0216 in 1985 and 2005 respectively. This is far from perfect mapping, which is quite understandable considering the complexity of trade relation between countries and the difficulties of reducing big relational data (98 countries in 1985 and 114 countries in 2005) into two dimensional vectors.

One of interesting feature we can observe from mapping of countries based on their trade connection is the tendency of grouping. Our previous MST analysis reveals that the structure of global trade in parts and components tends to be circulated within groups of country. The MDS map in figure 3a and 3b compare the location of countries based on trade relations and their geographical location by color-coding the nodes following regional grouping described in Appendix B. This is useful to see if countries groupings show a resemblance to geographical regions.

We can see in Figure 3a, that regionalization as it is usually hypothesized finds less evidence in the MDS analysis of trade network in 1985. Some countries which are geographically closed to each other are connected quite significantly, such as the US and Canada, or some developed European countries. But beyond those few countries, most are not mapped according to their geographical location.

Most noted is the lack of existence of the Factory Asia. Japan, as the center of the region, is closer to the US and Canada than to many other countries in the region. Except for newly industrialized economies (NIEs) of this region, such as Hong Kong, Singapore and Korea, countries in the region are a little bit far from the centre of the map. Even for those NIEs, attachment to the US, probably as the main important market, are stronger than to other countries in the region. The rest of East Asian countries are scattered around, with no clear sign of clustering among them, with China and Vietnam located at the other end of the map.

Figure 3.a. MDS Map of Parts and Components in 1985



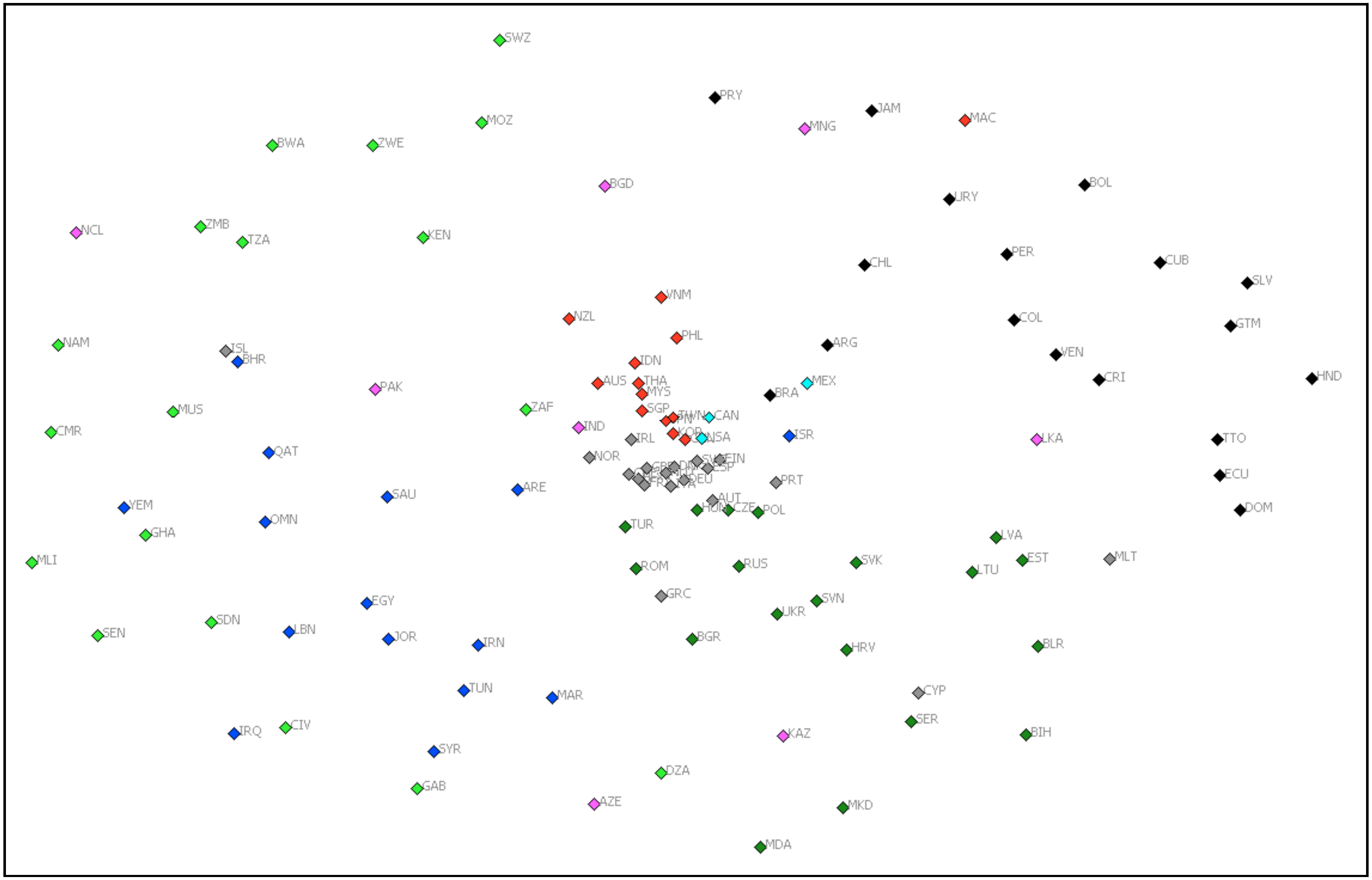
Similar pattern can be observed in other geographical groupings. The regionalization of European countries is also limited to some industrialized western European countries. Other European countries, such as Portugal and Ireland are yet fully integrated to the network of machinery production in the region. Eastern European countries are far away from the western European countries, indicating no significance trade relations between the two regions. Nor there is visible sign of clustering among the Eastern block countries. While most Latin American countries are located in the same part of the map, they are relatively far from each other indicating low intensity of trade in parts and components.

A totally different picture can be observed in Figure 3b, which describes the situation in 2005. Regionalization of trade in parts and components is more prevalent in this picture. East Asian countries seem to be more clustered during this time compare to the situation in 1985, with some more developed and developing countries are located closed to each other, indicating strong trade relation among them. Note that European and East Asian countries are located next to each other, with US and Canada being part of the core of the map.

We can also observe integration in other parts of the world in line with geographical location of the countries. Countries in Central and Eastern Europe tend to be clustered in the same part of the map, while some countries, such as Czech Republic, Poland and Hungary, are virtually integrated into the western part of the continent. To a lesser extent, Latin America countries are closely located to each other, particularly Brazil, Mexico and Argentina. Other regional groupings such as Africa and Middle East, while demonstrating trend of greater integration, are still located far from each other due to low intensity of trade relations in parts and components among those countries.

The results from MDS maps of trade in parts and components present some interesting features of global production sharing that is difficult to see using more conventional descriptive techniques. Regionalization of production fragmentation, which is normally only assumed in many studies, can be noticeably observed with the application of this technique. While mapping trade relation in parts and components provides clear visualization on the pattern of trade and the tendency of regionalization, it is useful to see this regional indication using more appropriate techniques to supplement our ongoing exploration on global production sharing.

Figure 3.b. MDS Map of Parts and Components in 2005



Further Notes on Regionalization of Trade: Cluster Analysis

One method that complements the application of multidimensional scaling is clustering analysis. Clustering is the process of organizing a set of data into groups in such a way that observations within a group are more similar to each other than they are to observations belonging to a different cluster (Martinez and Martinez, 2005). Although this type of analysis is not normally considered as part of network analysis, we employ some techniques to present a clear cut analysis on regionalization of production sharing.

In this paper, hierarchical clustering method will be applied to the results of multidimensional scaling from previous section to see the degree of association between regionalization of trade pattern and geographical distribution. Hierarchical clustering is a simple agglomerative algorithm based on a set of nested partitions. Given a set of **V** objects with $v \times v$ distance matrix $\mathbf{D}=\{d_{rs}\}$, where its elements is the Euclidean distance between countries *r* and *s* from our previous multidimensional scaling results, hierarchical clustering runs from *v* number of clusters each containing a single object to a single cluster containing all objects.

The goal in hierarchical clustering is to link the two closest clusters at each stage of the process. At the first stage, two closest clusters are simply two closest objects, where the distance between them is minimum. However we need to define the distance between clusters at the next stages of clustering iteration. In this analysis we follow *Complete* method in which distance between two clusters *p* and *q* is described as the furthest distance between objects in those two clusters.

The most common way to visualize the result of hierarchical clustering is by visualizing it using a dendrogram. A dendrogram is a tree diagram which final leaves represent all individual objects evaluated. Each object is connected to the other by sub-branches of the tree, arranged in a hierarchical or nested manner. The position of each object in a dendrogram determines its relevance to other objects. Objects that belong to the same sub-branch of the tree are relatively closer than the ones belong to different sub-branches. In our exercise, the objects are all nations in the sample. Their positions in the nested-tree dendrogram determine how countries can be clustered together.

Figure 4.a Dendrogram of Parts and Components 1985

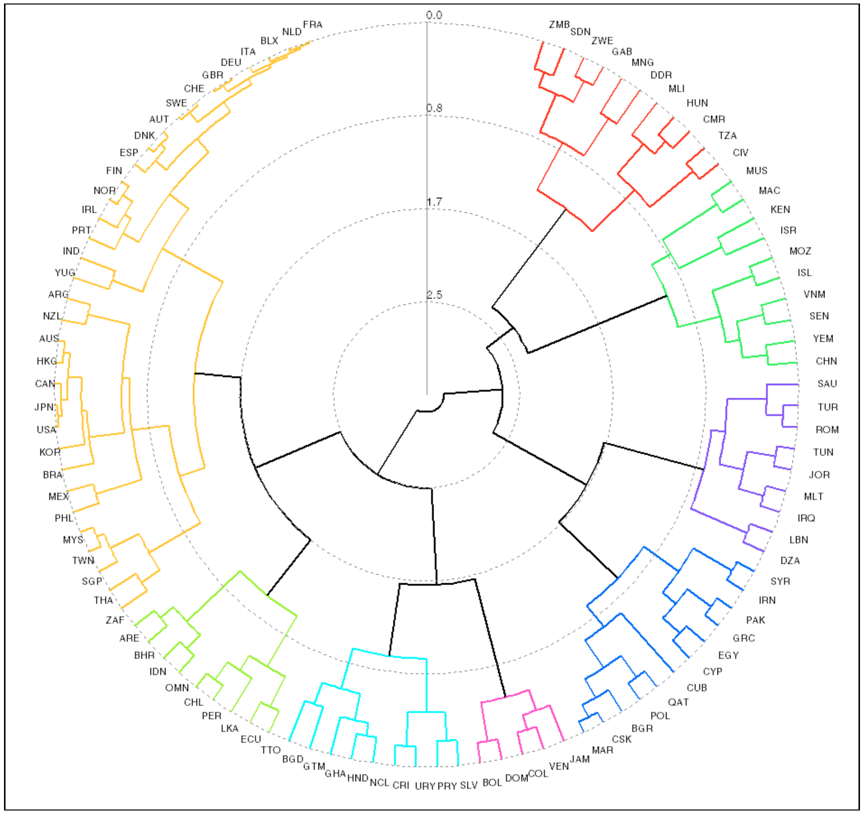


Figure 4.b Dendrogram of Parts and Components 2005

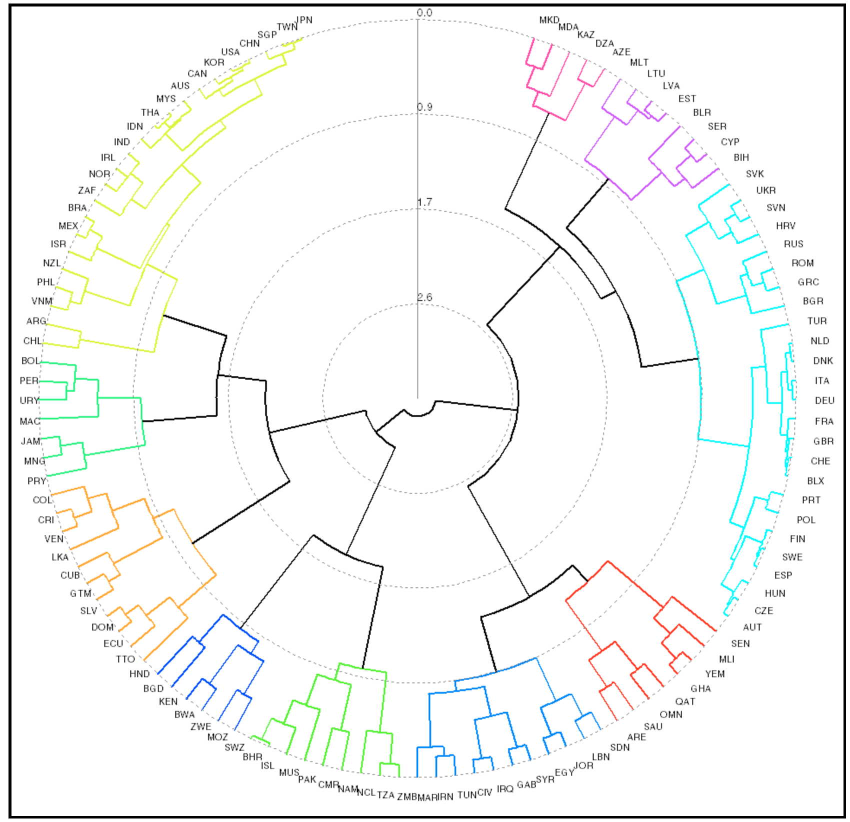


Figure 4.a and 4.b present the results of our clustering exercise. As can be seen in the dendrogram for 2005, the leaves for China (CHN) and USA, for example, are closely positioned and belong to the same farthest sub-branch, indicating strong relation in trade of parts and components between the two countries. China and USA are also relatively closed to Korea (KOR) and Canada (CAN) as they belong to the same sub-branches, despite at higher level. Interestingly, China is relatively far from Japan since they share sub-branches of the dendrogram at relatively higher level.

This dendrogram serves as a basis for further analysis which leads to grouping of countries. There are several common methods for grouping of objects based on information in the dendrogram. The simplest one is to get a group based on certain level of sub-branches. Countries belong to, for instance, the 4th sub-branches from the center are grouped together. Most common way is to classified countries based on the distance between the center and sub-branches.

The normalized distance is represented in the dendrograms by radian circles in the graph with certain values attached. In dendrogram of 2005, if we have a cut-off point of less than 0.5, most East Asian countries, together with Canada and USA will be grouped together. Color-coding of sub-branches in our dendrograms is based on cut-off point of 1. Countries with the same color belong to the same group. This results to countries being grouped according to the color-coding.

More proper way to classify objects is by deciding certain number of groups to which all objects would belong to. Based on the distance between leafs – a bit different than distance from the center previously used for color-coding the leaf - each country can then be placed in a particular group. A *rectangle tree map* (Wills 1998) is a convenient way to present and evaluate clusters with their associated members. Figure 5.a and 5.b present tree maps for countries based on trade in parts and components for 1985 and 2005 in 10 groups.[10]

---

[10] The original tree map normally uses color-coding to see the clustering of objects by comparing to certain criteria. Here, we just spell out the grouping of countries and do the comparison using different method. Selection of 10 groups is basically arbitrary although one can use more formal method to choose the appropriate number of groups.

Figure 5.a Treemap of Countries in 1985

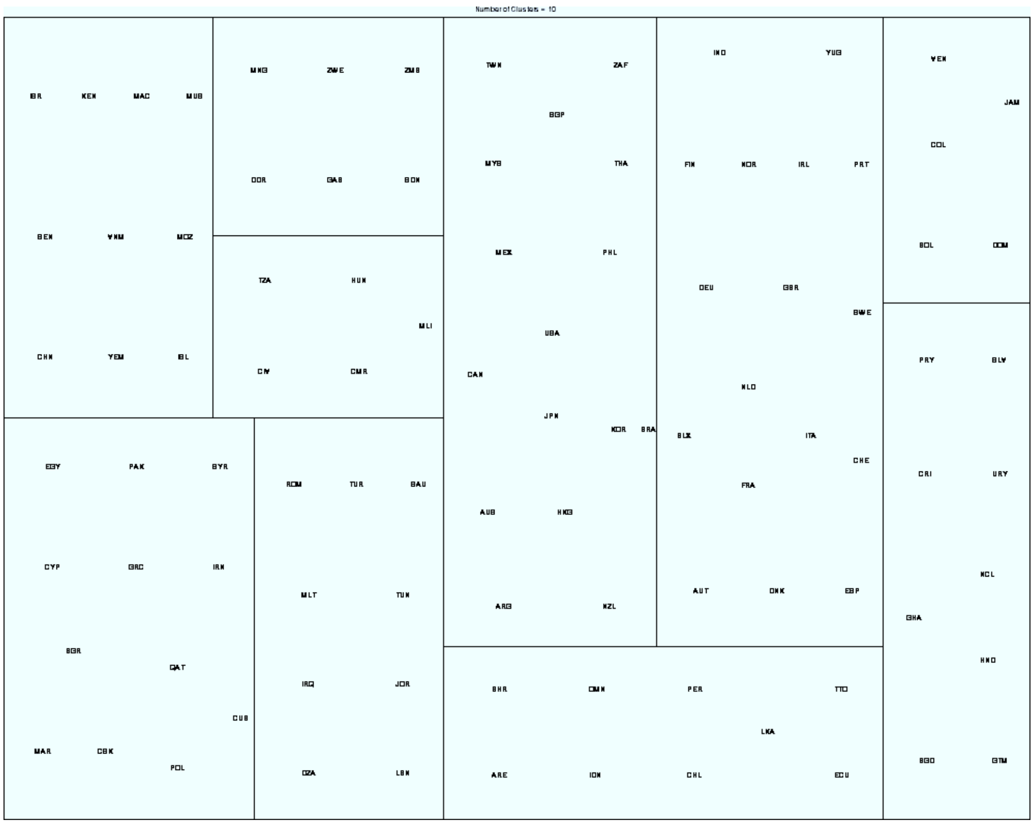
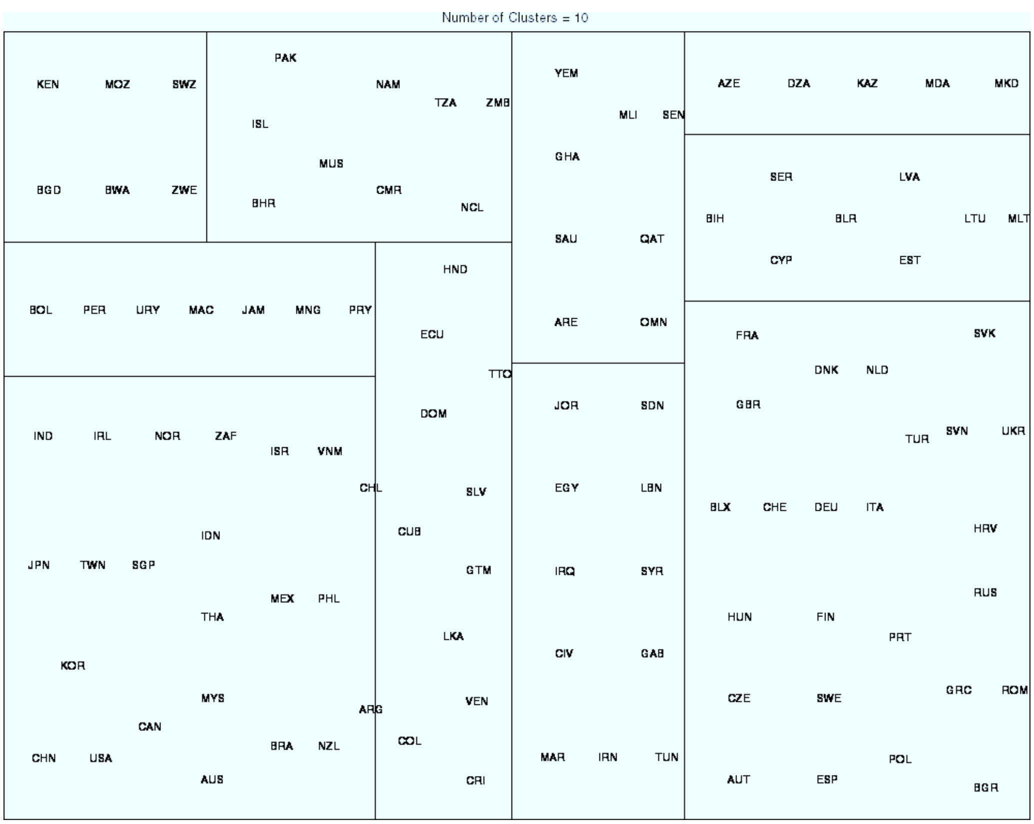


Figure 5.b Treemap of Countries in 2005



As we can see, the grouping of countries follows loosely regional classification commonly recognized, although here and there, there are some exceptions. It is interesting to see how far this grouping resembles regional classification, and how different the situation is in 1985 and 2005. Following the results, we can see that countries in the same geographical regions are more inclined to be grouped together. This grouping is even more observable in 2005. East Asian and North American countries are closer recently than in the previous period. Latin American countries also belong to the same group while they are rather scattered in 1985. Similar pattern of regionalization as it is observed in our previous network analysis are more apparent using this cluster analysis. To provide clear-cut examination, we can compare how far the grouping from clustering analysis bears resemblances to geographical regions.

One way to see it is by looking at *adjusted Rand index* (RI_A) which measures the similarity between classifications. The index indicates the proportion of objects that agree between two groupings, which is calculated as the ratio of the difference between numbers of pairs in agreement and its expected value (N) with the difference between maximum numbers of pairs in agreement and its expected value (D). Given two partitions of G_1 and G_2, each has p and q number of groups, RI_A is defined as

$$RI_A = \frac{N}{D} = \frac{\sum_{pq}\binom{n_{pq}}{2} - \frac{\sum_p \binom{n_{p.}}{2}\sum_q \binom{n_{.q}}{2}}{\binom{n}{2}}}{\frac{\sum_p \binom{n_{p.}}{2}\sum_q \binom{n_{.q}}{2}}{2} - \frac{\sum_p \binom{n_{p.}}{2}\sum_q \binom{n_{.q}}{2}}{\binom{n}{2}}}$$

where n_{pq} is the number of objects placed into group p in G_1 and q in G_2, while $n_{p.}$ and $n_{.q}$ denote the sum of n_{pq} with respect to each partition. Therefore RI_A is a standardized measure that gives a value zero when the groupings are randomly placed and one if they perfectly match each other.

We compare the groupings of countries presented in Figure 5.a and 5.b with respect to common regional classification described in Appendix B. The adjusted Rand index for 1985 is 0.308, indicating relatively weak correspondence between regional groupings and groupings based on trade relation in that period. The index is also still low in 2005, which is only 0.464[11]. Roughly speaking, this index shows that almost half of the nations in our sample fall into the same category of their geographical regions in 2005, an increase from only 30% of them in 1985. While the match between those two grouping are still low, there is a tendency of higher regionalization in trade relations.

The application of clustering analysis supports the indications we obtained in the previous section. Global trade in parts and components tends to occur between nations belong to the same region and it becomes stronger over the period of observation. Clustering also provides some information on the extent of this regionalization.

How Different 1985 and 2005? Globalization vs Regionalization

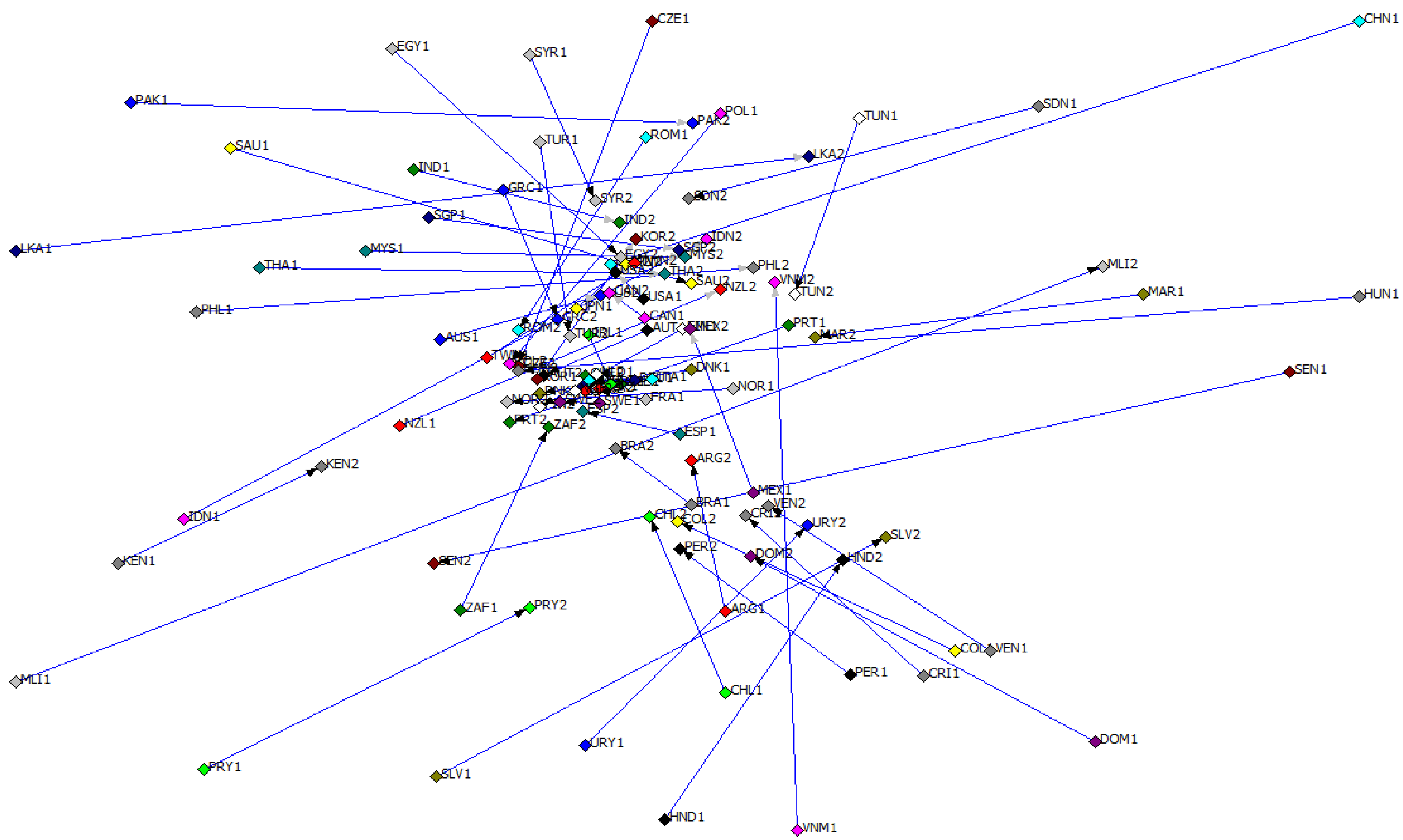
The notion that trade relation, particularly in parts and components tends to be increasingly regionalized is quite noticeable in our preceding analysis. The maximum spanning trees for trade network in parts and components show that the connection mostly takes place among a particular hub country and its spoke, indicating grouping in global production sharing practice. Visual observation with the map of multidimensional scaling analysis shows that countries tend to have more trade relation with their neighbours, in particular for East Asia, European and Latin America economies. In all those regions, one big and important country performs as the hub and its smaller neighbours become the spokes. This regional tendency is further confirmed by clustering analysis, which clearly outlines intensification of regional activities in the production fragmentation.

Rand index of clustering analysis shows that the grouping of countries based on trade relations in 2005 follows regional classification more closely than in 1985. However, it does not say much on to what extent the pattern of regionalization has changed during twenty years of observation. Once again, we apply the MDS analysis to see the pattern of trade in parts and components for two observation periods of 1985 and 2005. Rather than having two maps separately presenting the two periods, the comparison can be done on the same map. The comparison cannot be done directly by putting the MDS coordinates of the two periods directly, since both maps are produced on different spaces: 1985 trade relations and 2005 trade relations. In order to do the comparison, both maps need to be translated, rescaled, and rotated to place the countries in the same space.

---

[11] Alternatively, we can also compare the clustering outcome from trade relation and clustering based on geographical distance of countries. The index for this comparison is 0.26 in 1985 and 0.39 in 2005.

Figure 6. MDS Map of Parts and Components in 1985 and 2005



A statistical analysis known as *Procrustes* provides general transformation of shapes into a different space. The application of Procrustes transformation to the MDS maps of trade relation is presented in Figure 6[12]. The map places the countries on the same two dimensional space describing trade relation in parts and components for the period of 1985 and 2005 together to allow direct comparison. Nodes with country label 1 denotes the position of each country in 1985, while nodes with label 2, represent the position in 2005. To make the map more readable, we only show positions for 50 countries in Figure 6.

Again, the tendency of regionalization is quite noticeable. Countries in East Asia, Europe and Latin America are closer to each other in 2005, and tend to cluster following geographical regions. However, there is also a tendency that all countries to become closer as a whole. While countries have more intensive trade relations with their neighbours, they also increase their trade with the rest of the world. The MDS map shows that the groups have a tendency to move closer to the center of the map, indicating more intensive relations between countries from other different groups. The result of this examination suggests that while the development of production network of machinery has taken place at regional level, it also has occurred at the more global level.

In summary, our exercise in this section using statistical methods and techniques borrowed from network analysis and graph theory presents some interesting indication. Following the hub and spoke structure of trade network, trade relations tend to be concentrated to several important nations. These countries play important roles in building production sharing network among their group of nations. Further analysis reveals that this grouping follows geographical regions, and becomes stronger in the recent time. However, in addition to regionalization, there is also a tendency towards more globalization as each region becomes more actively connected to others. To complement the analysis on trade network, we now turn to information provided by input-output tables in the next section.

3 Beyond Trade Data: The Network of Production

Analysis in the previous section describes several features of global production sharing by looking at trade data on parts and components using various tools from network analysis and graph theory. Using trade statistics to examine production fragmentation suffer the risk to

[12] There are also some attempts to develop dynamic MDS procedure, in which time dimension is taken into account directly in the formation of the map, instead of doing it separately. However, Procrustes analysis offers much simpler procedure with reasonably accurate outcomes (Cox and Cox 2001).

overestimate its importance due to double counting in the construction of the data as discussed in the introduction section. Some attempts have come up with more comprehensive measure by combining information from international trade data and table of input output of production. Hummels, Ishii and Yi (2001) pioneered for this approach. In this section, we follow their lead in using input output tables as a complement to trade statistics. The goal is to reveal more features – especially the network features – of international production sharing.

The method developed in this paper differs from current methods of combining trade statistics and input output tables in which we take into account the network properties of global production sharing. Existing methods mostly measure production sharing activities of a country as the role of imports to production and exports. For example, the parts of US exports (both final and intermediates) that comes from its intermediate imports; the basic approach is to calculate the import-contents of US exports. In other words, it focuses on triangular linkages between domestic production, imports and exports of a single country.

Although this approach can be applied to a lot of number of countries, the single-country perspective misses the higher order network linkages. For example, the US imports of parts and components from other countries is likely to contain some sub-parts and components from the US manufacturers itself. The standard way would not recognise that some of the US imports of intermediates actually contain US value added. There are many other examples of network features that the focus on triangle linkages misses. In short, the standard approach does not capture effects of the whole global network of production sharing to countries in question. By putting it in a network perspective, our proposed method tries to capture such aspect more completely.

In order to take advantage of the new analysis, we need to transform information from input-output tables, together with trade data, to represent international linkage of production process. But before going on to the core of the analysis, we first examine some indicators using current procedures to enable comparison with the proposed procedure.

The input-output tables used in this section come from the OECD IO tables. These tables provide harmonized information on production structure of 20 good sectors (and 17 service sectors) based on the aggregation of 2 digits International Standard Industrial Classification (ISIC) version 3. It includes information on input-output structure of production for 7 machinery products[13]. There are IO tables for 42 countries of OECD and several emerging countries available every 5 years. To complement the information from OECD IO tables, we also collect three more IO tables of East Asian countries, which are not available from the OECD database[14].

3.1 Some Indicators of Production Unbundling

Before explaining our new methods, we apply standard methods to the IO tables in order to provide the basis of comparison between the standard methods and our new methods. Specifically, we calculate indicators based on methodology proposed by Hummels et al. (2001), i.e. the use of imported inputs to produce goods that are afterwards exported. These indicators are applied to look at the importance of international production sharing in the machinery sector.

Import Contents of Exports

The first indicator is the value of import contents of exports, also known as vertical specialization index in Hummels et al. (2001). This indicator is computed by taking into account the share of imported inputs, directly and indirectly, used in production, including for exports. The result is the value of exports coming from imports. The formula can be written as

$$IC_r^k = c_r^k X_r^k$$

Where

$$c_r^k \in \mathbf{n}'\mathbf{C^m}(\mathbf{I} - \mathbf{C^d})^{-1}$$

X_r^k is exports of product k from country r, $\mathbf{C^m}$ and $\mathbf{C^d}$ are the coefficient matrices imported and domestic intermediate input respectively derived from the input-output table of r, while **n** is a column vector with elements of zeros and ones indicating certain intermediate inputs to be included in the calculation. This column vector acts as the summation vector of the share of intermediate inputs in the production. In our calculation, elements of the vector are kept to be zero except for the ones related to the machinery sectors.

---

[13] The seven machinery sectors include general machinery, electrical machinery, office machinery, motor vehicle, other transport, precision machinery and telecommunication.

[14] We complement the data with IO tables from Malaysia, Singapore and Thailand. Fortunately, machinery sectors are relatively well defined and classified quite uniformly in various countries IO tables. It makes the harmonization attempts for those tables are relatively easier.

By assuming that the production structure of exports is the same as the production structure of domestic consumption, we can use the calculated coefficient of c_r^k, combined with the value of exports from trade statistics, to compute imports value of country *r* embedded in its exports for each product *k*. Notice that these *IC* measures are basically measures of a single node's involvement in the entire network, i.e. imports from all nations are summed, and exports to all nations are summed.

Figure 7 presents the distributions of import contents for each seven machinery sector. As we can see, the import contents of each product differ significantly across country. Electronic sector, which include electrical, office and telecommunication, are the most varied sectors in terms of import contents. They are also among the most import intensive sectors, other than motor vehicle.

Figure 7. Import Contents of Production across Countries

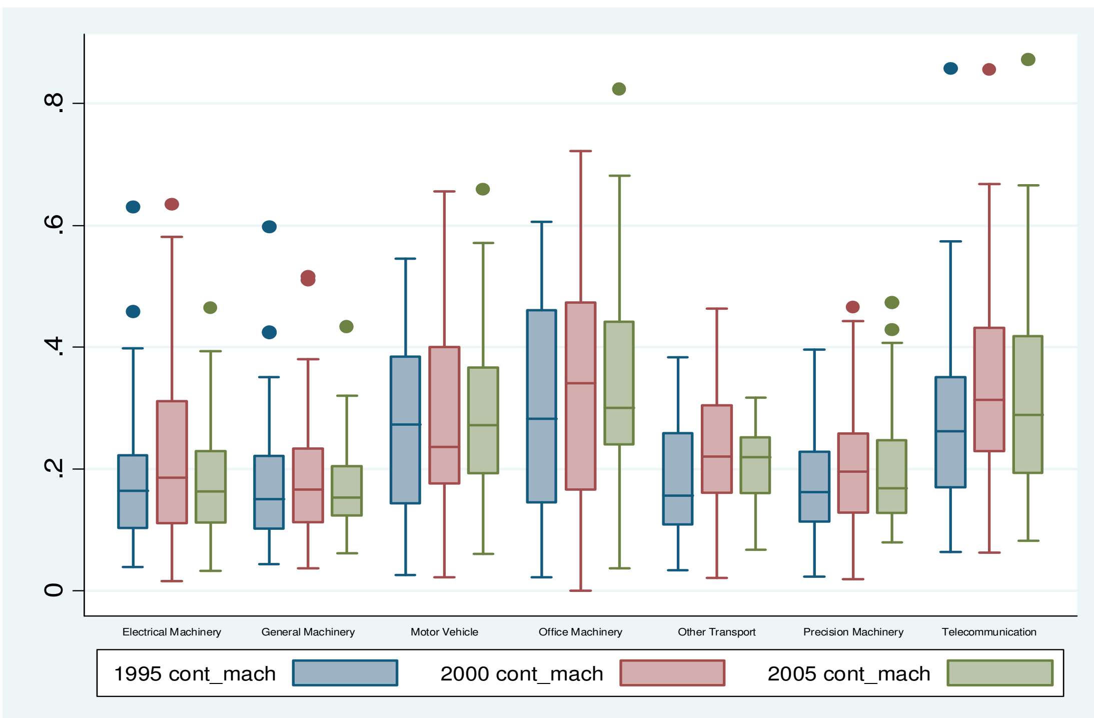
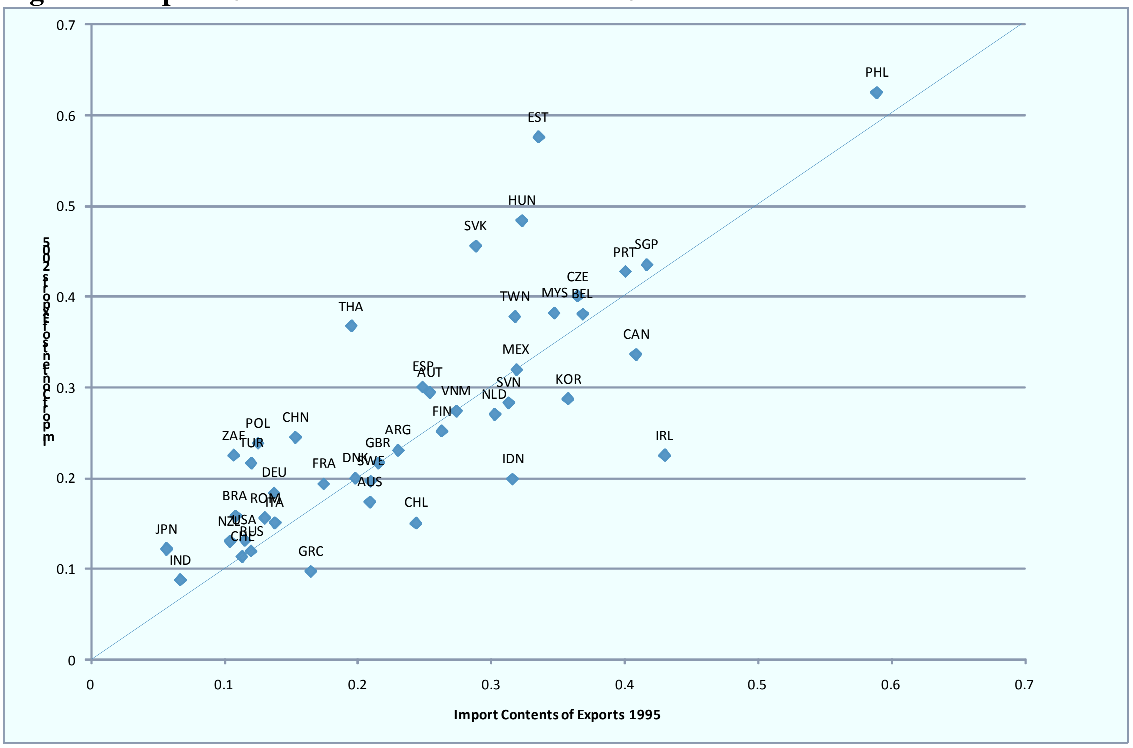


Figure 8 presents the share of import contents of exports (*IC*) for machinery products in 1995 and 2005 for 45 countries in the sample. This is calculated as weighted average of import contents of exports for each of seven machinery products, with export value as the weight. Therefore there are two factors that can explain the change of import contents during the ten years period, which are the production structure of each of seven machinery sectors and the importance of each sector in exports of machinery. Bigger trade in one of the machinery products that consumes more imported inputs would result in higher share of import contents of the machinery.

Figure 8. Import Contents of Production across Countries



Re-exporting Share and Production Integration

As mentioned above, the import contents of exports is only part of the story. The other part of the story is related to the share of imports from other countries that would be further processed for exports. This indicator *RX*, which stands for re-exporting index, shows the importance of a particular country in the network. Higher share of imports that would be further exported indicates higher integration of the country into global production network. A country that uses most of its imports to produce exports can be considered as an important link in the network of production sharing, while a country that only uses a small share of its imports in its exports to be less influential.

$$RX_r^k = IC_r^k \, X_r^k \big/ M_r^k$$

Furthermore, the *RX* indicator can be used to give a preview on network aspect of production sharing. Network features of production sharing imply that parts of the exports of a particular country *o* would be re-exported by its destination country *r*. When a country *o* exports its products to country *r*, and country *r* embeds these imports in exports to other nations, the global production network has enabled country o to export to the rest of the world, but indirectly.

If a significant part of *o*'s exports goes to destinations with high *RX,* it is likely that a significant share of the exports would be used for producing destination countries' exports. South East Asian countries, for example, are better connected to the global network since their major destinations are China and Japan, which embed high shares of imports in their exports (*RX*). This indicator of *PI*, stands for production integration, captures certain network aspects of production sharing by looking the second-degree relations in trade and production. Assuming that country *r'*s share of imports embedded in its exports (*RX*) is invariant to the origin of imports, then *PI* of nation *o* is simply a weighted average of its destination's *RX* and each market's export share.

$$PI_o^k = \sum_r \frac{X_{or}^k}{\sum_r X_{or}^k} RX_r^k ; \quad r \in R : \text{country in the sample}$$

Figure 9. Re-exporting Share of Imports (RX)

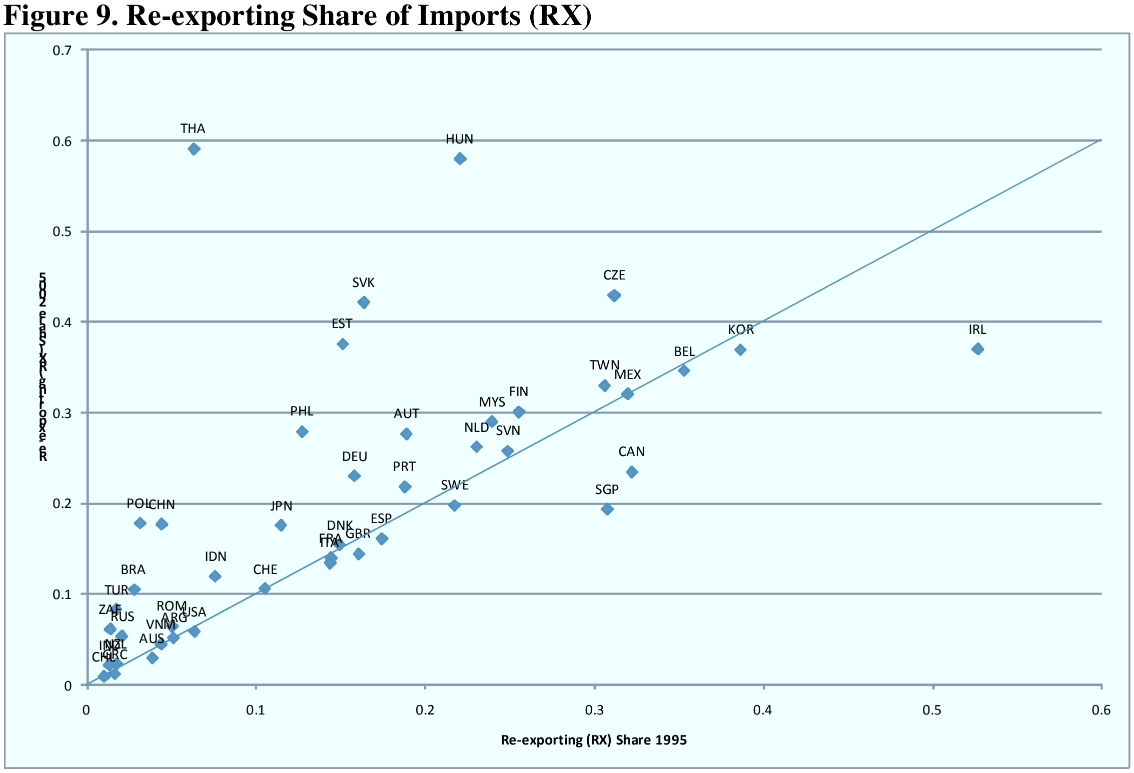
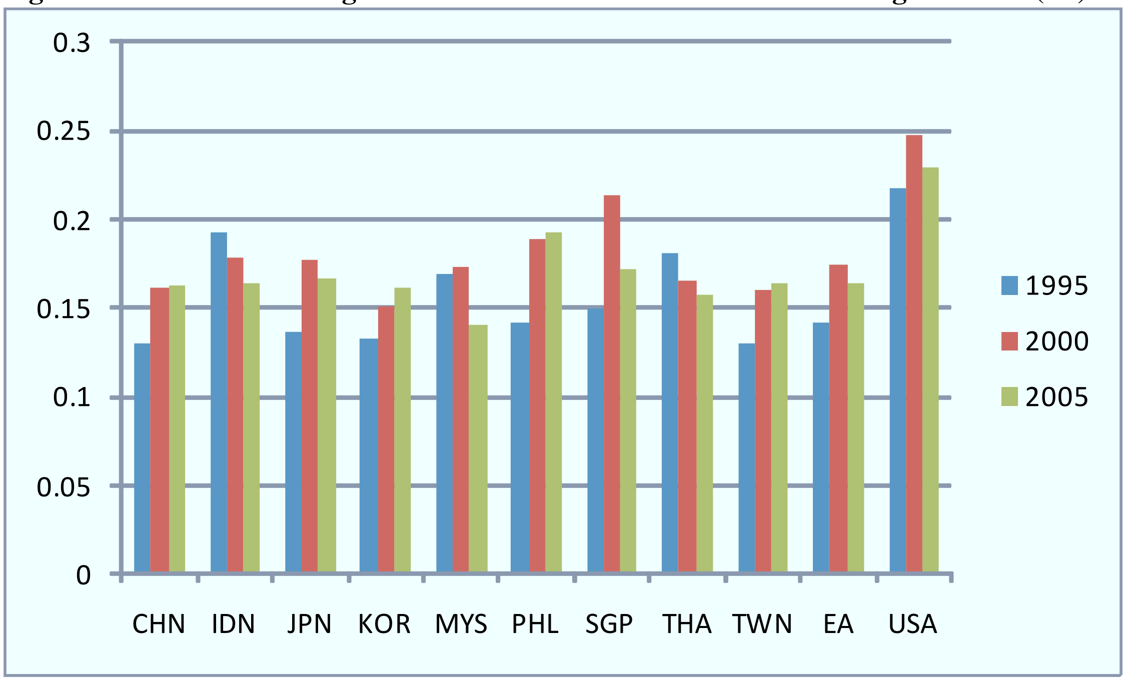


Figure 9 presents the share of imports re-exported further of 45 countries for 1995 and 2005. The noticeable feature from the graph is that most countries only re-export further small parts of their machinery imports. Here we can see that the biggest part of the imports remain to in the domestic economy. However, there clearly is an upwards trend of this re-exporting share for most countries.

Figure 10 describes how well connected countries in East Asia and USA are to the international network of production sharing. In general, more than 10% exports of these countries are embedded to their partner's exports. China and some other countries are clearly becoming more integrated, while some others slightly reduce their interconnections.

Figure 10. East Asia's Integration to International Production Sharing Network (NI)



Some indicators explained and calculated above give some indications on the patterns of production sharing. The calculation of import contents of exports (IC) can give indication of how important production sharing is in a particular country. Moreover, the indicator can be used to see how well the country has been integrated into the global production network by looking at the extents to which its production is used by other countries.

However, as discussed above, they focus only on triangle linkages (a single nation's imported inputs, production and exports). *IC* index for country *r*, for example, only measures effect of country *r*'s imports on its exports. Index for production integration (*PI*) of country *o,* while take the analysis a bit further, is still limited to examine the effect of *o*'s production on production activities in its destination countries. It is difficult to see production linkages beyond this triangular relation. This might lead to a misperception of the true nature of the production network.

Indicators of *IC* and *RX* for our sample of countries, for instance, might lead to conclusion that countries like Philippines or Thailand are better connected to global production sharing network than China and Japan (Figure 8 and 9). A priori, such a conclusion is not credible given the abundant anecdotal evidence[15]. The two indicators basically tell us that production sharing is important and might shape performance of the countries' trade and production. They do not, however, tell us about how important and how well connected these countries are in the global network.

While *PI* indication provides some aspects of the necessary information, it is focusing only on triangle connections; it takes no account of effects from the rest of the network. As such, it might lead to inaccurate conclusions. In East Asia, for instance, the indicator shows that South East Asia countries seem to be more connected than their northern counterparts (Figure 10). This is not in line with common proposition based on case studies and our analysis of trade network in previous section. These shortcomings are what motivate our search for a new procedure that does not only offer better way in calculating the indicators, but also better perspective to approach the problem.

The next sub-section offers new angle in looking at production sharing with the help of input output tables. The new procedure enables us to see the contribution and role of a particular country, not only to its direct partners, but also to the whole global network of production sharing.

3.2 New Measure of International Production Sharing

As discussed earlier in the introduction section, the recent development of international production sharing is a complex arrangement involving not only production process, but also intensive logistics and cross-border transportation, as well as sophisticated coordination and management systems. However, at the very basic form, this phenomenon is similar to other economic activities, in which production flows from one place to another, where the value of products is improved by further processing. The input-output table is basically constructed to describe the flow of production across sectors in a single economy. In the following, we look at the international production sharing activity as the flow of production

[15] Some surveys of Japanese MNCs shows that their activities in China are much higher than their counterparts in ASEAN countries. See survey from METI available at http://www.meti.go.jp/english/statistics/tyo/kaigaizi/index.html, or from JBIC at http://www.jbic.go.jp/en/about/press/2010/1203-01/index.html

– but rather than describe flows across sector within a nation, we put emphasis on cross-borders flow within a single sector.

Input-Output System of Network Flow

The insight that economy can be visualized as a system similar to network flow model is not new. In fact, the famous input output model shares many characteristics of network flow model, where goods and services flows across sectors satisfying a set of constraint (Leontief 1974). Olsen (1992) demonstrates that both quantity and price model of economic input-output resemble special cases of network flow problems commonly found in network of transportation and network of electricity current.

A system of economic input-output can be described as a matrix which is equivalent to the adjacency and weight matrix of a network. The basic form of input-output matrix normally follows the description below.

$$\mathbf{T} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} & d_1 \\ a_{21} & a_{22} & \cdots & a_{2j} & d_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & d_i \\ f_1 & f_2 & \cdots & f_j & 0 \end{bmatrix} = \begin{bmatrix} \mathbf{A} & \mathbf{D} \\ \mathbf{F} & \mathbf{0} \end{bmatrix}$$

Sub-matrix **A** in the IO system corresponds to cross-sectoral links of intermediate inputs, where a_{ij} is the amount of products from sector i sold and used for further processing activities in sector j. Sub-matrix **D,** with d_i as the elements, refers to final demand, where products are sold and used for final consumption, while sub-matrix **F**, with elements f_j refers to primary factors used in the production sectors. The zero reflects the fact that the total value of inputs equals the total value of output in a closed economy.

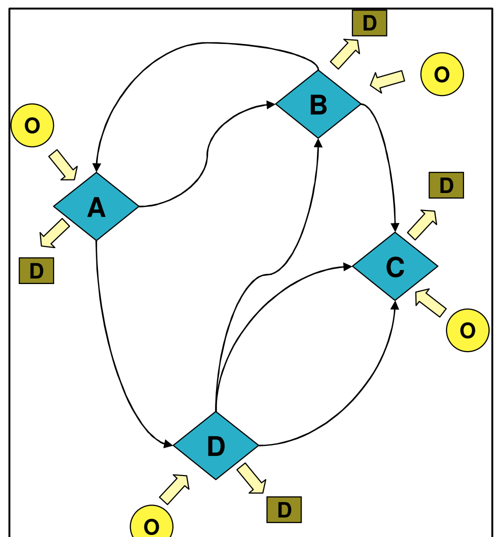
From a network flow perspective, the table represents a system of production, in which the internal part of the system, **A,** receives flow of primary inputs, **F**, from the environment and giving back **D** to the environment. In formal terms of network flow model, the intermediate input part of the table is known as internal flow of the network. Both primary factors and final demand parts of the table are known as boundary flow, where economic activity flows into and from the sectors in economy.

Using this concept of network flow, various techniques related to graph theory and network analysis can be employed to examine the structure of an economy represented by an IO table. Earlier works of this literature include Slater (1978) which employ maximum-flow concept of network flow theory to examine the structure of US economy. More recent papers including Muñiz et. al. (2010) examine core-periphery structure of European and Spain economy using network analysis and an extension of cross-entropy method[16], whilst in the same spirit Blöchl et. al. (2010) examines the centrality of cross-sectoral relations in OECD member countries.

The analysis that follows in this section shares the same perspective of the literature in network and IO system, but with emphasis on international aspects. The international linkage of production can be regarded as the flow of cross-border economic activities, not only cross-sectoral flow as described in a domestic IO model. Therefore we need to extend the information from IO by combining it with trade statistics.

Stochastic Process of Production Flow

By seeing international production flow as a network flow between countries, equivalent to cross-sectoral flow in IO model, in principle we should be able to follow the path of production flow between countries. Referring to the diagram of international production flow on the right, we should be able to follow what happens to one dollar value produced in machinery sector in country **A**: whether it is consumed domestically as final demand (D), exported to **B**, or exported to **D**. On its way through the international network of production, that one dollar value can be improved by having more inputs (O) from other production sectors and primary factors. We should also be able to follow even further the path of its travel until it reach a destination where it would be disbursed out of the system as final product (D). Information from this analysis can then be used to provide useful information on several features of production sharing, e.g. to see country's importance and role in the international value chain or to calculate its value added contribution.



International Flow of Production

[16] Cross entropy method is a method widely used to update IO table based on limited or partial newer data. It works by minimizing the distance between a-priory information derived from newer data and existing IO table.

Some case studies from supply chain and international business literatures basically follow this kind of perspective by following the path of value added in international value chain. These studies normally follow the transformation of value added of a single particular good, such as countries' value added contribution on the production of iPod (Linden et al. 2007). One problem with this type of study is they take a lot of resources to collect data and information that might not be available publicly. It is almost impossible to conduct similar study at the more aggregate level of production, such as for the whole sector, let alone for several industrial sectors.

While following cross-border path of production flows for a large number of products is not feasible in principle, it is possible to use the framework of network flow with some additional assumptions and available information to infer various features of the network.

Our new analysis proposes to see cross-border movements of value added and production in one sector following a stochastic process equivalent to a Markov process. Since we don't have any information on the path of value added and production originated from a particular country before it is discharged out of the network, in this study we assume that it follows a mechanism of random walk. In graph theory, a random walker starting from a given position chooses its next position based on certain probability of transition.

Certain parts of automobile produced in a factory near Bangkok, might end up in the assembly line of a car produced in that country, being exported to Japan or other countries, or perhaps sold in an auto-parts store in downtown Bangkok. While we do not precisely know what happens to those parts, given enough information and assumptions we can estimate probability of each situation. In a Markov stochastic process probability of change from one state to another is known as the probability of transition.

In our international network of production this probability of transition can be used to predict the likelihood position of value added and production. We can predict how likely the parts above to be exported to Malaysia or to Columbia. This information can be further exploited to calculate some random walk features that give meaningful economic interpretations. For instance, information on probability of transition can provide information on how fast production flow to reach a certain country.

In a closed economy network of production across sectors, a probability of transition matrix from one sector to another can be derived from IO tables, particularly the table of intermediate inputs. Ideally, in international framework, probability of transition requires the availability of international IO table describing not only inter-sectoral flow of production activities but also international linkages.

Since the availability of international IO data is rather scarce, we try to overcome the problem by constructing a system representing cross-country network flow of production focusing only in a particular sector, namely machinery sector.[17] The procedure explained below produces a matrix of international production linkage in the machinery sector, using available IO tables and relevant trade statistics. The matrix serves as a basis for calculation of probability of transition in international setting.

Matrix of International Production Linkage

The basic form of the matrix looks exactly like an IO system, but rather than illustrating cross-sectoral relations, its elements describe linkages between countries in a particular sector.

$$\mathbf{U} = \begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1s} & d_1 \\ m_{21} & a_{22} & \cdots & m_{2s} & d_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ m_{r1} & m_{r2} & \cdots & m_{rs} & d_r \\ o_1 & o_2 & \cdots & o_s & 0 \end{bmatrix} = \begin{bmatrix} \mathbf{M} & \mathbf{D} \\ \mathbf{O} & \mathbf{0} \end{bmatrix}$$

Sub-matrix **M** represents international links of production in a particular sector, here machinery sector, in which its elements m_{rs} correspond to the value of machinery production sold in country s, originated from country r. While the flow of production can stream between machinery sectors in different countries, at one point the production might flow out of the internal system to satisfy final demand **D.** Production activities from other sector and primary factors contribution **O**, can also flow into the internal system to add more value and activities to the machinery sector.

In the world as a whole, this is a closed system; the flows that can be treated like a normal IO system for a closed economy. Next is a brief explanation on how the table of international production linkage is constructed using information from the available IO tables and international trade statistics.

[17] Institute of Developing Economies (IDE) Japan has constructed international IO tables of East Asian countries for several periods. While these tables fit into the needs of such analysis, the limited coverage of the tables might not provide comprehensive picture on the structure global production linkage.

The IO system described above has one main condition that characterizes its equilibrium: the column sum of T is equal its row sums, emphasizing that supply of each sector's production equal to its demand.

$$\mathbf{t} = \boldsymbol{\iota}'\mathbf{A} + \mathbf{F} = \mathbf{A}\boldsymbol{\iota} + \mathbf{D} \qquad (1)$$

where $\boldsymbol{\iota}$ denotes a vector with all elements of one and $\mathbf{t}$ is a vector of sums of rows or columns.

While matrix T describes a closed economy system, most IO tables also contain some information about exports and imports from the rest of the world. In an open economy system, equilibrium condition of IO tables of country *s* can be represented as follow.

$$\sum_j a_{ij}^s + \sum_j m_{ij}^s + f_j^s = \sum_i a_{ij}^s + l_i^s + x_i^s - m_i \qquad (2)$$

where a_{ij} and f_j are the same as elements of closed-economy IO system. In this system imported intermediate inputs m_{ij} is present, while final demand is decomposed into domestic final demand l_i, exported final x_i and imported final m_i.

Compiling elements of the table to describe activities in one sector of the economy resulting to

$$\begin{aligned} & a_{ij,i=j}^s + m_{ij,i=j}^s + o_j^s = a_{ij,i=j}^s + d_i^s \quad where \\ & \qquad o_j^s = \sum_j a_{ij,i\neq j}^s + \sum_j m_{ij,i\neq j}^s + f_j^s \\ & \qquad d_i^s = \sum_i a_{ij,i\neq j}^s + l_i^s + x_i^s - m_i^s \end{aligned} \qquad (3)$$

which illustrate activities in one sector only *i=j*, machinery sector in our case, for one country *s* combined with information on how this sector relates to the same sector in the rest of the world *m*, a composite input from another sector in that country *o*, and inputs from the same sector in the country itself *a*.

The open economy part of this system, *m*, can be expanded to capture the source country of intermediate input of machinery sector. Assuming that the composition of imported parts and components used in machinery sector of country *s* follows the same pattern as its imported parts and components *M*, imported intermediate inputs of machinery sector in s originated from machinery sector in *r*, m^{rs}, can be calculated as

$$m_j^{rs} = \alpha_j^{rs} m_j^s \quad \text{where} \quad \alpha_j^{rs} = \frac{M_j^{rs}}{M_j^s} \qquad (4)$$

Identity condition derived from a matrix **U** for country *s* is written as follow.

$$a_j^s + \sum_r m_j^{rs, r \neq s} + o_j^s = a_j^s + d_j^s \quad \text{where } a_j^s = m_j^{rs, r=s} \tag{6}$$

The left hand side of the equation represents the column of the matrix of international linkage for specific country *s*. Our matrix is constructed from 45 country specific IO tables that compose 45 of its columns. The equilibrium condition of the whole matrix should take the form as follow.

$$\sum_r m_j^{rs} + o_j^s = \sum_s m_j^{rs} + d_j^r \tag{5}$$

While the left hand side of (6) can be taken directly from (5), the right side hand needs some adjustments particularly with regards to final demand d^r. There are many methods in the literature of input-output models developed to address such discrepancies[18]. However, since most of proper methods require additional information that is beyond the scope of this paper, not to mention that we basically focus on the use of intermediate input in machinery sector, in this paper we use a simple approach to calibrate the system by treating final demand of row *r* as a residual.

Using this new identity, we can construct a matrix representing cross-border production linkage in a single sector. It takes form like an IO table as described in matrix **U** above. The elements of the matrix describe production linkages for the global machinery sector, which is basically total production of seven sub-sectors, between row countries and column countries. Each element describes machinery products produced in the row country that are used by machinery sector in the column country. The last row of the matrix captures the contribution of factor of production and other sectors of production in each column country. The last column presents row country's net production consumed as final demand.

Similar to previous analysis on international trade network, conventional descriptive analysis on bilateral relations of production linkage is difficult to carry, in part because it involves quite big number of relations; in our case there are 2045 bilateral relations. The matrix is also composed by "generated data" from IO tables and trade statistics, in which

---

[18] The RAS biproportional adjustment method for updating IO table, for example, can be applied to come-up with a balance matrix of international linkage. However, we need to deal with different information on the sources of discrepancies

direct interpretation of its value might be subjected to many constraints[19]. Moreover, the nature of connections described in this matrix perfectly suits the needs for analysis of higher-order relations in a network, as previously discussed. Therefore in this paper, we use information from the matrix to apply some new concepts and methods from network analysis in order to examine some features of global production sharing.

3.3 Most Important Countries: Centrality Measures

One of the recent developments in network analysis is the application of random walk principle based on the stochastic process in examining structural characteristics of a network. Random walk model of network assumes that a walker start from a particular vertex and move to the adjacent vertices in order to reach a destination vertex. The choice of which vertices the walker choose in the next move depends on a probability determined by the associated weights. Newman (2004) uses the principle to propose some methods in analyzing weighted networks, specifically in looking at centrality structure of the network and sub-grouping of vertices.

Centrality Measures

The concept of random walk fits nicely to capture various characteristics of the production linkages described earlier. Production activity streamed from country *r* randomly chooses, based on certain probability, the next country *s* in the network, where it might get additional economic value, consumed directly as final product, or simply being transferred to another country. In this section, we focus the application of random walk principle to see centrality structure of the international production network.

We take advantage of information from the constructed matrix of international production linkage, particularly the sub-matrix **M** which captures cross-border transition of production in machinery sector. By dividing the elements of the matrix to its row sums, the probability of cross-border transition can be acquired as the basis for further analysis.

$$\mathbf{W} = (diag\ (\mathbf{M}\ \boldsymbol{\iota}))^{-1}\mathbf{M}$$

The transition matrix **W** can be seen as a weighted network *G(V, E, w)* of international production sharing, equivalent to the one for international trade previously discussed. But

---

[19] As mentioned already, the matrix is constructed following a simple procedure due to availability of information. Interpreting elements of the matrix directly might not give much information and prone to inaccuracies. Even a carefully constructed IO table is rarely used to give direct information on the flow of production, but rather used for further analysis.

unlike the network of trade relations, the diagonal elements of **W** are not zero. These non-zero diagonal elements indicate the importance of domestic machinery sector in supplying parts and components for its own production. In network analysis term, this suggests the existence of self-loop relations that has to be taken into consideration.

While it is possible to apply our earlier techniques to examine this network of production, its flow characteristic opens up more possibilities than just considering the relations as proximity, such as measuring the role and position of vertices in the network using the concept of centrality.

The concept of node centrality is an important measure in network analysis, particularly with regard to the network of social interaction. It provides information on how important a node in the network and what role it plays. In our network of production, it can be interpreted as the importance of each country in the global network of production sharing. There are three main concepts of node centrality: degree centrality, closeness centrality and betweenness centrality.

In this section we look at centrality of countries in the network of production using the concept of closeness and betweenness based on random walk. By looking at node centrality of the network, now we move from network level analysis in the previous section to individual node analysis.

Closeness Centrality

Closeness centrality indicates how close a vertex to other vertices in the network. It can be regarded as an indicator of how long the flow from one vertex reaches other vertices in the network. While the measure of closeness is clear in a distance metric like in our previous analysis, there are various ways to define closeness in a non-distance graph such as the international flow of production. Traditional method of network analysis normally defines closeness in term of geodesic distance, which is basically the shortest path between two vertices. However since the network of international production tends to be dense, geodesic distance gives little insight to its structure. Based on random walk model, Noh and Rieger (2004) suggests the use of mean first passage time (*MFPT*) to measure the distance between vertices.

MFPT basically indicates how long on average does it take for a random walker to start from r to reach a destination vertex s for the first time if it chooses the path randomly based on certain probability distribution. It calculates the expected number of steps between the two points

$$MFPT_{rs} = \sum_{x=1}^{\infty} x \, P(x|_{rs})$$

where $P(x|_{rs})$ is the probability to reach *s* from *r* at exactly *x* steps. While Noh and Rieger (2004) proposes method to calculate *MFPT* for non-weighted network, Blöchl et. al. (2010) modifies the method to accommodate calculation for weighted network. The probability can be inferred from the elements of matrix **W** by prompting that it can be decomposed to the probability of arriving at node $t \neq s$ after *x-1* step and the probability of going from *t* to *s* in the next step. Therefore

$$P(x|_{rs}) = P(x-1|_{rt}) \, P(1|_{ts}) = \sum_{t} \omega_{rt} \; w_{ts}$$

where ω_{rt} is the element of matrix $(\mathbf{W_{-s}})^{x-1}$, a modified of **W** without its *s*-th row and column, and w_{ts} the element of **W**. In practice, the vector of **FPT** denoting *MFPT* from all vertices in the network to reach a particular vertex *s* is calculated as follow.

$\mathbf{FPT} = (\mathbf{I} - \mathbf{W}_{-s})^{-1} \boldsymbol{\iota}$ where **FPT** is a vector size $r \times 1$ and $\boldsymbol{\iota}$ a suitable vector of ones.

The random walk closeness centrality *RWCC* for vertex *s* is then the inverse of *MFPT* of the vertex.

$$RWCC_s = \frac{n}{\sum_{r} MFPT_{rs}}$$

This centrality measure can be interpreted as a measure of efficiency of the flow to reach the vertex. Country with high *RWCC* means that it can be reached by the flow of production originated from anywhere easily, while low centrality indicates that the country is relatively out of reach by the international production flow.

Betweenness Centrality

Betweennes centrality defines different aspect of centrality, namely how important a vertex lies on the paths between others. In other words it measures to what extent the importance of a particular vertex to keep the network intact and to influence the flow. Conventional betweenness centrality of a particular vertex is normally measured by counting how many shortest path between other vertices go through it. However the density of international flow of production and other characteristics require more attention. Newman (2004) proposes to measure betweenness of vertex based on random walk model, by counting how often the node is visited by the walker in its effort to travel between other vertices. Here we follow Blöchl et. al. (2010) to calculate betweennes centrality for a network with self-loop nodes.

The betweenness centrality of node *s* is defined as the average number of times the node is passed through by the flow originated from all nodes *r,* including *s* itself, to the destination $u \neq r$.

$$BC_s = \sum_{r,u \neq r} \frac{PT_s^{ru}}{n(n-1)}$$

Where PT_s^{ru} is the frequency of the flow passes through *s*, calculated based on transition probabilities in **W**.

$PT_s^{ru} = \frac{\sum_u w_{st} \varpi_{rs}^u + w_{ts} \varpi_{sr}^u}{2}$ where ϖ_{rs}^u is element of $(\mathbf{I}-\mathbf{W}_{-\mathbf{u}})^{-1}$, and $\mathbf{W}_{-\mathbf{u}}$ transition probability matrix **W** without *u*-th row and column.

3.4 Centrality Measures of Countries in Production Network

Table 4 presents the result of centrality calculation based on random walk principle, both for closeness and betweenness centrality. Given that IO tables, as the most important component in constructing international production flow, are not available widely for the whole range of countries over a long period of time, in this study we restrict the analysis to only two period of time, 1995 and 2005. The analysis focuses on examining the role and position of countries in international production flow and how it changes over period of observation.

While there is a certain degree of similarity in the order of countries' centrality based on the two methods of estimation, the results also show differences due to the measurement of different aspect of centrality as discussed earlier.

Closeness centrality of countries in the network of production sharing indicates how fast production flow to reach a particular country. Higher closeness centrality of a country is related to faster time needed for production flowing from other countries to reach it. In 2005, China, USA, Germany and Japan are among the countries with highest closeness centrality measure. This suggests that those countries are easily reached by the production flow originated from all other countries. With closeness centrality of 0.055 for USA and

China in 2005, we can figure out that it takes less than 18 steps on average for production of parts and components in other countries to reach the two.

Table 4. Centrality Index of International Production Flow

	Closeness Centrality				Betweenness Centrality			
	Country	**1995**	**2005**	**Rank in 1995**	**Country**	**1995**	**2005**	**Rank in 1995**
1	USA	0.061	0.055	1	CHN	32.340	184.508	6
2	CHN	0.008	0.055	15	USA	137.097	175.014	1
3	DEU	0.044	0.045	2	JPN	102.788	112.271	2
4	JPN	0.031	0.028	3	DEU	66.956	105.967	4
5	KOR	0.024	0.022	4	KOR	94.424	69.666	3
6	FRA	0.021	0.019	6	SGP	20.949	56.187	9
7	TWN	0.014	0.018	9	FRA	35.476	47.820	5
8	MEX	0.006	0.017	18	TWN	18.164	36.832	11
9	SGP	0.023	0.016	5	CAN	19.170	34.891	10
10	GBR	0.019	0.016	7	BRA	25.584	34.573	7
11	CAN	0.017	0.016	8	GBR	24.485	27.999	8
12	ITA	0.013	0.013	10	ESP	14.888	27.112	13
13	ESP	0.010	0.012	12	ITA	17.249	25.567	12
14	MYS	0.011	0.010	11	MEX	5.508	25.542	20
15	THA	0.005	0.009	20	MYS	9.753	22.049	14
16	HUN	0.004	0.008	22	IND	2.643	16.971	29
17	BEL	0.009	0.006	14	THA	3.992	15.203	23
18	CZE	0.001	0.006	31	ZAF	2.717	13.009	28
19	SWE	0.007	0.006	17	SWE	6.813	10.837	18
20	BRA	0.005	0.006	19	HUN	2.977	9.711	27
21	IRL	0.009	0.005	13	CZE	1.596	9.588	33
22	NLD	0.007	0.005	16	BEL	9.203	9.198	15
23	AUT	0.004	0.005	21	AUT	3.703	7.912	24
24	PHL	0.003	0.005	23	NLD	8.237	7.677	16
25	FIN	0.003	0.004	24	IRL	6.886	7.405	17
26	POL	0.001	0.003	33	FIN	4.302	7.103	22
27	IDN	0.003	0.003	25	POL	2.327	6.074	31
28	PRT	0.003	0.003	27	PHL	2.471	5.987	30
29	SVK	0.000	0.002	37	AUS	5.094	5.760	21
30	AUS	0.003	0.002	26	IDN	6.596	5.380	19
31	IND	0.001	0.002	34	PRT	3.341	3.899	26
32	ZAF	0.001	0.002	36	SVK	0.523	3.726	40
33	DNK	0.002	0.001	28	NOR	1.564	2.848	34
34	TUR	0.001	0.001	32	DNK	2.091	2.676	32
35	NOR	0.001	0.001	30	TUR	3.630	2.271	25
36	ISR	0.001	0.001	29	ISR	1.391	1.543	35
37	SVN	0.001	0.001	35	SVN	1.032	0.903	36
38	EST	0.000	0.001	41	ROM	0.534	0.681	39
39	ROM	0.000	0.001	38	EST	0.242	0.659	41
40	GRC	0.000	0.000	40	GRC	0.646	0.477	38
41	CHL	0.000	0.000	39	CHL	0.783	0.199	37
42	LUX	-	0.000	42	LUX	-	0.104	42

The result of centrality estimation based on “closeness” concept is in line with the previous analysis on the structure of trade in parts and components. In analysis of trade network, we find that those countries play important roles in the network. Here, we also see that those countries are closer than others that make them strategically located in the international network of production sharing.

This measure of centrality can also be interpreted as the measure of how sensitive a particular country to a shock started in other countries in the network. A supply shock that occurs in any other countries would affect countries with higher centrality measure faster and, over a period of time, more intensely than the ones with low measure. A positive supply shock, such as an increase in final demand of machinery products, would provide better opportunities to machinery sector in China than, say, other developing countries in East Asia.

The reverse is also true. Negative supply shock would hurt machinery sector in China and other countries with high centrality measure more considerably. This is in line with what happened during the financial crisis of 2008/2009, where the machinery sector saw a very significant drop in trade and production due to the fall of demand. Countries fully connected in the international value chain of the sector, such as China and USA are affected faster and more significantly than other less connected countries (Baldwin 2009).

Betweenness centrality measures the importance of a country by estimating how often that particular country is visited by the flow of production streaming from a certain part of the network on the way to other parts: higher number of visits indicates the country’s importance as a “bridge” in the production network. This is a basic concept of betweenness centrality. However, since the network of international production flow is a weighted network and consists of domestic processing of the flow (self-loop), the centrality should also considers how long the production flow is inside the country for processing before it leaves. The stochastic random walk method used in this study takes that aspect into account: larger weight of self-loop increases centrality of the country.

Similar pattern of centrality can be observed following the estimation of betweenness centrality. USA, Japan and China are among the most central countries in the network. Like analysis of trade network shows, those countries are among the most important hubs in the global network of production linkages. High measure of betweeness centrality indicates that if we drop one of these countries from the network, then it significantly disturb its structure and interrupts global production sharing activities.

It is worth mentioning that China's importance in the network is mostly due to its size of domestic machinery sector. The calculation also considers the weight of domestic sector to capture how long the production flow remain in the country, even though some countries might serve as more important "bridge" in the network.

Table 4 also presents the centrality measures of the same countries in 1995. It is quite obvious that there are some changes on the role and importance of those countries in international production of machinery. In addition to China, that significantly has become more important within ten years of observation, other countries, notably Mexico and several Eastern European countries, have also become closer to other countries in the network. That might be related to greater integration of those countries to other important countries in their region: USA for the case of Mexico, Germany and France for Eastern Europe.

The network of international production flow in machinery is presented in Figure 11. In order to simplify visualization of the network, only 5 highest production flows from each country are presented in the graph. Each node denoting a country is placed according to radial representation of a network based on the random walk centrality measures estimated previously. Countries with higher centrality measure are located closer to the central of the graph, while the lowest ones are the farthest. Figure 11.a shows the network of production flow according to closeness centrality measure, while Figure 11.b follows betweenness centrality.

In addition to the measures of centrality, countries in the network are also placed in relation to their interactions in the production flow. Countries with higher flow coming in and out to each other are located closer than countries with relatively low interaction. Width of the links between countries in the graph also indicates the magnitude of the production flow between them. In line with our finding in Section 2.3, countries tend to regionalize in this network of production, where countries from the same geographical region (color-coded) tend to be closed to each other. Comparing the graphs for 1995 and 2005 suggests that this regionalization is more prevalence in 2005 than in the former decade.

Figure 11.a International Production Flow with Closeness Centrality Measures

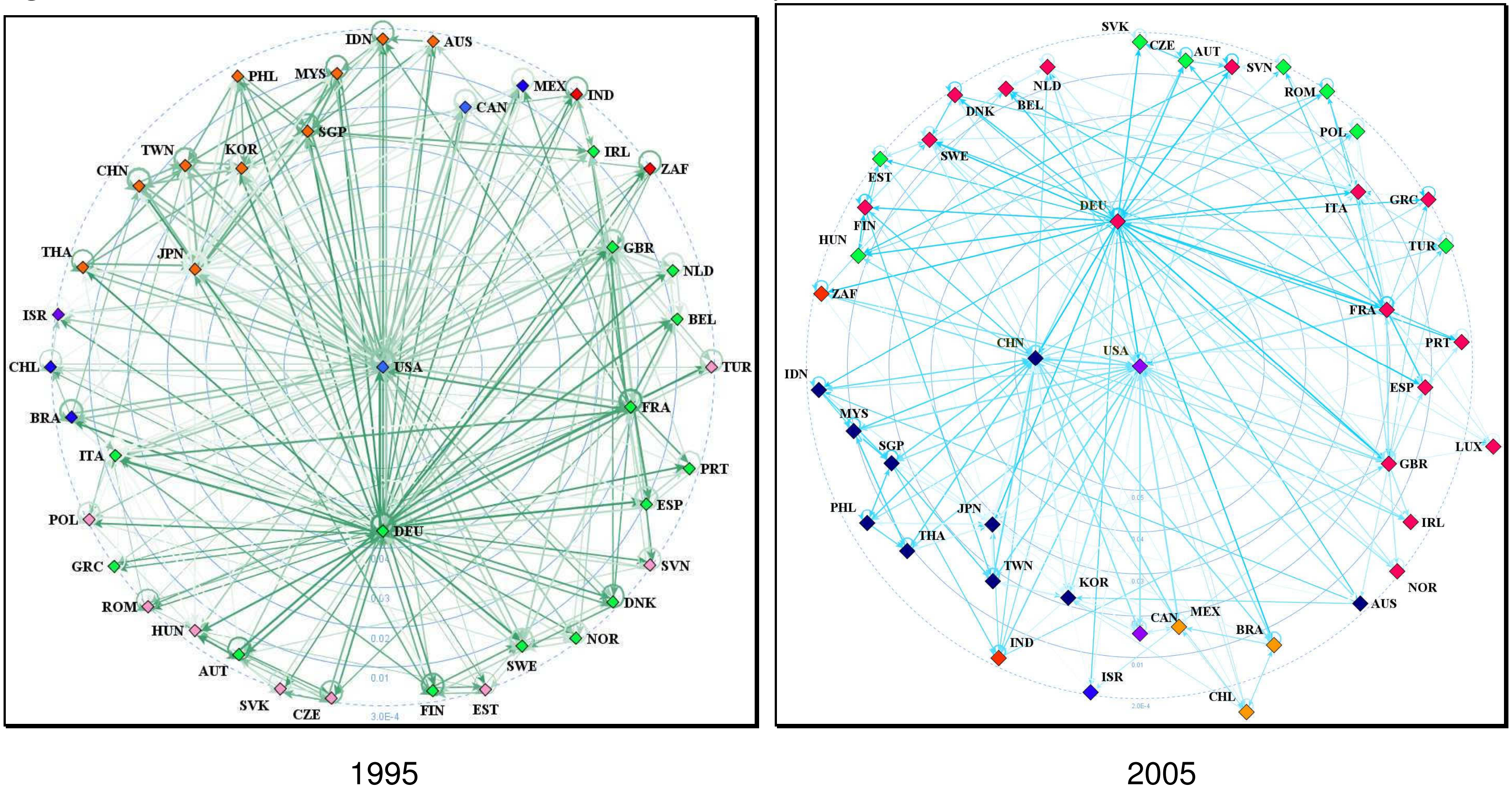
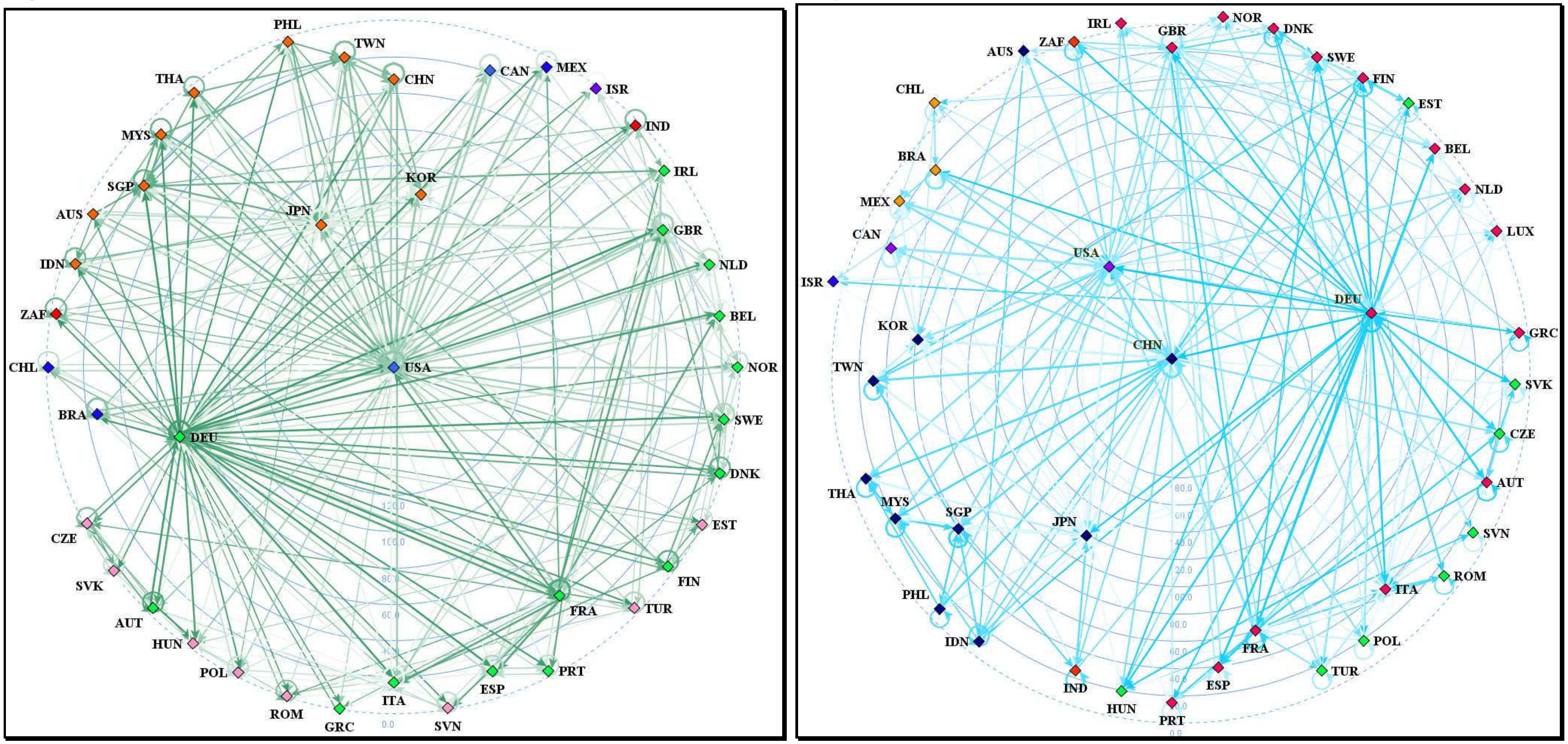


Figure 11.b International Production Flow with Betweenness Centrality Measures



1995 **2005**

3.5 International Product Fragmentation in Other Sectors

So far we have examined the pattern of international production sharing in parts and components of machinery sector. Does the new production trend can only be observed in machinery sector? To what extents are the importance of production sharing or international flows of intermediate goods in other sectors? In order to answer these questions we employ the centrality measure to examine international flow of production in some other sectors. We choose to investigate agriculture sectors as a representation of resource intensive sectors and textile as another manufacturing.

While both centrality measures normally provide indication on the position of vertices within a particular network, the nature of closeness centrality can also present meaningful suggestions towards the pattern of interaction between vertices in a particular network. It then can be compared to the pattern of interaction in other network. Since RWCC is based on calculation of MFPT, the (inverse of) centrality measure of country *s* can be interpreted as the average number of steps needed by production flow to reach that country from other parts of the world. The measure of certain countries in the networks of production of different sectors can be compared to each other to see the differences in their pattern.

Table 5. Closeness Centrality of Other Sectors (Top 15 Countries)

Agriculture		Textiles		Machinery	
USA	0.022	CHN	0.031	USA	0.055
CHN	0.009	ITA	0.024	CHN	0.055
JPN	0.005	USA	0.018	DEU	0.045
MEX	0.001	DEU	0.012	JPN	0.028
FRA	0.001	MEX	0.009	KOR	0.022
GBR	0.001	FRA	0.008	FRA	0.019
KOR	0.001	JPN	0.006	TWN	0.018
DEU	0.001	GBR	0.005	MEX	0.017
NLD	0.001	ESP	0.003	SGP	0.016
ITA	0.001	CAN	0.003	GBR	0.016
ESP	0.000	BEL	0.002	CAN	0.016
CAN	0.000	KOR	0.002	ITA	0.013
TWN	0.000	PRT	0.001	ESP	0.012
BEL	0.000	NLD	0.001	MYS	0.010
SGP	0.000	ROM	0.001	THA	0.009

The closeness centrality of agriculture and textile sector, along with machinery, is presented in Table 5. Only the centrality of top 15 countries is shown in the table.

From the table, it is quite clear that closeness centrality measure for countries according to their production flow in the other two sectors are quite different than the measure of their machinery sector's production. Countries that are highly important in machinery might not be that significant in the other sectors. We can also see that the magnitude of centrality is quite different. For instance, the centrality index of the most important country in the network of machinery production is 0.055, while in agriculture it is much smaller to 0.022, and in textile 0.03.

This index can be interpreted as the speed of production flow to roam around in a particular network. In machinery, it takes only around 18 steps in average for production flow to reach USA, the most centered country, for the first time, while it takes almost 50 steps for production flow in agriculture, and around 30 in textile sector. These indicate that international production flow in other sector might not be as fast as the one in machinery sector. It becomes even clearer when we compare less important countries in each network. While in machinery sector, the top 5 countries tend to have similar centrality measure, in agriculture the difference between the top country and the second one is very significant.

From this simple interpretation of the measure, we can figure out that production sharing in two other sectors might not be as intensive as in machinery sector. Textile industry shows its sign of the internalization of production, although still incomparable to what has taken place in machinery.

4 Conclusion

International production sharing has been emerging rapidly during several last decades. It has attracted scholarly attention from various perspectives including from international trade economists.

While there are many studies examining various trade features of this new phenomenon, most studies are either focus on regional structure of production sharing or case studies of several countries. Very little analysis has been done on the global pattern of bilateral trade in parts and components. For this reason, the existing literature underplays the network aspect of production sharing.

One obstacle in doing analysis at bilateral level of on a global data set is that it involves considerable amount of data. Some help with this problem comes from network analysis (NA) and graph theory, which provide some useful tools for extracting clear patterns from masses of data. However, applying network analysis on trade data requires careful consideration. Trade data typically focuses only on what NA calls first-order relationships (e.g. Chinese exports to the US). Many methods in network analysis, by contrast, focus on higher order relationships (e.g. when it comes to friendship network, what matters is not only the first order relations, which are friends, but also the higher order relations, which are friends of friends, etc.).

These features of NA's methods would seem ideally suited to illuminating the nature of production sharing relationships. In case of China exporting iPod to the US, for example, the relation is equivalent to the first order relations of US's imports. The nations supplying parts and components to China would be higher order imports. Unfortunately, the gathering of bilateral trade statistic was established before production sharing was common, so the data only reflects the gross value of shipments between two countries. Since there is no information on higher order trade relations, applying NA's tools might lead to inaccurate results.

There are two ways to deal with these data limitations. The first is to select NA tools that take account this characteristic. The second is to reconstruct trade statistics in a way the reveals the higher order relationships. This paper pursues both of these.

NA tools and bilateral trade data

In the first part, the paper employs several methods in network analysis and graph theory that rely only on first-order relationships. Here, we consider trade relations as proximity between countries and applying tools related to proximity relations. One lesson from applying methods from network analysis to pattern of trade in parts and components is that the practice of international production sharing tends to be concentrated in several countries. Analysis on the topological structure of trade network reveals that this global network takes form as hub and spoke. Some countries, such as USA, Germany, Japan, and latter China, serve as hubs and play more important role in connecting the rest of the world into global network of production sharing. Other countries may also play more important role than others by connecting the hubs to other lesser important countries. This tendency towards inequality of country's positions in the global network does not only appear in the network of trade in parts and components, but also in the analysis on international production flow.

The analysis on network of trade in parts and components also tells us that trading activities in parts and components occur more frequently among countries in the same regions. Visualization of countries' locations relative to others following their bilateral trade relations shows that the countries are spread with similar pattern to their geographical locations. Further examination using some clustering methods also support the finding that production sharing is heavily regionalized.

While this tendency towards regionalization has been intensified more in recent year, more exploration to trade network also support proposition that production sharing is a global practice and countries in general have become more interconnected over the years. Regionalization and globalization of parts and components trade takes place at the same time as countries trade more intensively within their regional group, but at the same time increase their trade relations with the rest of the world. This indicates that the practice of international production sharing has become more intensified and involves more countries in the last two decades.

NA tools and production sharing as a higher order network

The second part of the paper turns to studying the characteristics and features of global production sharing focusing on international production linkages. A number of efforts have already been made in the literature by combining information from input-output tables (IO) with trade statistics.

This paper offers a new way to explore IO information by applying stochastic principles of network to estimate the pattern of international production linkage. The new method captures information beyond first-order bilateral relations between countries as normally described by trade statistics. This is important given the complexity of the flows in international production networks. It also provides better examination on production sharing than the current methods employing IO tables by looking at not only direct international backward and forward linkage (or in network jargon, second-order relations), but also linkages for the whole network of production.

In order to get a clearer picture of global production sharing, a matrix of international production linkage is constructed using IO table of 45 countries and trade statistics. This matrix describes the flow of production between countries. It takes a form like an IO table, but instead of having production sectors as row and column, it has countries in its row as the sources of production and in its column as the destinations.

Cross border production linkages between countries in the matrix can be used to estimate the magnitude of higher-orders relations of global network of production sharing. The new method uses this higher-orders information as a basis for stochastic process assumed to be a feature of international production sharing. In practice, the matrix of international production linkages needs to be transformed into a transition matrix explaining probability of production originated from one country to be transferred to a particular country.

There are various methods that can be applied to this stochastic feature of international production flow. In this paper, we use an important concept of vertex centrality in network to see role and position of countries in the global network of production sharing.

Two main concepts of vertex centrality in network is worth more attention: closeness and betweenness. Closeness centrality refers to the closeness proximity of a particular country relative to other vertices, while betweenness centrality measures that country's importance in linking another country to the entire network. Assuming that production from one country moves globally following stochastic process described in the transition matrix, the two concepts of centrality of countries in network of production sharing can be estimated.

Both closeness and betweenness centrality confirm the result of previous analysis on trade in parts and components. International production sharing in machinery sector tends to be concentrated in a handful of countries. Big countries such as USA, Germany, Japan and recently China, are closer than other countries; making them more sensitive to both positive and negative shocks occur in other parts of the network. They also play more important role as "bridges" to keep the global network of production flow intact. Exploring the network of relations of those important players in machinery sector also reveals pattern of regionalization in production sharing.

In general, analysis of global production sharing by employing stochastic principle and information from IO table leads to similar insight to the result of analysis on trade in parts and components. While examination on international production flow takes into account many aspects that are not captured in the trade statistics, using the statistics to see the pattern of production sharing might not be a bad choice, considering the widely availability of trade data.

In addition to the analysis on machinery sector, analysis of international production flow can also be carried out to see the features of production sharing in other production sector. It is interesting to look at whether this practice can also be observed in other sector besides machinery. Applying stochastic principle and estimating centrality of countries in international production flow of agriculture and textile shows that production sharing in both sectors is not as strong as the one in machinery. Textile sector, however, carries much more resemblance to the machinery than agriculture.

Conclusion

This paper illustrates how the application of network analysis and principle of stochastic process opens up several possibilities for further analysis on international production sharing. There are some other applications of network analysis that are not discussed here, including deeper analysis on characteristics of regionalization of production sharing. The work in this paper is mostly exploratory. However, the findings can serve as the basis for hypothetical testing using more conventional econometric approach.

References

Athukorala, Prema-chandra & Yamashita, Nobuaki, 2006. "Production Fragmentation and Trade Integration: East Asia in A Global Context," The *North American Journal of Economics and Finance* 17, no. 3: 233-256.

Amiti, Mary and Jozef Konings, 2007. "Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia," *American Economic Review* 97, no. 5: 1611-1638

Arndt, Sven, 2002. "Production Sharing and Regional Integration," *Claremont Colleges Working Papers* 2002-10.

Baldone, Salvatore, Fabio Sdogati and Lucia Tajoli, 2007. "On Some Effects of International Fragmentation of Production on Comparative Advantages, Trade Flows and the Income of Countries", *The World Economy* 30, no. 11: 1726–1769

Baldwin, Richard, 2006. "Globalisation: The Great Unbundling(s)", Chapter 1, in *Globalisation Challenges for Europe*, Secretariat of the Economic Council, Finnish Prime Minister's Office, Helsinki.

Baldwin, Richard and Frederic Robert-Nicoud, 2007. "Offshoring: General Equilibrium Effects on Wages, Production and Trade," *NBER Working Papers* 12991

Baldwin, Richard, 2009. "The Great Trade Collapse: What Caused It and What does It Mean?", in Richard Baldwin (ed.), *The Great Trade Collapse: Causes, Consequences and Prospects,* VoxEu.org, Centre for Economic Policy Research.

Barabási, Albert-Laszlo and Eric Bonabeau, 2003. "Scale-Free Networks", Scientific American 288: 50-59

Batra, Raveendra N. and Francisco R. Casas, 1973. "Intermediate Products and the Pure Theory of International Trade: A Neo-Hecksher-Ohlin Framework", *American Economic Review* 63, no. 3: 297-311.

Blöchl, Florian, Fabian J. Theis, Fernando Vega-Redondo, Eric O'N. Fisher, 2010. "Which Sectors of a Modern Economy are most Central?", CESIfo Working Paper No. 3175.

Chen, Hogan, Matthew Kondratowicz & Kei-Mu Yi (2005), 'Vertical Specialization and Three Facts About U.S. International Trade', North American Journal of Economics and Finance 16, no. 1: 35–59.

Cox, Trevor F. and Michael A.A. Cox, 2001. *Multidimensional Scaling*. Chapman and Hall.

Dixit, Avinash K & Grossman, Gene M, 1982. "Trade and Protection with Multistage Production", *Review of Economic Studies* 49, no. 4: 583- 594.

Dunning, John, 1989. *Explaining International Production,* Unwin Hyman, London.

Egger, Hartmut and Egger, Peter, 2001. "Cross-border Sourcing and Outward Processing in EU Manufacturing," *The North American Journal of Economics and Finance* 12, no 3: 243-256.

Fagiolo Giorgio, Javier Reyes and Stefano Schiavo, 2007. "On the Topological Properties of the World Trade Web: A Weighted Network Analysis," *Quantitative Finance Papers*.

Feenstra, R.C. and G.H. Hanson, 1996. "Globalization, Outsourcing, and Wage Inequality", *American Economic Review*, 86, 240-245.

Giorgio Fagiolo, 2006. "Directed or Undirected? A New Index to Check for Directionality of Relations in Socio-Economic Networks," *Economics Bulletin* 3, no. 34: 1-12.

Grossman, Gene M. and Esteban A. Rossi-Hansberg, 2006. “Trading Tasks: A Simple Theory of Offshoring”, *NBER Working Paper Series* 12721.

Hummels, David, Jun Ishii and Kei-Mu Yi, June 2001. "The Nature and Growth of Vertical Specialization in World Trade," *Journal of International Economics* 54, no. 1: 75-96

Inomata, Satoshi, 2008. “A New Measurement for International Fragmentation of the Production Process: An International Input-Output Approach”, *IDE Discussion Papers* No.175.

Johnson, Robert C. and Guillermo Noguera, 2009. “Accounting for Intermediates: Production Sharing and Trade in Value-Added.” Manuscript. Dartmouth College.

Jones, Ronald. and H. Kierzkowski, 1990. “The Role of Services in Production and International Trade: A Theoretical Framework”, in Jones and Anne Krueger (eds.) *The Political Economy of International Trade,* Blackwells

Jones, Ronald W. and Henryk Kierzkowski, 1998. “Globalization and the Consequences of International Fragmentation”, in Rudiger Dornbusch, Guillermo Calvo and Maurice Obsfeld, eds., *Money, Factor Mobility and Trade*: *The Festschrift in Honor of Robert A. Mundell,* MIT Press, Cambridge, MA.

Jones, Ronald W. and Henryk Kierzkowski, 2001. “A Framework for Fragmentation” in S. Arndt and H. Kierzkowski Arndt, Sven and Henryk Kierzkowski, (eds.), *Fragmentation: New Production and Trade Patterns in the World Economy*, Oxford University Press, Oxford.

Kimura, Fukunari and Mitsuyo Ando, 2005. "Two-dimensional fragmentation in East Asia: Conceptual framework and empirics," *International Review of Economics and Finance* 14, no. 3: 317-348.

Kimura, Fukunari, 2007. "The Mechanics of Production Networks in Southeast Asia: the Fragmentation Theory Approach," *CEI Working Paper Series* 2007-8, Center for Economic Institutions, Institute of Economic Research, Hitotsubashi University

Kruskal, Joseph, B., 1956. “On the Shortest Spanning Subtree of a Graph and the Travelling Salesman Problem”, *Proceedings of the American Mathematical Society* 7, no. 1: 48–50.

Lemoine, Francoise and Deniz Unal-Kesenci, 2004. "Assembly Trade and Technology Transfer: The Case of China," *World Development*, Elsevier 32 no. 5: 829-850.

Leontief, Wassily, 1974. “Structure of the World Economy: Outline of a Simple Input-Output Formulation”, The American Economic Review 64, no. 6: 823-834.

Linden, Greg, Kenneth L. Kraemer, Jason Dedrick, 2007. “Who Captures Value in a Global Innovation Systems: The Case of Apple’s iPod”, Irvine CA: Personal Computing Industry Center.

Markusen, James, 2005. “Modelling the Offshoring of White-Collar Services: from Comparative Advantage to the New Theories of Trade and FDI”, *NBER Working Paper* 11827.

Martinez, Wendy L. and Angel Martinez, 2005. *Exploratory Data Analysis with MATLAB.* Chapman and Hall.

Muñiz, Ana Salomé García, Antonio Morillas Raya and Carmen Ramos Carvajal, 2010. “Core Periphery Valued Models in Input-Output Field: A Scope from Network Theory”, Papers in Regional Science 90, no. 1: 111-121.

Newman, Mark E.J., 2004. “A Measure of Betweenness Centrality Based on Random Walks”, Social Networks 27, no. 1: 39-54.

Noh, Jae Dong and Heiko Rieger, 2004. “Random Walks on Complex Networks”, Physical Review Letters 92, no. 11:

Olsen, Asger J. 1992. “Input-output Models, Directed Graphs and Flows in Networks”, *Economic Modelling* 9, no. 4: 365-384.

Paul, Donna L. and Rossitza B. Wooster, 2008. “An Empirical Analysis of Motives for Offshore Outsourcing by U.S. Firms”, *The International Trade Journal* 24, no. 3: 298 – 320.

Scott, John, 2007. *Social Network Analysis: A Handbook*. Sage Publications Ltd.

Slater P., 1978. “The Network Structure of the United States Input-Output Table”, *Empirical Economics* 3, no. 1: 49-70.

Smith, David A. and Douglas R. White, 1992. “Structure and Dynamics of the Global Economy: Network Analysis of International Trade 1965–1980”, *Social Forces* 70, 857–893.

Swenson, Deborah L., 2005. "Overseas Assembly and Country Sourcing Choices," *Journal of International Economics* 66, no. 1: 107-130.

Venables, Anthony J., 1999. "Fragmentation and Multinational Production," *European Economic Review* 43, no. 4: 935-945.

Wills, Graham J., 1998. “An Interactive View for Hierarchical Clustering”, *Proceedings of the 1998 IEEE Symposium on Information Visualization*.

Yeats, Alexander J., 1998. “Just How Big is Global Production Sharing?”, *World Bank Policy Research Working Paper* No. 1871.

Appendix A Product Classification used in Section 2 and 3

Classification of parts and components of machinery products used in the trade network analysis and gravity equation is based on the SITC version 2 of several products under heading 7 and 8.

71191 71199 71319 71331 71332 7139 71491 71499 7169 71889 72119 72129 72139 72198 72199 7239 72449 72469 72479 72591 72599 72689 72691 72699 72719 72729 72819 72839 72849 7369 73719 73729 74149 7429 7439 74419 7449 74519 74523 74999 75911 75915 75919 7599 7641 7642 7643 76481 76482 76483 76491 76492 76493 76499 77129 7721 7722 7723 77579 77589 77689 77819 77829 77889 7841 7842 7849 78539 78689 79199 7929 87429 88119 88121 88129 88411 88529

Calculation of various indicators in section 3 requires the classification of trade in machinery products into seven main products following 2 digit ISIC version 3. The trade dataset is composed from SITC version 2 following the classification below

ISIC 29 - General Machinery
7112 71191 71199 7126 7129 71331 71332 7138 71488 71499 71882 71888 71889 72111 72112 72113 72118 72119 72121 72122 72123 72124 72129 72131 72138 72139 72191 72197 72198 72199 7223 7224 7233 72341 72342 72343 72344 72345 72346 72348 7239 72431 72439 72441 72442 72443 72449 72451 72452 72453 72454 72461 72469 72471 72472 72473 72474 72479 7248 72511 72512 7252 72591 72599 72631 72641 72671 72672 72681 72689 72691 72699 72711 72719 72721 72722 72729 72811 72812 72819 72831 72832 72833 72834 72839 72841 72842 72843 72844 72845 72848 72849 73611 73612 73613 73614 73615 73616 73617 73618 73619 73621 73622 73623 73628 7367 7368 7369 73711 73719 73721 73729 73731 73732 7411 7412 74131 74132 74141 74149 7415 7416 7421 7422 7423 74281 74288 7429 7431 7434 7435 7436 7439 74411 74419 74421 74422 74423 74424 74425 74428 7449 74511 74519 74521 74522 74523 74524 74525 74526 74527 7491 7492 7493 74991 74992 74999 77511 77512 77521 77522 7753 7754 77571 77572 77573 77578 77579 77581 77582 77583 77584 77585 77586 77587 77589 7784 78612 8121 89461 89462 89463

ISIC 30 – Office Machinery and Computing
75111 75112 75121 75122 75123 75128 75181 75182 75188 7521 7522 7523 7524 7525 7528 75911 75915 75919 7599

ISIC 31 – Electrical Machinery
7161 71621 71622 71623 7163 7169 77111 77118 77121 77122 77129 7721 7731 77324 77325 77811 77812 77819 77821 77822 77824 77829 77831 77832 77881 77882 77883 77885 77886 77887 77889 81241 81242 81243 88112 89425

ISIC 32 – Radio, Television and Communication
7611 7612 7621 7622 7628 76311 76318 76381 76388 7641 7642 7643 76481 76482 76491 76492 76493 76499 7722 7723 7761 7762 7763 7764 77681 77689 77884

ISIC 33 – Precision Machinery
76483 7741 7742 82121 87101 87102 87103 87104 87109 87201 87202 87203 8731 8732 87411 87412 87421 87429 8743 8744 87451 87453 87454 87482 87483 87489 8749 88111 88119 88121 88129 88131 88139 88411 88412 88421 88422 88511 88512 88513 88514 88521 88522 88523 88524 88525 88526 88529 89731 89961 89962

ISIC 34 – Motor Vehicles
7132 7139 7810 7821 7822 7831 7832 7841 7842 7849 78611 78613 78681 78689

ISIC 35 - Other Transports
71311 71319 7144 71481 71491 7851 7852 78531 78539 7911 7912 7913 7914 79151 79152 79191 79199 7921 7922 7923 7924 79281 79282 79283 7929 7931 79321 79322 79323 79324 79381 79382 79383

Appendix B. Country List and Classification for Section 2 and 3

Country Code	Country	IO	Region
ARE	United Arab Emirates		ME
ARG	Argentina	Y	LA
AUS	Australia	Y	EA
AUT	Austria	Y	WE
AZE	Azerbaijan		RW
BEL	Belgium	Y	WE
BGD	Bangladesh		RW
BGR	Bulgaria		EE
BHR	Bahrain		ME
BIH	Bosnia and Herzegovina		EE
BLR	Belarus		EE
BOL	Bolivia		LA
BRA	Brazil	Y	LA
BWA	Botswana		SA
CAN	Canada	Y	NA
CHE	Switzerland	Y	WE
CHL	Chile	Y	LA
CHN	China	Y	EA
CIV	Cote d'Ivoire		SA
CMR	Cameroon		SA
COL	Colombia		LA
CRI	Costa Rica		LA
CUB	Cuba		LA
CYP	Cyprus		WE
CZE	Czech Republic	Y	EE
DEU	Germany	Y	WE
DNK	Denmark	Y	WE
DOM	Dominican Republic		LA
DZA	Algeria		SA
ECU	Ecuador		LA
EGY	Egypt, Arab Rep.		ME
ESP	Spain	Y	WE
EST	Estonia	Y	EE
FIN	Finland	Y	WE
FRA	France	Y	WE
GAB	Gabon		SA
GBR	United Kingdom	Y	WE
GHA	Ghana		SA
GRC	Greece	Y	WE
GTM	Guatemala		LA
HKG	Hong Kong, China		EA
HND	Honduras		LA
HRV	Croatia		EE
HUN	Hungary	Y	EE
IDN	Indonesia	Y	EA
IND	India	Y	RW
IRL	Ireland	Y	WE
IRN	Iran, Islamic Rep.		ME
IRQ	Iraq		ME
ISL	Iceland		WE
ISR	Israel		ME
ITA	Italy	Y	WE
JAM	Jamaica		LA
JOR	Jordan		ME
JPN	Japan	Y	EA
KAZ	Kazakhstan		RW
KEN	Kenya		SA
KOR	Korea, Rep.	Y	EA
LBN	Lebanon		ME
LKA	Sri Lanka		RW
LTU	Lithuania		EE
LVA	Latvia		EE
MAC	Macao		EA
MAR	Morocco		ME
MDA	Moldova		EE
MEX	Mexico	Y	NA
MKD	Macedonia, FYR		EE
MLI	Mali		SA
MLT	Malta		WE
MNG	Mongolia		RW
MOZ	Mozambique		SA
MUS	Mauritius		SA
MYS	Malaysia	Y	EA
NAM	Namibia		SA
NCL	New Caledonia		RW
NLD	Netherlands	Y	WE
NOR	Norway		WE
NZL	New Zealand	Y	EA
OMN	Oman		ME
PAK	Pakistan		RW
PER	Peru		LA
PHL	Philippines	Y	EA
POL	Poland	Y	EE
PRT	Portugal	Y	WE
PRY	Paraguay		LA
QAT	Qatar		ME
ROM	Romania	Y	EE
RUS	Russian Federation	Y	EE
SAU	Saudi Arabia		ME
SDN	Sudan		SA
SEN	Senegal		SA
SER	Yugoslavia		EE
SGP	Singapore	Y	EA
SLV	El Salvador		LA
SVK	Slovak Republic	Y	WE
SVN	Slovenia	Y	EE
SWE	Sweden	Y	WE
SWZ	Swaziland		SA
SYR	Syrian Arab Republic		ME
THA	Thailand	Y	EA
TTO	Trinidad and Tobago		LA
TUN	Tunisia		ME
TUR	Turkey	Y	EE
TWN	Taiwan, China	Y	EA
TZA	Tanzania		SA
UKR	Ukraine		EE
URY	Uruguay		LA
USA	United States	Y	NA
VEN	Venezuela		LA
VNM	Vietnam	Y	EA
YEM	Yemen, Rep.		ME
ZAF	South Africa	Y	SA
ZMB	Zambia		SA
ZWE	Zimbabwe		SA