An Anatomy of the World Trade Network

Dr. William Chow   5   July, 2013

Executive Summary

- This paper evaluates the current state of world trade from the perspective of networks. These are graphs made up of nodes and edges, representing countries and trade links. Unlike other conventional approaches, e.g. gravity models, where other economic variables are explicitly introduced, network analysis takes a top down approach by looking at the connectivity of the trading countries.

- While the world is geographically diverse, the trade network is rather dense, authenticating the impact of globalization and the so-called "small world" phenomenon. Each node (country) can be reached by another in a reasonably short path.

- Whether viewed as a binary network which pinpoints the presence of a link or one that takes into consideration the intensity of trade flows, the network exhibits a core-periphery structure. Indeed, the world trade pattern has a disassortative characteristic, meaning to say countries with intense links tend to trade with those who have less intense links.

- The likelihood of any two trading partners of a country being trading partners themselves is not very high in general. Intensively linked countries tend to have partners that do not trade much among themselves.

- As of 2009, U.S., China, Germany and Japan were among the most significant players and potentially the hubs of the world trade networks. Mexico, Portugal and Brunei were the least important in the sample (the periphery).

1. Introduction

1.1   Conventional trade studies analyze issues like trade costs (comparative advantage), external balance and exchange rate policy, and cost-benefit aspects of trade protection and liberalization. Each one of these plays a pivotal part in the trade literature without a doubt. Yet, the focus is often the behavioral paradigms of the trading partners in predefined economic settings. More specifically, the subject economies inside a bilateral (or multilateral) trade relationship, instead of the trade network itself, take the center stage of the analysis.

1.2   This paper looks at the properties of the world trade network from a top-down perspective. The features and the implications observed from the system will be discussed. The network approach to world trade, and in fact to economic analysis as a whole, is relatively recent. It employs graph theory in mathematics[1] to help evaluate network structures and the interrelationship of the entities embedded inside. This approach allows a clear exposition of the connection of the parties and provides a blueprint of potential diffusion processes.

1.3   Schweitzer *et al.* (2009) offers a concise review of the application of complex networks in economics. One can also refer to Goyal (2007) and Jackson (2010) for book-length discussion of the topic. In finance, there were applications of networks to the study of interbank markets and financial contagion, see the survey of Allen and Babus (2009). Trade is a natural subject for network studies as well, and the papers by Fagiolo *et al.* (2010, 2012) give good accounts of the methodology. The conceptual tools introduced in this paper are basic network analytics which can be found in the references cited above.

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[1] Some researchers used game theory to study the interactions of agents inside different kinds of networks. Spatial model is an alternative for analyzing players' interactions.

2. A First Look at World Trade with Network Basics

2.1 In network analysis, economic and social networks are portrayed as graphs intertwined with nodes (subject entities) and edges (the linkage or relationship). There are two broad types of graphs – binary and weighted. A **binary** network is one in which only the contiguity or the presence of a link matters. Two nodes can separately link up with a third node without any differentiation in the intensity of these relationships. In a way, each edge in the network carries equal weights. A **weighted** network, on the other hand, can have asymmetric and highly differentiated (e.g. in width) edges that signify heterogeneity in the relationships, e.g. via money flows.

2.2 A binary or weighted network can either be **undirected** or **directed**. The former refers to a case where the edges have no implied directional or causal linkages, while the latter have edges often marked with "arrows". In this paper, for reasons explained below, a weighted undirected network (WUN) will be the primary configuration referenced.

2.3 Figure 1 shows the world trade network as of 2009. For clarity, it is plotted as a binary undirected network (BUN) here. Note that all edges have the same width, regardless of the size of the bilateral trade flows. The data are retrieved from the OECD statistics database and are aggregate exports of economies measured in value added terms (USD). The figures are in constant 2005 dollars and include both merchandise and service exports. The list of $n = 57$ countries (used interchangeably with economies throughout) is stated in the Appendix, and these cover the OECD countries, non-OECD economies and the group termed rest of the world (ROW).

2.4 The numerical configuration of a network hinges on the adjacency matrix A of a binary network and the weight matrix W of a weighted network. The binary matrix A has elements a_{ij} equals 1 if a certain criterion defining a tie is met and 0 otherwise. It will be symmetric if

the network is undirected and asymmetric otherwise. The matrix W, on the other hand, has continuous entries which are functions of designated economic variables (more on this later).
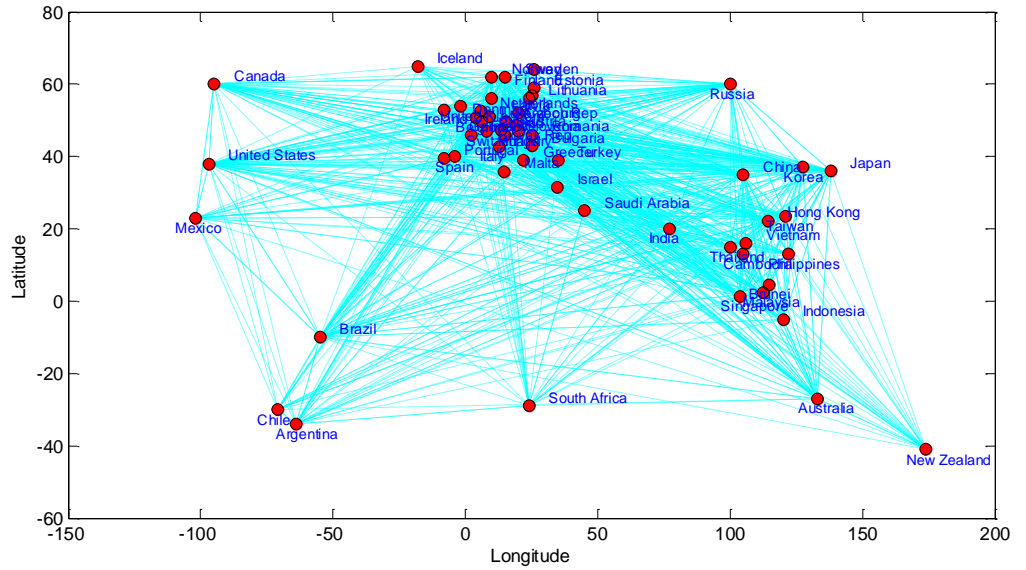
2.5   The diagram is generated using an adjacency matrix that indicates trade linkage. The entries of A are inserted according to the rule:

$$a_{ij} = \begin{cases} 1 & \text{if } e_{ij} > 1\% \text{ of } \sum_j e_{ij}, \\ & \text{or } e_{ji} > 1\% \text{ of } \sum_i e_{ji} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$a_{ij} = a_{ji}.$$

where e_{ij} is the exports from country i to j. So a threshold of 1% of a country's total export (and of import) is imposed and only those ties in excess of that is regarded as significant enough to be denoted by an edge in the network.
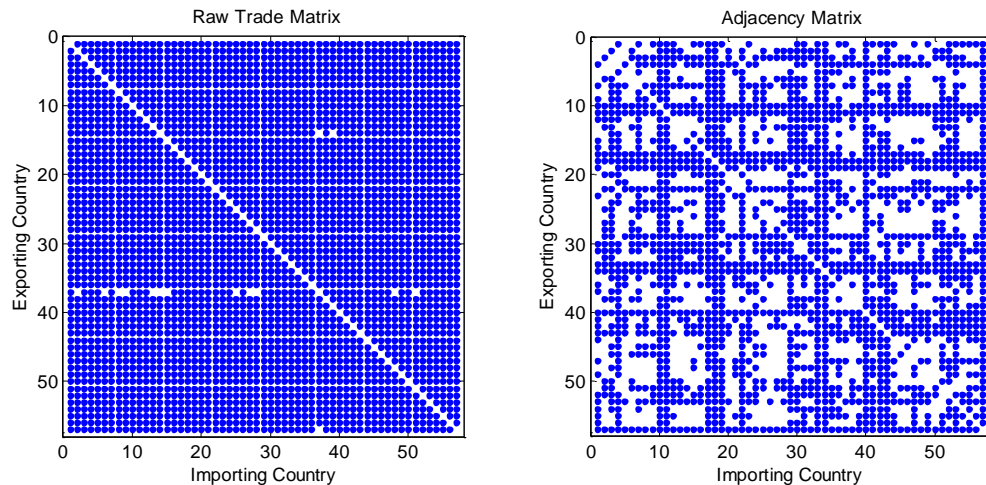
Figure 1: The World Trade Network 2009

Remarks: The links are significant trade relationships of the economies in the network. Links with the rest of the world is not shown in the diagram.

4

2.6 To gain insights from the diagram, we need to introduce further tools of network assessment. For a binary graph, the **degree** (d_i) of a node is the number of links the node has established. It is easy to see that when most nodes have a large degree, the connectivity of the network is higher. A **path** is a (consecutive) sequence of nodes linked up by edges. There can be more than one path for any two non-neighboring nodes. A graph is **connected** if there is a path between any two nodes.

2.7 So is the world trade network in Figure 1 well connected? Do these countries have on average many trading partners (links)? From the look of it, the answer is affirmative for the first question as *the network forms a single giant component with no isolated/disconnected nodes*. However, there is some heterogeneity in the connectivity of individual nodes. China, U.S. and the developed European countries appear to be well connected (major trade hubs). Portugal and Brunei, on the other hand, have the weakest links (periphery, one may say). Is this a fair representation of the actual trade pattern? Figure 2 shows two diagrams summarizing the linkages implied in the raw trade data and the adjacency matrix used to construct the network we envisaged.

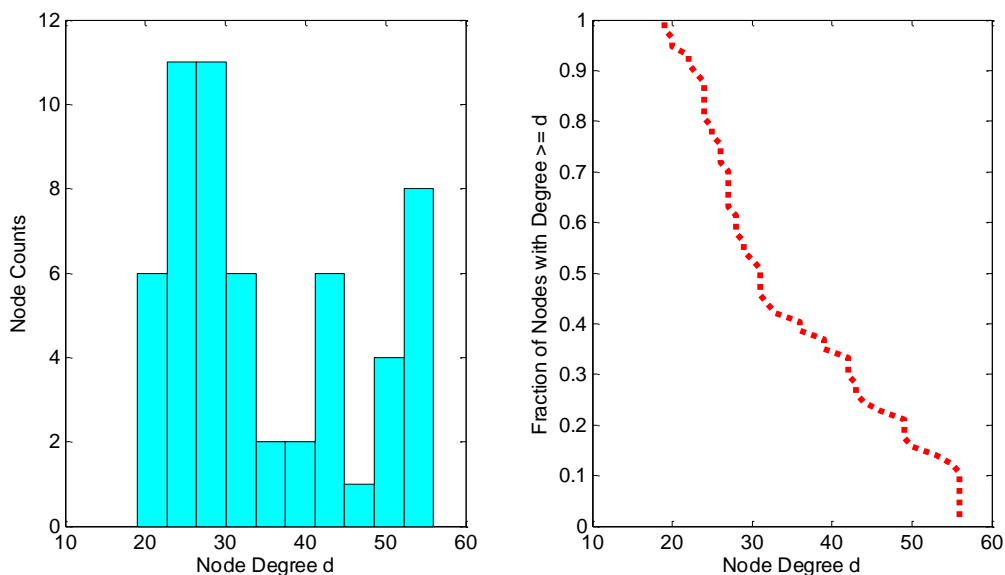Figure 2 : Actual Trade Data 2009 and the Adjacency Matrix

2.8 The LHS diagram contains a tightly packed matrix with non-empty entries only on the diagonal (because one does not export to oneself) and for the trade flows of a few small non OECD countries. Without the screening process of (1) above, we will have a very dense trade network with virtually all nodes being linked up to one another in the graph by the same magnitude. Trade relationships will hence be difficult to differentiate and their impact on economic diffusion will be considered identical. The RHS diagram is what we are left with after purging the insignificant (below threshold) trade links. Recall that the threshold is a meager 1% of a country's export/import and that is enough to wipe out a fair amount of trade flows (the empty spots).

2.9 Given the screened network, we can derive broad measurements of the network's connectivity. Figure 3 shows the distribution of the node degrees of the BUN configuration of world trade. The LHS panel shows the histogram of node degrees calculated from the adjacency matrix, and the RHS shows the corresponding cumulative distribution. The distribution is multi-modal with the majority of the countries having a node degree between 20 and 30. Only about 20 percent of the countries have 50 plus trade partners.

2.10 There are two related concepts that can help quantify the basic topology of the world trade network. The first is the **diameter** and the second is the **average path length**. The diameter is the largest geodesic (shortest path between two nodes) distance in the network which shows how "big" the network is[2]. For our trade network, the diameter is 2, meaning to say one needs at most two steps to export a commodity from one country to any place in the world. The average path length, meanwhile, measures the average distance (in steps) between any two nodes in the network. It signifies how efficient economic signals or actions can traverse around the network.

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[2] With a small diameter, the network is small not in the geographical sense, but in terms of compactness. A transportation network is "small" when the number of transits to make from travelling between two distant places is small.

Obviously, the smaller the average path length, the more efficient the communication and the more desirable it is. The average path length for the BUN in Figure 1 is 1.38 between any two nodes. So both the diameter and the average path length suggest that *globalization may have facilitated world trade and made it a smaller world than it appears geographically*[3].

Figure 3: Degree Distribution of the World Trade Network 2009

2.11 What if we prefer a weighted network? Applying a BUN hides the heterogeneous details implicit in the trade patterns. For instance, if we believe financial contagion is primarily influenced by trade flow, we should distinguish the better connected or intense links from the others. Shocks that rippled out from a poorly connected regional hub with insignificant trade flows are not going to cause the same trouble as one that handles lots of trade. In a weighted network, the edges are defined by weights (trade flows in our case) and have varying widths indicating the differences in intensity of the linkage or relationship.

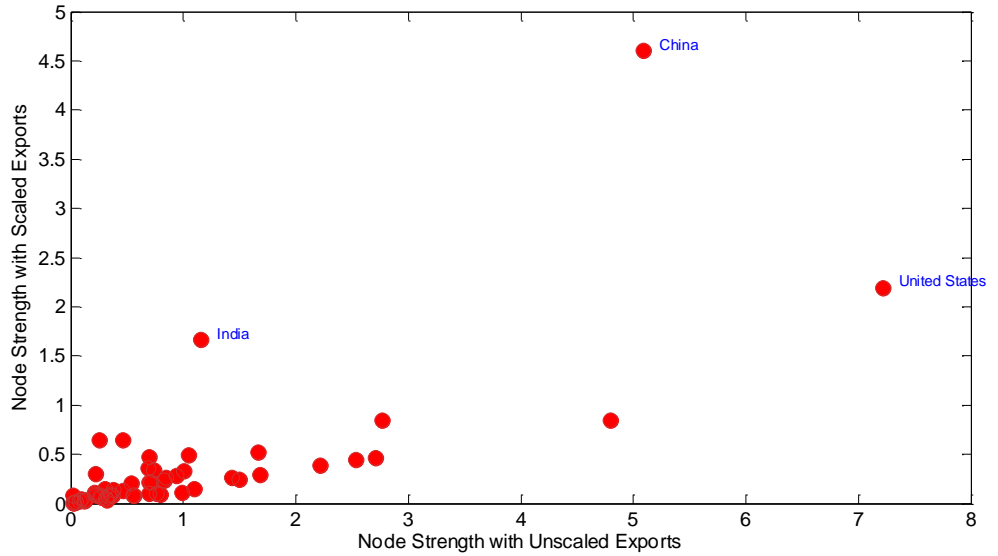[3] The average path length dropped steadily from 1.417 in 1995 to 1.38 in 2009.

The indicator analogous to node degree is the node **strength**, or the intensity or capacity of the ties between nodes.

2.12 The specific format for presenting the weights is the next thing we need to consider. One option is to use the aggregate export figures as they are. Alternatives will be to scale them using either the exporting countries' or the importing countries' per capita real GDP. Figure 4 compares the node strengths of the network using (i) unscaled exports and (ii) exports scaled with per capita RGDP of the exporter. For both cases, a weight matrix W with entries w_{ij} is compiled as follows:

$$w_{ij}^0 = \frac{1}{2}(e_{ij} + e_{ji}) \qquad (2)$$
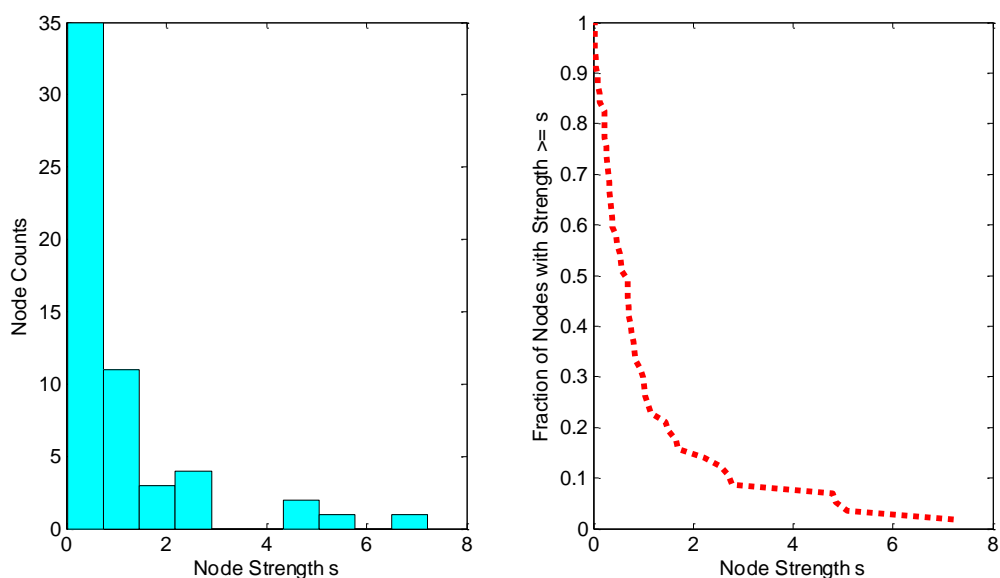$$w_{ij} = w_{ij}^0 / \max_{ij}\{w_{ij}^0\}$$
$$w_{ij} = w_{ji}$$

where e_{ij} is the gross export from i to j for the unscaled case and equals to the export adjusted for per capita RGDP in the scaled case. The node strength is calculated as $s_i = \sum_j w_{ij}$.

Figure 4: Node Strength from Different Weighting Schemes 2009

8

2.13 It is evident that different weighting schemes generate different distributions of node strength. China, for instance, has a high strength level regardless of the scheme. U.S., on the other hand, is a dominant player in the network on an unscaled basis, but its dominance is dwarfed once the export figures are divided by RGDP per capita. Eventually, to adjust the weights or not depends on what we perceive as a reasonable node configuration for the study on hand. If we regard the political prowess or the status of financial development as important, scaling the exports as we did here could bias the dominance of rich but less populated countries downwards[4]. Another concern is that we do not have data to proxy the per capita RGDP of the ROW. We therefore opt for the unscaled weights in this study.

Figure 5: Node Strength Distribution of World Trade Network 2009

2.14 The strength distributions of the weighted undirected network are presented in Figure 5. This is the weighted counterpart of Figure 3. As it turns out, the BUN and the WUN configurations show very dissimilar

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[4] For example, if we try to relate the network structure to the scope of financial contagion, the scaled weights here may overstate the influence of China and understate that of U.S.

patterns in that most nodes have very low node strength and the strength distribution is skewed to the right. In brief, a core-periphery structure is implied by Figure 5. In 2009, the node strengths of U.S. and China are individually about 2-2.5 times the network's 90th percentile and are, respectively, 8 and 6 times the average of all remaining nodes. The dominance of these two economies is clear.

2.15   One last remark is the choice between a directed and an undirected network. Again, this depends pretty much on what we want to focus on. If the differentiation of export and import capability is not of particular interest, an undirected network suffices. In addition, the symmetry of the raw data (export-import) matrix in Figure 2 will indicate if a directed graph is needed. Fagiolo *et al.* (2010) introduced indices to measure quantitatively the extent of symmetry. The raw data matrix is not perfectly symmetric but is not very inconsistent with symmetry. In brief, (i) the richer OECD countries export and import more; and (ii) U.S. imports more than its exports when compared to its major trading partners, especially China and Canada.

3. World Trade as a Weighted Undirected Network

3.1   Next, we explore the major characteristics of world trade in the context of a WUN. This is reminiscent of identifying members' relationship within a club. Specifically, we will look at various measurements that indicate the importance of the trading countries, their similarities and further aspects of network connectivity.

3.2   We have seen that the diameter and the average path length give a broad indication of the size and the connection of a network. A related question is whether countries that are strongly connected tend to trade with strongly connected countries (**assortative**), or with poorly connected countries (**disassortative**). The applicable indicators for measuring assortativity are (see Fagiolo *et al.,* 2010):

   ▪ **Average Nearest Neighbor Strength** (ANNS)

$$ANNS_i = \frac{A_{(i)}W\mathbb{1}}{A_{(i)}\mathbb{1}} \qquad (3)$$

where W and A are the weight matrix and the adjacency matrix earlier defined, and $\mathbb{1}$ is a column vector of ones.

- **Weighted Average Nearest Neighbor Degree** (WANND)

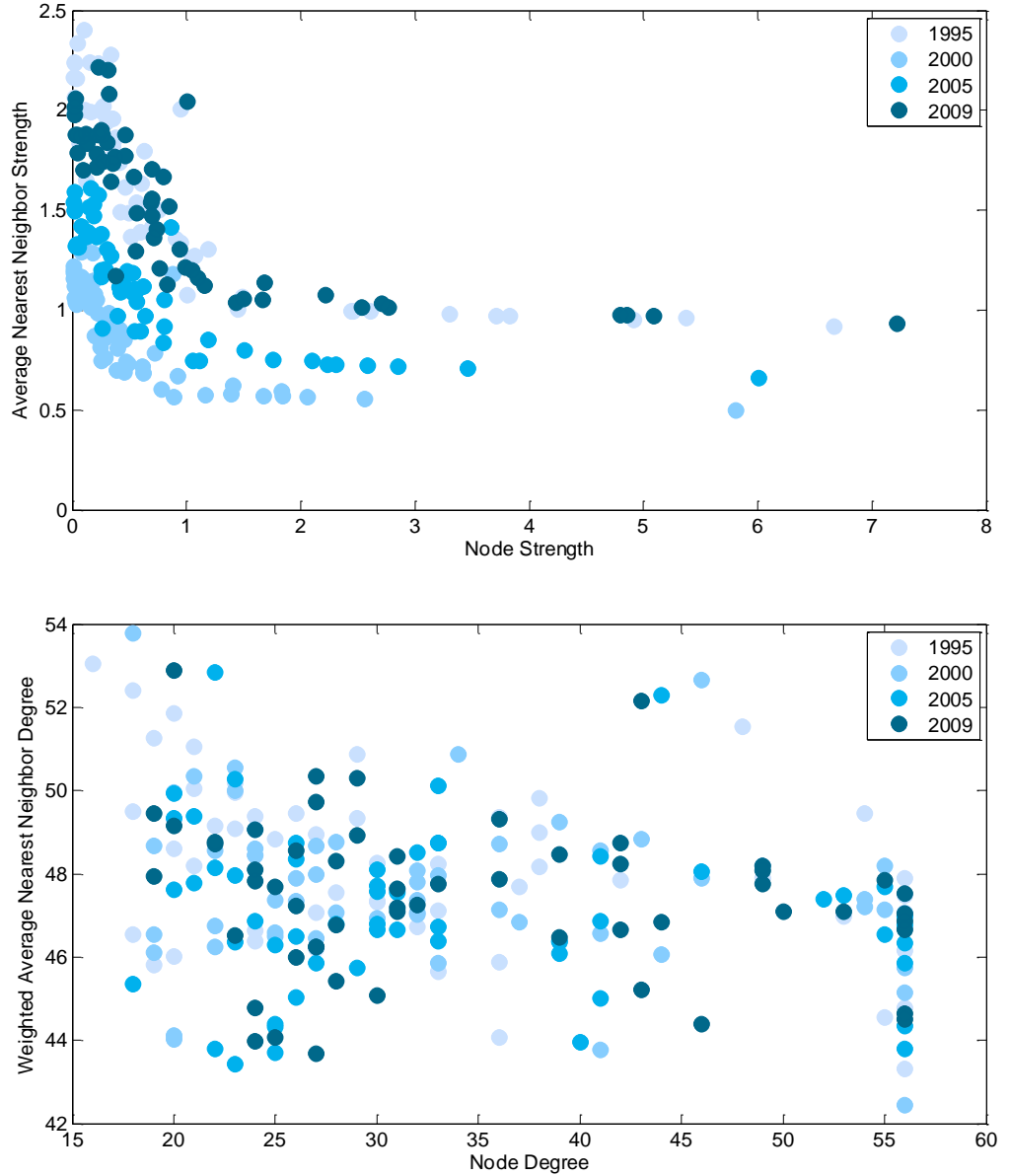$$WANND_i = \frac{W_{(i)}A\mathbb{1}}{W_{(i)}\mathbb{1}} \qquad (4)$$

- **Node Disparity** / Herfindahl Concentration Index

$$h_i = \frac{(n-1)\dfrac{W_{(i)}^{[2]}\mathbb{1}}{\left(W_{(i)}\mathbb{1}\right)^2} - 1}{n-2} \qquad (5)$$

where $W^{[k]}$ is the matrix W raised to the power k on an element by element basis.

3.3 The ANNS is basically the average strength of a node's neighbors. Plotting this against the node strength can indicate if world trade is assortative (if positive correlation) or disassortative (if negative correlation). WANND is similar except that it should be compared to node degrees instead. The node disparity is just the Herfindahl Hirschman index used in measuring market concentration in microeconomics. For a particular node, the larger the ratio, the more concentrated (less dispersed) the intensity of the trade links would be.

3.4 Figure 6 shows the correlation between node strength and ANNS and that between node degree and WANND from 1995 to 2009. The alignment of points in the top chart indicates clear negative correlations suggesting a disassortative trade network. The bottom chart is less obvious, but the correlation coefficients were indeed negative as shown in Figure 7 where the changes in the correlations over time are plotted.
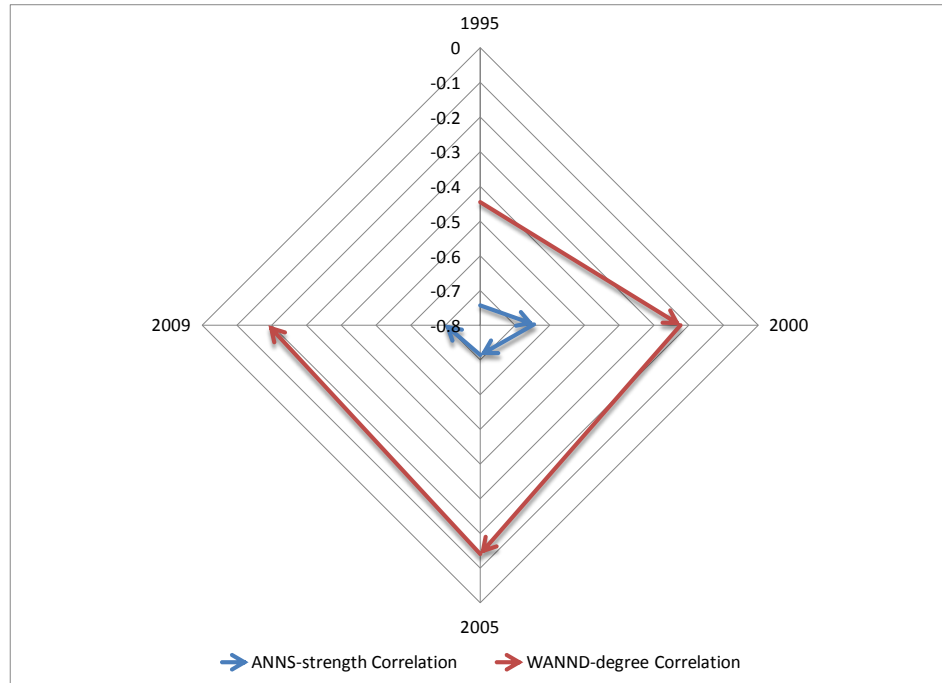
Figure 6: Disassortativity of the World Trade Network

3.5   We can argue that *countries with intense links tend to trade with those who have less intense links*. This again supports the presence of a core-periphery structure (Fagiolo *et al.,* 2010). That said, Figure 7 indicates that the arrows are spiraling outwards (moving towards zero) in general. So, the extent of disassortative trade association seems to have

reduced over the same period. This could be the result of globalization and the relocation of production base to formerly less developed countries.

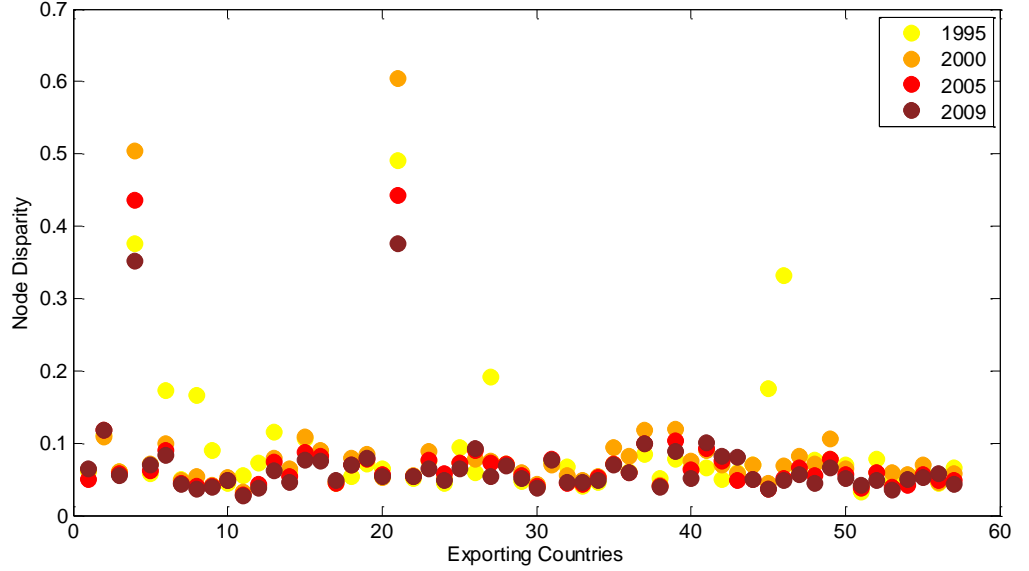Figure 7: Transitions of ANNS-Strength and WANND-Degree Correlations

3.6 Figure 8 plots the node disparity of the countries over the periods reviewed. Except for Canada (country 4) and Mexico (country 21), the nodes in the network have a relatively dispersed intensity of trade links, endorsing what we observed from the ANNS-strength correlations. The comparatively concentrated trade associations Canada and Mexico individually has probably reflects their reliance on intra-NAFTA trade.

3.7 In network analysis, an interesting aspect is to explore the extent of **triadic closure**. In our context, this means any two trading partners of a country are likely to be trading partners themselves. For binary networks, such likelihood is measured by the **clustering coefficient** (CC) of a node which is the number of existing links connecting a node's neighbors to one another divided by the maximum number of

links possible. So it evaluates the network by triples and counts how many such triples have edges that link up all three nodes concerned. This ratio is obviously bounded by 0 and 1.

$$CC_i = \frac{(A)_{ii}^3}{d_i(d_i - 1)} \qquad (6)$$

Figure 8: Concentration of Trade Links

3.8 Various weighted versions of the clustering coefficient (WCC) are available[5]. Two of them are considered in this article.

$$WCC_i^I = \frac{1}{s_i(d_i - 1)} \sum_{j,k} \frac{w_{ij} + w_{ik}}{2} a_{ij} a_{jk} a_{ik} \qquad (7)$$

$$WCC_i^{II} = \frac{(W)_{ii}^3}{(WW_{max}W)_{ii}} \qquad (8)$$

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[5] See for instance Saramäki *et al.* (2007). The choices here are to ensure the value computed falls within the [0, 1] interval.

where d_i is the degree of node i and W_{max} is a matrix with elements {max (W)}. As in the binary case, $WCC_i \in [0,1]$. Note that by definition, CC and WCC^I cannot be assessed for nodes with degrees less than 2. The other reference indicator WCC^{II} is thus included.

3.9   We can then compare the pair-wise correlations between node degree and CC, and the correlations between node strength with WCC^I and WCC^{II} respectively. The results are shown in Table 1. *If nodes of high degrees have low level of clustering, the correlation of CC-degree will be negative and highly connected nodes (the hubs) will have trade partners that do not tend to trade among themselves; and vice versa (for the periphery)*. This is exactly what we observe in the second column of Table 1 where a strong a consistent negative CC-degree correlation is observed. From the last two columns, we see that (i) the clustering of the weighted network is not as prominent as the binary network, (ii) the *inter-connection of triples involving strong edges has been enhanced over the past 15 years or so*.
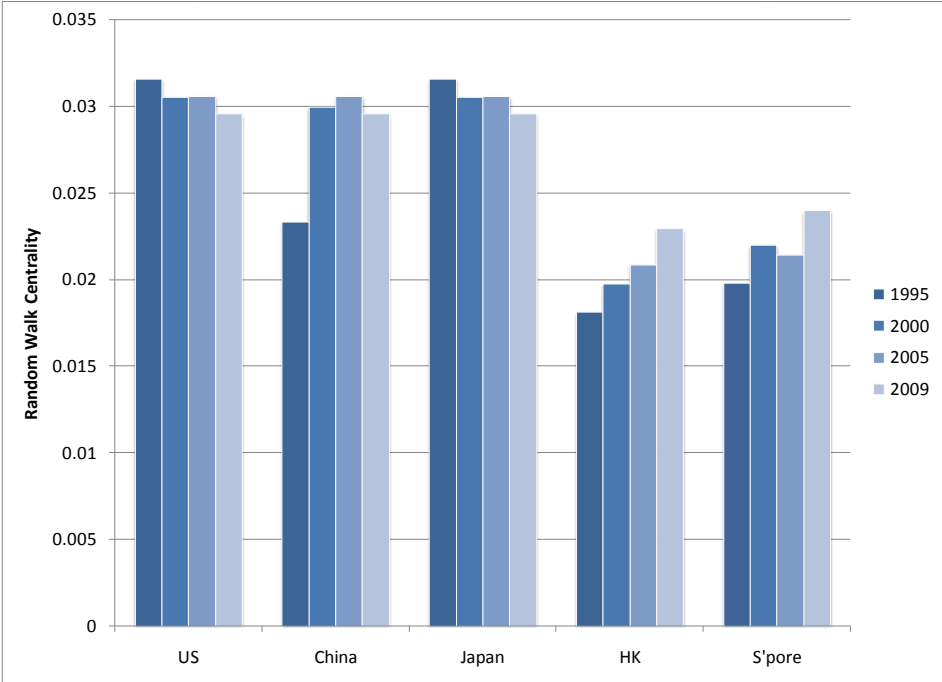
Table 1: Summary of Node Clusterings

Year	CC-Degree Correlation	WCC^I- Strength Correlation	WCC^{II}- Strength Correlation
1995	-0.974	0.149	-0.616
2000	-0.975	-0.241	-0.607
2005	-0.976	-0.104	-0.584
2009	-0.976	-0.022	-0.549

3.10   Finally, we will assess the relative importance of the nodes in the trade network by means of **centrality**. As in the case of clustering, there are various ways to evaluate centrality, each based on a slightly different perception of measurement. The two major classes are (i) the measure of closeness – how close a node is from other nodes, and (ii) the measure of betweenness – how often a node is located on the paths between two nodes. Centrality is a rather technical concept and one can refer, for instance, to Borgatti and Everett (2005) for further discussion. Two measures, the eigenvector centrality and random walk

15

centrality (Newman, 2005), were calculated and the indications are largely consistent with one another. We report only the result of the latter here[6].

3.11 Figure 9 shows the scores of the random walk centrality of selected nodes as an illustration. As one would imagine, U.S. and China are among the most "central" nodes, but they experienced a different shift in status. China climbed remarkably in centrality ranking over the surveyed periods while U.S. experienced the opposite. Despite the difficulties faced by the local economy at times during the period, HK also recorded an increase in centrality rating, presumably the result of increased economic affiliation with Mainland China.

Figure 9: Centrality of Selected Countries/Nodes

3.12 We wrap up the analysis with a summary of the observations, presented in the form of a table. Table 2 lists the selected rankings of countries based on the various indicators discussed. This should give

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[6] The random walk centrality measures the net number of time a current/shock/flow passes through the node along the way from a source node x to a target node y, averaged over all x and y.

us an idea which countries constitute the hubs and who are the peripheral countries.

Table 2: Summary of Observations as of 2009

	Node Degree	Node Strength	WANND	ANNS	WCC-II	RW Centrality
Rankings of Scores						
1st	Germany, Japan, UK, US, China	US	Mexico	Chile	S Africa	UK, US, Germany, China, ROW
2nd	-	China	Canada	Portugal	Malta	-
3rd	-	ROW	Malta	Luxembourg	Saudi Arab	-
4th	-	Germany	Ireland	Brunei	Brazil	-
5th	-	Japan	S Africa	Mexico	Chile	-
last 3rd		Brunei	Estonia	ROW	Austria	Mexico
last 2nd	Mexico	Cambodia	Slovak Rep	China	Mexico	Portugal
last	Portugal, Brunei	Iceland	Latvia	US	Canada	Brunei
HK's position	14/57	34/57	39/57	42/57	41/57	14/57
Remarks	Higher, better connection	Higher, more intensely connected	Higher, more better connected partners	Higher, more intensely connected partners	Higher, more inter-linked partners	Higher, more significant position in network

4. Conclusion

4.1   This article reviews the insights one can obtain in relation to world trade patterns from network graphs. This approach emphasizes on the intrinsic characteristics of the network and how the members are tied within the structure. The network does not embody other economic variables, but the network statistics produce output that can be used in other econometric analysis.

4.2   The network approach is just one other alternative for trade analysis. It does have its shortcomings, for instance, the study of temporal dynamics using network is still at an infant stage and looks a bit

atheoretical in economic sense. Until these issues are totally resolved, other techniques like gravity models (Feenstra, 2004) would remain a useful tool for the task despite the interesting observations one can extract from network analysis.

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Appendix

A1. There is a total of $n = 57$ economies where the last one represents the rest of the world (ROW). They are listed in a sequence consistent with the index number used in the article and the diagrams:

- OECD countries – Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.
- Non-OECD countries/economies – Argentina, Brazil, Brunei, Bulgaria, Cambodia, China, Chinese Taipei, Hong Kong, India, Indonesia, Latvia, Lithuania, Malaysia, Malta, Philippines, Romania, Russia, Saudi Arabia, Singapore, South Africa, Thailand, Vietnam.
- Others – Rest of the World.