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Structure and formation of top networks in international trade, 2001–2010

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ABSTRACT

We propose the construction of the international trade network based on top trade relations (i.e., country *i* is linked to country *j* if *j* is *i*'s top trade partner). The constructed network captures most important relations in international trade. The overall network displays a tree-like hierarchical structure. It is organized around global central countries (especially the US, China, and Germany) under which there are more levels of local centers. We develop a model that uses country behavior in local triadic environment to account for the formation of such network structure. The census of triads confirms the applicability of this model.

Introduction

As part of the ongoing globalization, cross-border trade flows bind the whole world into an international trade network. This network has greatly strengthened economic interdependence among countries, but has also rendered the world economy more susceptible to systemic crises. The 2008 financial crisis started from the US and spread rapidly to other parts of the world partly through this international trade network (Garas et al., 2010; Kali and Reyes, 2010).

Despite its obvious networked nature, traditional economics did not study international trade through the lens of network analysis for a long time (Goyal, 2007). Network analysis of international trade was actually first employed by sociologists inspired by world system theory (Breiger, 1981; Clark and Beckfield, 2009; Kim and Shin, 2002; Mahutga, 2006; Smith and White, 1992; Snyder and Kick, 1979; Van Rossem, 1996). Using various forms of blockmodeling, these studies identify a three-tiered structure (core, semi-periphery, and periphery) within the world economy and classify countries into three positions. Nevertheless, their main purpose is limited to empirical confirmation of the hierarchical structure predicted by world system theory (de Nooy et al., 2011), which overshadows the investigation of other important topological characteristics of the international trade network.

With the recent rise of "the new science of networks" across many disciplines (Barabási, 2002; Watts, 2004), more scholars in economics, mathematics, and even physics have started adopting the network perspective on economic activities (Easley and Kleinberg, 2010; Goyal, 2007; Jackson, 2008; Schweitzer et al., 2009). This new approach has been proved fruitful and shed new light on international trade (Baskaran et al., 2011; Bhattacharya et al., 2008; Fagiolo, 2010; Fagiolo et al., 2008, 2009; Garlaschelli and Loffredo, 2004, 2005; Garlaschelli et al., 2007; Li et al., 2003; Picciolo et al., 2012; Serrano and Boguna, 2003; Serrano et al., 2007; Squartini et al., 2011a,b; Wilhite, 2001). These studies find that the international trade network possesses typical properties of complex networks, including the "small-world" property, a scale-free degree distribution, a high clustering coefficient, and the presence of degree correlation between countries. All these topological properties indicate international trade cannot be simply reduced to a random-network description.

Existing network studies, from both sociology and other disciplines, have greatly contributed to our understanding of international trade. Some lacunas are also prominent in the existing literature, however. First, differential importance of a country's trade relations (that is, the ranking of a country's trade partners) has been neglected. All existing studies construct their trade networks using either binary networks (whether there is trade between two countries or whether the volume of bilateral trade reaches a designated threshold) (Breiger, 1981; Clark and Beckfield, 2009; Garlaschelli and Loffredo, 2004, 2005; Kim and Shin, 2002;

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Mahutga, 2006; Serrano and Boguna, 2003; Smith and White, 1992; Snyder and Kick, 1979; Van Rossem, 1996), or weighted networks (in which each trade tie is weighted by some proxy of the trade intensity it carries) (Bhattacharya et al., 2008; Fagiolo et al., 2008, 2009; Garlaschelli et al., 2007; Li et al., 2003). There has been no empirical research that pays explicit attention to the differential importance of trade relations.

Not all bilateral trade relations are equally important to a country. For a single country, its distribution of trade volume across trade partners is not uniform, but approximates a power-law distribution (Fagiolo et al., 2009; Garlaschelli and Loffredo, 2005; Serrano and Boguna, 2003). Its trade is concentrated in its ties with a few trade partners. This concentration is especially notable for developing countries, as most peripheral countries' foreign trade is heavily dependent on particular core countries, according to world system and dependency theories (Chase-Dunn and Grimes, 1995; Galtung, 1971; Lloyd et al., 2009; Wallerstein, 1974). Even for developed countries, this trade concentration also exists. Hence, a country's top trade partners are particularly influential in shaping its involvement in international trade. Despite this importance, no network studies have examined the network constructed from top trade relations. We have little knowledge about the structure and features unique to this form of the international trade network.

Second, when existing studies explore the structure of the international trade network, the analysis of triads has long been neglected. Network studies in sociology mainly use position and role analysis (Breiger, 1981; Clark and Beckfield, 2009; Kim and Shin, 2002; Mahutga, 2006; Smith and White, 1992; Snyder and Kick, 1979; Van Rossem, 1996), while those in economics and other disciplines are focused on the degree distribution (the number of trade relations of a country), average nearest-neighbor degree (the average number of partners of the neighbors of a given country), clustering coefficient (the fraction of a country's partners who are themselves partners), degree–degree correlation (the correlation between the degree of a country with that of its neighbors) (Baskaran et al., 2011; Bhattacharya et al., 2008; Fagiolo, 2010; Fagiolo et al., 2008, 2009; Garlaschelli and Loffredo, 2004, 2005; Garlaschelli et al., 2007; Li et al., 2003; Picciolo et al., 2012; Serrano and Boguna, 2003; Serrano et al., 2007; Squartini et al., 2011a,b; Wilhite, 2001), and network centrality[2] (the importance or prominence of a country in the overall international trade network) (Blochl et al., 2011; Fagiolo et al., 2008; Grassi, 2010; Grassi et al., 2007, 2010; Kali and Reyes, 2007; Newman, 2005; Noh and Rieger, 2004). They neglect the analysis of more fundamental network elements such as triads. Triads are building blocks of the overall network. The study of triads has the potential to reveal the process of network formation and to bridge the micro-level (country) behavior and the macro-level (network) structure.

In light of these gaps in the literature, we propose the construction of the international trade network based on top trade relations (that is, country *i* is linked to country *j* if *j* is *i*'s top trade partner; otherwise, there is no tie between *i* and *j*). Specifically, we construct the top 1 import network (that is, country *i* sends a tie to country *j* if *i* is *j*'s top import source) and the top 1 export network (that is, country *i* sends a tie to country *j* if *j* is *i*'s top export destination). We reveal important structural features of these top networks. We further develop a model that uses country behavior in its local triadic environment to account for the formation of top international trade networks. To test the applicability of this model, we apply the census of triads to the actual international trade network. We use data on bilateral trade flows from 2001 through 2010, extracted from the International Trade Center (ITC) database.[3] The empirical evidence supports our model.

Description of the international trade network

In network studies of international trade, countries are represented by nodes (or vertices) and trade relations between countries are denoted by ties (or edges) connecting nodes. Trade data used in this study cover 221 countries and span 10 years (2001–2010).[4] All data come from the ITC database. In this database, the exporting country and the importing country often report slightly different numbers due to country differences in reporting standards. For instance, the amount of exports to China reported by the US differs slightly from the amount of imports from the US reported by China. In these cases we take the average of the two reported numbers. We use the Matlab software to create a weight matrix based on the bilateral trade data W^t. In the matrix, w_{ij}^t stands for the value of exports from country *i* into country *j* at year *t*. Self-loops (ties connecting *i* to itself w_{ii}^t) are coded as 0. The international trade network constructed by this weight matrix is a directed weighted network. It contains both the direction and the intensity of trade relations. The resulting network is a complete international trade network.

Table 1 presents basic descriptive statistics about the complete international trade network from 2001 through 2010. The network grew rapidly between 2001 and 2008. First, the network became denser in this period, as the number of ties between countries increased. The number of existing bilateral trade relations grew from 25,135 in 2001 to 28,903 in 2008. On average about 423 pairs of countries established trade relations each year. As a result, between 2001 and 2008 the density of the international trade network increased from 0.527 to 0.583 and the average degree of a node grew from 229.5 to 255.4, whereas the average path length decreased from 1.474 to 1.417. Moreover, the maximal in-degree (i.e., the number of import sources) is 217, and the maximal out-degree (i.e., the number of export markets) is 219. Hence, some countries have trade relations with almost every other country in the world.

Second, the volume of trade flows also increased remarkably between 2001 and 2008, so the strength of ties in the network intensified in this period. The average tie strength (i.e., the average volume of trade flows) increased from 243.2 to 566.5 million US dollars. The annual growth rate reached as high as 12.8%. Furthermore, the average strength for all countries' topmost incoming ties (i.e., the average volume of all countries' greatest import ties) grew from 6.4 to 14.7 billion US dollars. The average strength for all countries' topmost outgoing ties (i.e., the average volume of all

[2] Scholars (Blochl et al., 2011; Grassi, 2010; Grassi et al., 2007, 2010; Kali and Reyes, 2007) have examined different centrality measures in economic networks including degree centrality (the number of a node's adjacent nodes), betweenness centrality (the number of the shortest paths connecting all pairs of nodes that pass through a node), closeness centrality (the average distance from a node to all the other nodes), and eigenvector centrality (the sum of a node's direct connections weighted by their own centralities). New centrality measures have recently been developed based on "random walks", such as "random walk" closeness centrality (Noh and Rieger, 2004) and "random walk" betweenness centrality (Blochl et al., 2011; Fagiolo et al., 2008; Newman, 2005).

[3] Available at http://www.intracen.org/trade-support/trade-statistics/ (retrieved May 2013). All data on international trade used by network scholars come from two major sources—the UN Comtrade database and the IMF DoT database. The ITC database used here is directly compiled from the UN Comtrade data. It records trade data that are more than 1000 US dollars.

[4] There are 219 countries from 2001 through 2005 when Serbia and Montenegro were still one country "Serbia and Montenegro." Serbia and Montenegro became two independent countries in 2006, so from 2006 through 2010 there are 220 countries. Although Timor-Leste became independent in 2002, it was already treated by other countries as an independent political entity before 2002 in trade data reporting. It is in our dataset throughout the 2001–2010 period.