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The state's role and position in international trade: A complex network perspective☆

Ying Fan [a], Suting Ren [a], Hongbo Cai [b], Xuefeng Cui [c,]*

[a] School of Systems Science, Beijing Normal University, Beijing 100875, China
[b] School of Economics and Business Administration, Beijing Normal University, Beijing 100875, China
[c] College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China

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ABSTRACT

Based on statistical physics and graph theory, the research paradigm of a complex network, which has sprung up in the last decade, provides us with new global perspective to discuss the topic of international trade. In this paper, we engage in the issue of countries' roles and positions in international trade using the latest complex network theories. On a mid-level structure, countries are classified into three communities that reflect the structure of the "core/periphery" using the weighted extremal optimisation algorithm and the *coarse graining* process. On a micro-level, countries' rankings are provided with the aid of network's *node centralities*, which presents world trade as a closed, imbalanced, diversified and multi-polar development. Further, we firstly introduce the improved bootstrap percolation to simulate cascading influences following the breaking down of bilateral trade relations. We find that the breakdown of EU's export relations can more easily form a cascading reaction, which would result in a global collapse of world trade. All the results highlight the important positions of the EU, USA and Japan in the international trade system, which plays a positive role in promoting the world economy.

1. Introduction

With globalisation of the world economy, close ties between various countries have combined global trade relationships into an organic whole. Increased international trade is becoming the key in shaping the global economic and political landscape. Mobility of international commodities and factors, technological innovation and development, contribute to economic integration called the "global village". Economic globalisation and integration lead us to consider the entire countries as a large system. From this perspective, global production and consumption transfers will result in a substantial complex network between countries and their trade partners. A complex network is represented as a set consisting of a number of vertices with links between them. Its representation offers a new level of description that goes beyond the country-specific analyses used in more traditional economic studies of trade.

As theories and the technology of the complex network have improved over the last decade, a significant amount of effort has been devoted to the empirical exploration of the *International Trade Network* (*ITN*) from this new perspective. The *ITN*, also known as the *World Trade Web* (*WTW*) and the *World Trade Network* (*WTN*), is defined as the network of import/export relationships between world countries in a given year. Because international trade is usually measured using the monetary value of exports and imports between countries, trading relationships are analogous to valued links in a network, which vary from country to country. In research, the *ITN* has many possible representations: binary or weighted, directed or undirected, and aggregated or disaggregated by commodity across several years. From the perspective of aggregated or disaggregated representations, the *ITN* can be discussed on a country level, firm level and product level. Based on the starting point that complex network studies focus on the overall, general and most basic universal laws in international trade, most research builds the *ITN* on a country level.

The earliest contributions studied the simplest type (binary and undirected) of *ITN* to explore the network structure of international trade relations by measuring trade in commodities from the 2000 dataset.

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* Corresponding author at: College of Global Change and Earth System Science, Beijing Normal University, No. 19, Xinjiekouwai Street, Haidian District, Beijing 100875, China. Tel.: +86 13681113976.
E-mail addresses: yfan@bnu.edu.cn (Y. Fan), bnurensuting@126.com (S. Ren), hongbocai@bnu.edu.cn (H. Cai), xuefeng.cui@bnu.edu.cn (X. Cui).

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This type means that any two countries can be either connected by a link or not, and link directions (import and export) do not matter. If two countries are connected, we say that they are "partners" or "nearest neighbours". To formally characterise such types of *ITNs*, it is sufficient to provide the so-called adjacency matrix. For an undirected *ITN* and a given year *t*, the adjacency matrix is a symmetric $N \times N$ binary matrix *A* whose generic entry $a_{ij} = a_{ji} = 1$ only if a link between countries *i* and *j* exists (and zero otherwise).[1] In the early constructions of the network, incomplete data were adopted to build a binary ITN for one particular year (2000 dataset). Building an unweighted *ITN* allows us access to the simple nature of the network, such as its *density* and the *degree distribution*. Studies have shown that *density* is observed to remain roughly constant, with values of approximately 0.52 for the same period. This network displays a scale-free *degree distribution*, small-world property, a high clustering coefficient, and degree–degree correlations between different vertices, which are the typical properties of complex networks (Serrano and Boguna, 2003). Further results show that the binary-directed representation of the ITN exhibits a disassortative pattern: countries with many trade partners (i.e., high node degrees) are, on average, connected with countries with fewer partners (i.e., low average nearest-neighbour degrees).[2] Further outcomes show significant synchronisation of economic cycles in representative developed countries with the United States (Li et al., 2003). All the properties make the *International Trade Network* a complex network that is far from being well described through a classical *random network* description (Serrano and Boguna, 2003).

Using a binary *ITN* analysis, researchers focus their attention on the problems of the intensity and evolution of international trade by weighted analysis to discuss issues such as the processes of globalisation and regionalisation (Erolay et al., 2011; Tzekina et al., 2008), the role of extensive and intensive margins of trade (Benedictis and Tajoli, 2011; Riccaboni and Schiavo, 2010), the core/periphery structure (Fagiolo et al., 2010; Kali and Reyes, 2007) and the role of *WTO* (Benedictis and Tajoli, 2011). They adopt weighted-network approaches by defining the elements of the weighted adjacency matrix as $\widetilde{w}_{ij} = \exp_{ij}$, $\widetilde{w}_{ij} = imp_{ij}$ or their combination.[3] Due to the results, which indicate that the *ITN* is a strongly symmetric network (Fagiolo et al., 2007a) where the majority of trade relationships (and their intensities) are reciprocated,[4] a good deal of research uses a symmetrical network approach by switching $\widetilde{w}$ to w through the relation of $w_{ij} = w_{ji} = \frac{1}{2}(\widetilde{w}_{ij} + \widetilde{w}_{ji})$.[5]

After finding the weighted adjacency matrix, they either build the *ITN* using a more complete time-series dataset or develop evolution models to explore the network's structure and feature. Research demonstrates that some important aspects of the *International Trade Network* have been remarkably stable from 1938 to 2003 (Kastelle et al., 2006), and the topology of the weighted *ITN* is crucially different from binary methods in a given year. The weighted *ITN* shows weakly disassortativeness, and, moreover, well-connected countries tend to trade with partners that are strongly connected (Fagiolo et al., 2008). The distribution of the total trade intensity carried by each country (i.e., node strength) is right-skewed, indicating that a few intense trade connections co-exist with the majority of low-intensity ones (Fagiolo, 2010; Fagiolo et al., 2008, 2009). Another universal feature is observed in the power-law growth of the trade strength with the gross domestic product, the exponent being similar for all countries (Bhattacharya et al., 2008). In addition, Tzekina et al. consider the formation of trade "islands" and their evolution to identify community structures and hubs and find mixed evidence for globalisation (Tzekina et al., 2008).[6] These studies display that the *complex network analysis* can be used not only to describe network structures but also to discuss some actual topics of international trade from a new, intuitionistic angle.

Following the network's structure analysis above, scholars (Foti et al., 2011; Kali and Reyes, 2007; Lee et al., 2011; Serrano et al., 2007) try to explore robustness and (crisis) propagation problems of the *ITN* instead. To investigate robustness (stability of the international trade system), Foti et al.(2011) introduce the notion of extinction analysis, showing that over time, the *ITN* moves to a "robust yet fragile" configuration where it is robust to random failures but fragile under targeted attack. Scholars believe that a network approach that is capable of incorporating the cascading of interdependent ripples that occur when a shock hits a specific part of the network will provide us with a deeper understanding of economic and financial contagion (Kali and Reyes, 2007). They find that a crisis is amplified if the crisis epicentre country is better integrated into the trade network. Another study develops a general procedure capable to progressively filter out in a consistent and quantitative way the dominant trade channels and provides new quantitative tools for a dynamical approach to the propagation of economic crises (Serrano et al., 2007). A recent study uses a simple toy model of crisis spreading, finding that the GDP of a country cannot fully account for its avalanche size and an individual country's role in crisis spreading is dependent not only on its gross macroeconomic capacities but also on its local and global topological structure in the world economic network (Lee et al., 2011).

The above research provides a good snapshot of the structure and features of *ITNs*, enabling us to understand international trade as a whole. In this paper, we provide another picture of the mid-level structure and even micro-level elements of *ITNs* using the latest complex network theories. We first explore the cascading influence of the interdependent ripples that occur when trading relationships change in the *ITN*, which cannot be measured by traditional economic methods.

In this paper, after presenting the main topology and structure of the *ITN* (Section 2), we introduce the *coarse graining* method and the weighted extremal optimisation algorithm (*WEO*) to divide the countries into communities, which help us discuss the trade patterns on a mid-level structure of the *ITN* (Section 3). With this context of mid-level structures, six centrality indicators are raised to measure vertices' importance in the *ITN*, and issues of the roles of countries and the EU will be discussed. The results provide countries' ranking order and some conclusions about trade imbalance, globalisation and regionalisation. Moreover, by using a simple bootstrap percolation process, we discuss the topic of cascading failure caused by disconnecting vertices' linked in the *ITN*, which is the key objective of this paper (Section 5).

2. 2010 *International Trade Network*

As a supplementary and typical example of an *ITN* study, we build a 2010 *International Trade Network*, and make empirical analyses using the latest achievements in complex network theory.

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[1] Self-loops, i.e. links connecting i with itself, are not typically considered, which means that aii = 0 for all i. Considering the direction, an adjacent matrix A can be a non-symmetric matrix, such that rows of A represent exporting countries whereas columns represent importing countries.

[2] It can be further proven that the partners of well-connected countries are less interconnected than those of poorly connected ones, implying some hierarchical arrangements, as proposed by Garlaschelli D. and Loffredo M. I. (2005), 'Structure and evolution of the world trade network', *Physical A*, 355, 138–44.

[3] In some conditions, link weights of $\widetilde{w}_{ij}$ usually have to be filtered by setting the cut-off value (Kastelle, 2009; Kastelle et al., 2006). Other researches may define link weights of $\widetilde{w}_{ij}$ in different ways. For example, $\widetilde{w}_{ij}$ can be the percentage of imports or exports of the total international trade (Kali and Reyes, 2007; Tzekina et al., 2008) or can be defined as $\exp_{ij}$ divided by the GDP of country *i* (Fagiolo et al., 2007a, 2007b, 2008, 2010).

[4] Another reason is the limitations of the technical means.

[5] Finally, to have $w_{ij} \in [0,1]$ (and to remove all trend-related factors) for all (i,j) and *t*, all entries in *W* can be re-normalised by their maximum value of w_{ij}, which means that the symmetrised weight *W* is proportional to the total trade (imports plus exports) flowing through the link *i*, *j* in a given year.

[6] To analyse the structure and behaviour of the network through time, they use the notion of islands, which is implemented in *Pajek*, as a means to identify communities and hubs. Islands correspond to connected components in which the weights of the arcs within the community are significantly larger than those outside the community.