Management Potential of an International Trade Network Based on Cointegration Analysis

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Abstract

This article investigates whether cointegration approach can be the basis of an international trade network and whether such a network is relevant for analysis. We fit data on international-trade flows with a cointegration specification using cointegration approach. In addition, we use the force algorithm of Kamada and Kawai for replicating the weighted international trade network. We find that the cointegration approach in combination with the Kamada and Kawai algorithm successfully replicates the weighted international trade network structure. The presented methodological toolkit allowed to distribute the countries-participants of the network into separate groups (communities). We also identify the specific network participants – network-drivers which have specific management functions in the international trade network. Driver countries are able to change the system configuration with a relatively small impact on them. This means that to change the network configuration, it is advisable to act on the driver nodes.

Keywords: world trade, complex networks of international trade, complex weighted network, World Trade Web, cointegration, network-core, network-drivers

Introduction

The modern world trade is very complicated and multidimensional and therefore requires new approaches in order to assess of its dynamics; identify regularities of its development and systematization of the results obtained. The emergence of a new wave in the empirical analysis of the international economy, the expansion of the use of econometrics, the use of interdisciplinary approaches, and the increasing availability of statistical data make it possible to develop a tool for studying international trade. Such approaches may be a cointegration analysis of international trade relations and the subsequent visualization of the results obtained by creating complex networks.

The main idea of this approach is the presentation of the trade relations as a weighted network where countries play the role of nodes and connecting arcs between nodes show the presence of trade (export / import) between any two countries (and, possibly, the intensity of this flow). We call such a network as World Trade Web (WTW).

The network does not include other variables, in addition to the indicators of trade between countries. Unlike other conventional approaches, such as the gravity model of international trade, where other economic variables are important, network analysis uses only export/import indicators to analyze the ties among countries-nodes and the possibilities of its compound into a common interrelated system of the international trade.

The advantages of using the network analysis over other methods of studying the world trade is that it is not the absolute or relative attributes and characteristics of the country go in the first place, and mainly there are a relationships among the countries, and the international trade is viewed as the complete system. This method of analysis can be an excellent addition to the existing methods of analyzing world trade.

Review of Relevant Studies and Problem Statement

A network may be defined as a directional or non-directional graph that contains a specific set of nodes and arcs that connect certain pairs of these nodes according to a determinate mathematical algorithm. These arcs are not just links between nodes, but also certain channels through which flows of information, the capitals, material resources, etc. are transmitted. Originally, interest in the using of networks for scientific and applied research arose in logistic networks and mathematical programming for the solution of production and transport problems in the 1950s. Afterwards, network analysis began to be actively used in informatics, physics, biology and other spheres due to the significant development of methodological and applied tools.

The methodological toolkit that was formed and developed in the technical and social sciences has become increasingly popular in the finance and economics. Wide dissemination of the network approach has received in finance, where network analysis is applied to the analysis of financial markets, the characteristics of the distribution of insurance and banking risks, a contagion banking relationships, centralization and decentralization of banking structures, the formation of the inter-linkages to enhance the sustainability and reduction of contagion (Allen and Babus, 2009; Gai and Kapadia, 2007).

In recent times, there are significant fundamental studies of application of the network approach in economics. In the work of Schweitzer and others (2009) provides an overview of the employment of complex networks in the economics. Fundamental books by Goyal (2007) and Jackson (2010) consider Economic Networks as specific economic tools. As a result, the idea that certain economic players, the markets, industries, or world economy, can be considered as network structures became more and more accepted also among empirical economists. In this context, a network-based approach began to be used in empirical studies of international trade (Serrano and M. Boguñá, 2003; Li et al., 2003; Garlaschelli and Loffredo, 2004, 2005; Kastelle et al., 2005; Serrano et al., 2007; Bhattacharya et al., 2007, 2008).

Ideas of the network analysis, various methodological tools have found applications for the analysis of the international economic processes, first of all international trade. International trade is the main subject of the analysis in numerous scientific works of Fagiolo et al. (2010, 2012). In these works are applied interesting conceptual decisions of analysis of the international trade flows, are presented reports on the methodology and results of researches. This paper employs network analysis to study the statistical and topological properties of the web of trade relationships among world countries, and its evolution over time.

Research Methodology

Our conclusions and proposals based on the results of the analysis and interpretation of basic concepts that are associated with the analysis of complex networks of international trade among selected countries. We also make a special emphasis in research in Russia, because it has important practical implications for us. From a methodological point of view, we use new methods and their combinations to obtain cointegration networks of the international trade. The cointegration network may be possible if the sample of countries that are being investigated have multiple cointegration dependencies.

We build international trade networks on the basis of the cointegration dependencies (Navrotskaia et al., 2019) while in the existing literature used regression dependencies. The cointegration approach has some advantages for our research over regression analysis methods, because it investigates long-term dependencies and analyzes the possibilities of restoring the equilibrium of international trade relations. We extend the paper by Sopilko et al. (2017) and continue to draw separate conclusions.

We use the result of this paper that the last year's export makes the strongest impact on the current export by comparison with other exogenous and endogenous factors that have been investigated. In view of the above, the cointegration approach may have significant advantages, because studying the long-term relationships and dependencies as well as take into account the influence of the autoregression.

We investigate whether the cointegration approach can provide a satisfactory theoretical benchmark able to reproduce the observed network architecture of international trade relations. We study the international trade networks as the complex weighted network while the bulk of the relevant literature on international trade networks has indeed studied a binary and/or simple version of the international trade networks.

The data used for the analysis is statistical information on exports and imports of countries, Russia's largest trading partners for the period from 1996 to 2015 (Annex 1) provided by UNCTAD (the UN industry classification). We analyzed mutual trade of Russia with selected countries and also mutual trade between selected countries to distinguish possible external effects for international trade ties.

Results

Cointegration is an important specific dependence on many economic variables in which, despite the random nature of the changes in certain economic parameters, there is a long-term relationship between them, leading to some joint interrelated change (Nelson and Plosser, 1982). This means that any changes in the dynamics of the development of trade relations of one of the cointegrators instantly breaking the balance system and inevitably cause corresponding changes in the dynamics of the trade flows of the other cointegrator. In our study, time series were tested for the presence of a long-term stochastic trend – the cointegration relation, that is, the existence of some stationary linear combination of several integrated time series was verified.

Modeling the dynamic process of restoring equilibrium between the cointegrated series of international trade flows after temporary imbalances was made based on the Error Correction Model (ECM). This model is a dynamic model in which the change in the dependent variable in the current period is caused by a disequilibrium in the previous period due to the shock of the independent variable.

The assessment of ECM was made using the approach of Johansen (1994), which was based on a vector model of error correction (Engle and Granger, 1987). The model is as follows:

$$\Delta y_t = Cy_{t-1} + \mathrm{B}_1 \Delta y_{t-1} + \ldots + \mathrm{B}_q \Delta y_{t-q} + Dx + \varepsilon_t, \qquad (1)$$

where y_t – k-dimensional vector of endogenous variables;

x_t – is the d-dimensional vector of exogenous variables;
B_i – cointegration vector;
Cy_{t-1} and D – matrix coefficients that are subject to evaluation;
Dx – matrix of exogenous variables;
ε_t – is a vector of normally, independently and identically distributed errors with zero means and constant variances.

The result of modeling the trade relations of the chosen set of the countries was the cointegration models and coefficients that allowed to assess the nature of the interrelationships between international trade flows, to identify sectors and countries of critical dependence, which may be important for assessment of economic capacity of the countries.

The cointegration analysis gave us an opportunity to assess the dependencies between international trade flows of countries, to identify weak and strong positions of the country in certain sectors, to estimate the potential of the dynamics of the restoration of trade relations in consequence of their disruption due to external and internal shocks. This can be taken into account in the short-term forecasting of the development of international trade.

As in the study were used big data sets that was due to the selected set of countries and the study period, as well as a vector approach, the results of the of cointegration modeling represented a large set of information. This caused significant difficulties for further analysis of the cointegration co-factors, which were presented in vector form, and the economic interpretation of the results.

These problems of ordering and presenting the results obtained were solved by constructing complex weighted networks. In accordance with the goals and objectives that we set, we built cointegration networks for individual branch. For the construction of networks, a successive sorting of all importing countries was conducted and co-integration relations between the exporting countries were determined.

The disposition of the vertices was optimized according to the minimum of the "internal energy" of the system of elements with "spring" coupling by the force algorithm of Kamada and Kawai (1989). The model is as follows:

$$E = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \frac{1}{2} k_{ij} \left(\left| p_i - p_j \right| - l_{ij} \right)^2 , \qquad (2)$$

where n – number of vertices; p_i – is the position of vertex *i*;

k_{ij} – is the spring force between p_i and p_j;

l_{ij} – is the product of the desired edge length in the graph (on the plane) and the nearest distance between the vertices i and j.

Examples of received networks are presented in the following Fig. 1 and Fig. 2. In the presented figures, circle nodes represent the countries – participants in the network, the square nodes are country – drivers that can manage a certain group of countries (community) in the selected industries. The brightness of the edge reflects the force of the connection between countries – the brighter line, the closer relationship. The color of the nodes reflects belonging to different network communities. In the presented Figures, the core of the network and the periphery are clearly visible.

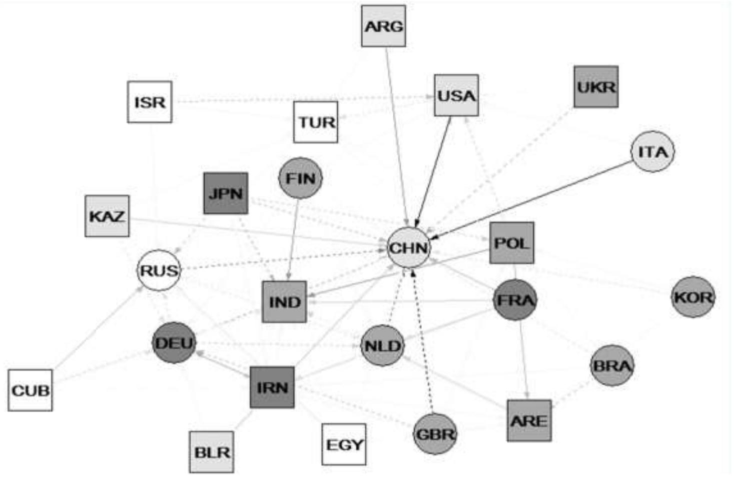

Fig. 1. The cointegration network of mutual trade in "Raw materials and mineral resources" industry

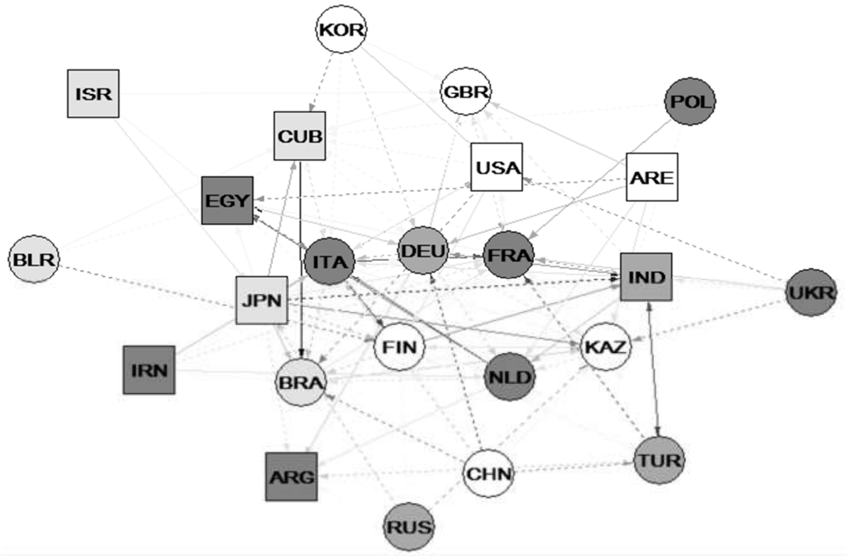

Fig. 2: The cointegration network of mutual trade in "Mechanical engineering" industry

In each of our WTW, we identified 4 different groups. Thus, in these examples of networks in Figure 2 (industry "Mechanical engineering"), four such groups were distinguished (in the color of the nodes): (1) USA, China, Great Britain, Republic of Korea, etc.; (2) Japan, Brazil and others; (3) Germany, Russia, India, Turkey and others; (4) Italy, France, the Netherlands, Poland, etc. The study groups of countries (communities) in the network can provide the key for understanding the processes of integration in the world economy.

Further, it is advisable to conduct the analysis of the constructed network models of trade relations from the standpoint of the theory of managing complex networks to identify the asymmetry of distribution (Liu et al., 2012). In our study, the effective identification of the minimum set of countries (driver nodes) that were necessary to distribute the channel weight and achieve complete control of networks with arbitrary structures was made using the algorithm of maximum geometric multiplicity (Yuan et al., 2013). The modularity of the graph used in our study is the fraction of edges that are located within the given groups minus the expected similar fraction if the edges were distributed randomly with the same number of tops, where each country (node) retains its degree of importance. The value of modularity lies in the range from (-1/2) to 1. The modularity of the graph is positive if the number of edges within the groups exceeds the number of random or short-term trade links. Measuring the power of the separation of the network into modules (groups, clusters or communities) is used to optimize the network structure.

In our WTW, we found two control systems: (1) through the core of the network and (2) through the nodes-drivers, as well as two levels of control – (1) control of the entire network and (2) control over group (community) of countries. The core of the network is a compact group of nodes where the most influential exporters in the industry are concentrated. They play a crucial role in maintaining the structural integrity of the network and shaping its architecture. In the networks presented for examples (Fig. 1 and Fig. 2), the cores and the periphery can be identified. So, in the industry "Raw materials and mineral resources" (Fig. 1), two cores with central nodes – China and India – are clearly distinguished. In the industry "Mechanical engineering" (Fig. 2), many central cluster aggregates are identified. It should be noted, that in the obtained networks the cores are not always located in the center. This is confirmed by the study of Li et al. (2011) that topological characteristics and network configuration do not affect its controllability.

But the core countries have only partial control over the network. In order to control the system, we also need to identify a set of nodes that we can control with different signals. In this case, we can provide full control over the system. We call these nodes as driver-nodes. A large number of drivers indicates the complexity of network management. Of particular interest is the definition of a minimum set of drivers that are sufficient to fully control the dynamics of the system.

It is paradoxical that in the networks we have received, the drivers are most often countries whose absolute and relative volumes of exports and imports in these industries are not significant. The logical question is why exactly these countries can manage the network. In this regard, it is necessary to clarify the specific role of driver-nodes in the network. Understanding this role can be explained through the concept of the amount of energy that is needed to affect a node. If the network cores are countries that are leaders in international trade in a certain industry, therefore, the amount of energy needed to influence these node-countries in order to change the configuration of the system can be very large. Unlike network core countries, driver-countries differ in their ability to change the system configuration with relatively little impact on them. This means that in order to change the network configuration, it is advisable to influence the driver countries. Important in this approach is that we can simulate a possible change in the network configuration by defining new parameters for the participation of driver countries after a possible external impact on them. These conclusions can be used to build predictive dynamic models and analyze the consequences of using various trade policy instruments.

The core nodes and nodes-drivers provide full control throughout the network, but important for the analysis of the network architecture is the identification of interrelated groups (communities) and control in these groups. In each of our networks we have identified four different groups. It is likely that further study of the structure of the resulting networks is advisable to carry out on the selected groups. The allocation of groups in the network allows to identify not only explicit, but also hidden connections and opportunities for development of international trade relations.

Conclusions

This paper presents the results of the study of international trade, using the cointegration weighted networks. We have generated cointegration networks of international trade for a selected group of countries in enlarged industries. Our exercises show that the cointegration approach does a very good job in replicating the weighted-network structure of the international trade flows. It should be noted as the success of the combined application of the cointegration approach and the force algorithm of Kamada and Kawai for the reproduce of the network of the international trade.

The consideration of international trade as a network and the study of its topology and characteristics allowed us to carry out a systematic positioning of countries; to identify the subjects of control – network cores and network drivers; to establish control mechanisms in the distribution network; to identify features and management potential in networks. In our WTW, we found two control systems: (1) through the core of the network and (2) through the nodes-drivers, as well as two levels of control -(1) control of the entire network and (2) control over group (community) of countries.

Using management positions, the specific roles for core countries and driver countries in the WTW were substantiated. The core of the network is a compact group of nodes where the most influential exporters in the industry are concentrated. They play a crucial role in maintaining the structural integrity of the network and shaping its architecture. Driver countries are able to change the system configuration with a relatively small impact on them. This means that to change the network configuration, it is advisable to act on the driver nodes. It has been established that the drivers in the networks we receive are most often countries whose absolute and relative volumes of exports and imports in these industries are not significant.

These findings give us the opportunity to study the control mechanisms in the network; simulate a possible change in network configuration, after an external impact on driver countries. These findings can be used to analyze the consequences of using various trade policy instruments and forecasting international trade flows. The presented networks raise many questions, the answers to which can deepen our understanding of the structure and dynamics of the development of international trade. Of interest is the analysis of hierarchical interactions of nodes: between network cores, between a core and peripherals belonging to one or different groups, between network drivers, etc., which may become the object of further research. The conducted studies showed the prospects of further study of international trade using cointegration networks. Understanding of the topological properties of the WTW, and their development over a long period of time, becomes fundamental importance for the explaining the problems of international trade, such as economic internationalization and globalization.

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Annex 1: Countries included in the model calculation

#	Conventional signs	Country	#	Conventional signs	Country
1.	ARG	Argentina	13.	DEU	Germany
2.	BLR	Belarus	14.	ARE	The United Arab Emirates
3.	BRA	Brazil	15.	POL	Poland
4.	GBR	Great Britain	16.	KOR	The Republic of Korea
5.	EGY	Egypt	17.	RUS	Russian Federation
6.	ISR	Israel	18.	USA	The USA
7.	IND	India	19.	TUR	Turkey
8.	ITA	Italy	20.	UKR	Ukraine
9.	IRN	Iran	21.	FIN	Finland
10.	KAZ	Kazakhstan	22.	FRA	France
11.	CHN	China	23.	JPN	Japan
12.	NLD	Netherlands	24.	CUB	Cuba