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MODELING THE INTERNATIONAL-TRADE NETWORK: A COINTEGRATION APPROACH

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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 a 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 who have specific management functions in the international trade network.

Keywords: *international trade, international trade network, cointegration, weighted network analysis*

Introduction

The modern world trade is very complicated and multidimensional and therefore requires new approaches in order to identify regularities of its development, assessment of its dynamics 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 to show trade relations as a 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 will use the name of this network as the 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 a 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

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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 directed 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 use 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 (e.g., Dorfman at el., 1958; Ford and Fulkerson, 1962).

In the future, Network analysis began to be actively used in informatics, physics, biology and other spheres due to the significant development of methodological and applied tools (Albert and Barabasi, 2002; Dorogovtsev and Mendes, 2003; Newman, 2003; Pastos-Satorras and Vespignani, 2004). Academic scientists actively began to explore the parameters and properties of information, technological and biological networks. The use of network analysis here included the Internet, energy systems, logistics routes and links airlines, electronic circuits, neural networks, metabolism and protein interaction, and so on.

Network-based theory also developed rapidly for the analysis of social and psychological processes. At the end of the 20th century, the major empirical contributions to the theory and practice of network analysis were made in the study of the socio-economic system (Wasserman and Faust, 1994). Sociologists and psychologists have used network analysis to examine samples of interactions established among individuals or social groups (Freeman, 1996; Scott, 2000).

Recently there has been significant progress in studying diffusion processes including explicit social network structures. Network analysis has also offered important insights into research and development (R&D) networks and trade agreements. All of this research begins to suggest how network analysis might be applied to understanding finance (e.g., Galeotti and Goyal, 2007; Lopez-Pintado, 2012; Watts, 2003).

The use of network theory is especially relevant for the analysis of the market, consumer behavior and market efficiency. The work by Katz and Shapiro (see Katz and Shapiro, 1994) examines the value of social network information for the player and find that it depends on the dispersion in social connections. The economic interest of these results is displayed via a discussion of the different economic applications, among which an important one is advertising through communication and seeding a network.

Recently there has been substantial progress in the study of social network structures; diffusion of information products through social networks, individual's behavior as a result of a strategic choice (Galeotti and Goyal, 2007; Goyal and Anderson, 2016; Lelarge, 2012; López-Pintado, 2012).

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, branches, or world economy, can be considered as network structures more and more became 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 interesting and daring conceptual decisions of analysis of the international trade flows are applied, good reports on the methodology and results of researches are presented.

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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. Understanding of the topological properties of the WTW, and their development over a long period of time, acquires fundamental importance in explaining the problems of international trade, such as economic globalization and internationalization.

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 international trade networks of the international trade. The cointegration network will 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, 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 influence 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 the network architecture of international trade relations.

We study the international trade networks as a 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.

An informational base in our research is data about export and import in Russian partner countries for 1996–2015. We analyzed mutual trade of Russia with selected countries and also mutual trade between selected countries to distinguish possible external effects for Russian international trade ties. The data of international trade (export/import) were grouped together as a matrix, including branch indexes for 1996–2015.

Results and Discussion

Cointegration is an important specific dependence of 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.

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

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

where y_t – k-dimensional vector of endogenous variables;
x_t – is the d-dimensional vector of exogenous variables;
B_i – cointegration vector;

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Cy_{t-1} and D – matrix coefficients that are subject to evaluation;
Dx – matrix of exogenous variables; εt – 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 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.

So, the greatest dependences between trade flows can be tracked between Russia and Germany in branch "Raw materials and mineral resources", Russia and India – "Ores", Russia with Israel and Finland in branch "Nonferrous metallurgy". Weak interrelations were received in the international trade flows of Russia in branch "Mechanical engineering" as confirmed by the low level of its participation in the global value chains (GVCs). This fact shows that Russian industry should look for opportunities to increase the involvement of Russian enterprises in GVCs, the optimization of trade and business communications and the identification of the most promising areas of international cooperation.

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:

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

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 branches. 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. Core-nodes and driver-nodes provide complete control of the entire network, but it is important for the analysis of the network architecture to identify the interconnected groups (communities) and the monitoring mechanism in these groups.

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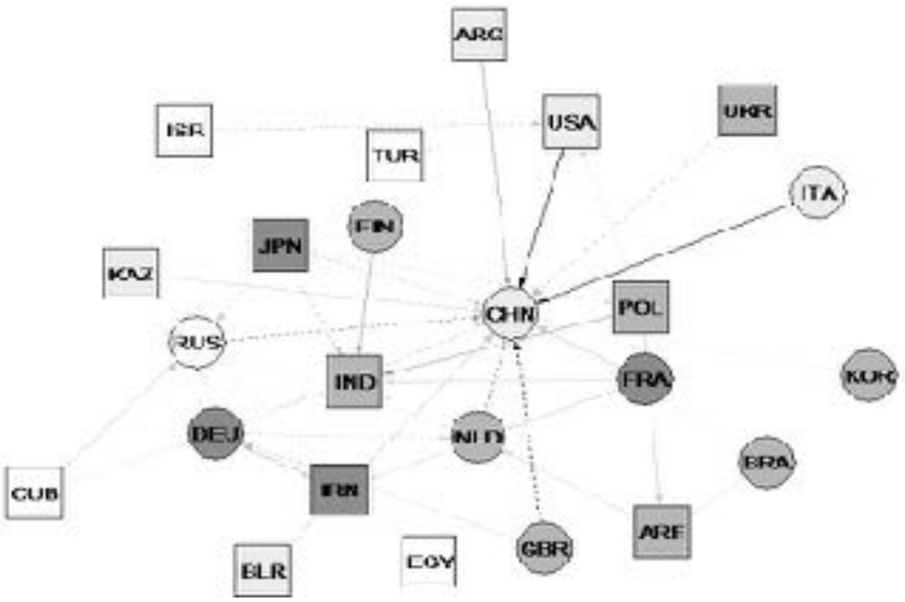

Fig. 1: The cointegration network of mutual trade in branch
"Raw materials and mineral resources"

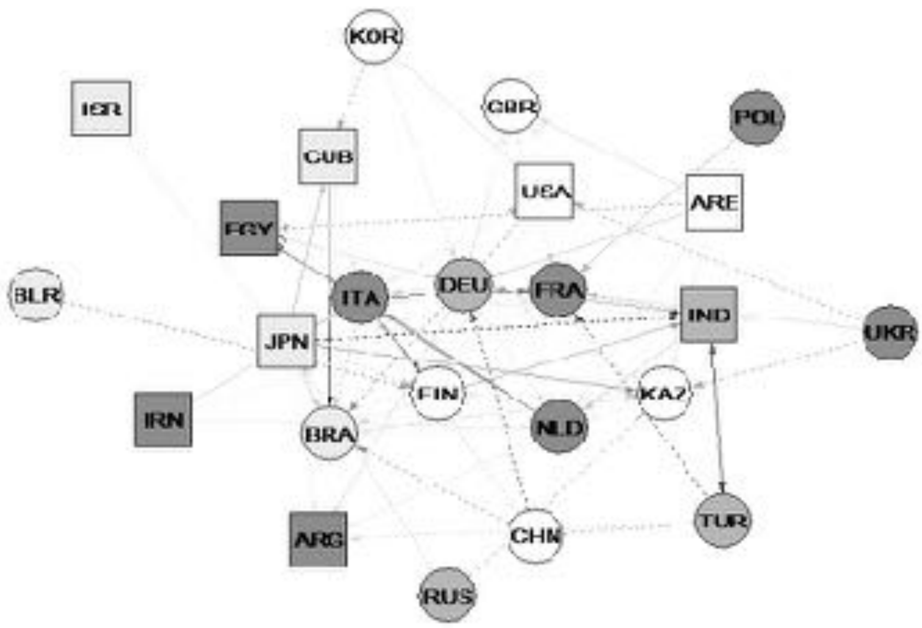

Fig. 2: The cointegration network of mutual trade
in branch "Mechanical engineering"

In each of our networks, we identified four different groups. Thus, in these examples of networks in Figure 2 (branch "Mechanical engineering"), three such groups were distinguished (differing 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. The study groups of countries (communities) in the network can provide the key to understanding the processes of integration in the world economy.

Conclusions

Our exercises show that the cointegration does a very good job in replicating the weighted-network structure of the international trade flows. The conducted studies showed the prospects of further study of international trade using cointegration networks. 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

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reproduce of the network.

It is interesting to analyze the hierarchical interaction of different nodes: between the cores of the network, between the core and the periphery, between the network drivers, taking into account their belonging to one or different communities, which may become the object of subsequent research.

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