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Research paper

Estimation of the Degree of Entropy of Russia's Foreign Economic Relations in the Choice of an International Industrial and Technological Partnership

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Abstract

The article studies the orderliness of Russia's foreign economic relations in the context of industrial and technological partnership with the other countries. The research is based on a combination of the logical-probabilistic approach of complex networks. It was noted that the issue of choosing the best ways for international production and technology cooperation should be resolved from the point of view of deliberate ordering in the most significant sectors for the planned outstripping development. The most significant industries for the Russian economy are identified: coal, oil and gas, machine building and high-tech sectors of the economy. The indicators of relatively low entropy (orderliness) of foreign economic relations in these significant areas are obtained. That means that there is a high potential for expanding the production and technology partnership. Although it was noted that Russia is not an active participant in industrial and technological integration with many countries in the world. The results of the study confirmed the possibility of using entropy indicators to assess the degree of development of foreign economic relations and determine the optimal directions of industrial and technological partnership.

Keywords: *Entropy of foreign economic relations, industrial and technological partnership, information processing theory, complex systems.*

1. Introduction

A key issue in exploring the possibilities of an industrial-technological partnership is the choice of the best ways to develop it.

Domestic and foreign scientists, based on the use of the logic-probabilistic approach, consider various aspects of the industrial and technological partnership of countries, including Russia [1]. One of the most productive tools for determining the direction of development of industrial and technological partnership is the definition of entropy of existing foreign economic relations.

In a general sense, entropy is a measure of the disorder of the external environment. The definition of entropy of Russia's foreign economic relations, carried out in the context of the main export and import commodity groups, makes it possible to identify those areas where the measure of entropy characterizing unpredictability of the process has very significant implications. In the economic sense, this means that the use of the relative entropy of the motive, in combination with the other characteristics of cointegration networks, makes it possible to determine the most promising directions for the development of the international production and technology partnership for a number of key sectors of the Russian economy.

The authors of this article selected three key product groups, to which the issue of the appropriateness of changing the density of links and key participants in the production and technology partnership: "coal oil and gas"; "Products of mechanical engineering"; "High-tech products" was considered. The choice of the commodity group "coal, oil and gas" is due to the prevalence of revenues from this group in the amount of state budget revenues and the most significant volume of exports. The choice of the commodity group "engineering products" is connected with its infrastructural role in the economy of the country and the importance for the development of other industries, as well as an essential need for cooperation. The choice of the commodity group "high-tech products" is due to its importance as a driver for the development of other industries and the need to be integrated into the international scientific space when creating high-tech products and serial production.

The theory of information processing in complex systems is presented by G. Markowitz's portfolio theory, supplemented by J. Tobin and W. Sharp [2], works of scientists developing the theory of complex networks [3], developments in controllability [4][5], the theory of network motives [6], and information sufficiency [7] and the deployment of communities in large networks [8]. The ways of development of foreign trade relations of Russia on the basis of the approach to their assessment based on the theory of complex systems were considered in the works of Russian scientists [9]. However, issues of development of optimization of such their the most important component of international economic relations, as production and technological cooperation were not covered.

2. Methodology of the Research

The methodological basis of this study was the work of scientists from different countries on the complexity and patterns of development of industrial and trade relations between countries and work on the theory of information processing based on the logical and probabilistic approach to the analysis of economic variables.

The choice among the tools of economic and mathematical modeling of Bayesian networks of trust (DBN – dynamic bayesian network) of J. Perl is due to the fact that they allow describing the hierarchical interactions of nodes [10]: between the core of the network, between the core and the periphery, belonging to one or different groups, between the network drivers and etc. These are graphical models with an oriented acyclic graph, where the vertices of the graph correspond to random variables, and the oriented edges encode the relations of the conditional probability dependence between the variables. Each node is associated with a probability function that takes as input a certain set of values from the nodes of the "parent" variables, and on the output gives the probability distribution of the variable of a single node.

The joint probability distribution of the variables of a Bayesian network satisfies the equation:

$$P[X_{1,\dots,}X_n] = \prod_{i=1}^{n} P[X_i | pa_i], \qquad (1)$$

where pa_i is the set of vertex ancestors of the vertex X_i.

In this paper, an algorithm based on the Bayesian network is used, as one of the few methods that allows us to schematically represent the network structure with variables containing continuous data and obtain data for the conditional Gaussian Bayesian network [11]. The choice of network analysis for selecting promising areas of industrial and technological partnership is based on the proposal for its application in the case of highly centralized and asymmetric global supply chains [12]. The maximum geometric multiplicity method is used, based on the calculation of the maximum multiplicity for effective identification of the minimum set of countries (driver nodes) required to achieve complete control of networks with arbitrary structures and channel weight distribution [5].

The study of publications devoted to the research of the international production and technology partnership of countries showed the diversity of opinions of scientists about its development in modern conditions. In the publications of recent years, the following conclusions, significant for the creation of a toolkit for the selection of optimal routes for the international production and technology partnership of Russia were made:

1. On the relationship between the international industrial and technological partnership of countries with innovative activity:

– the growth of the export potential of the nanoindustry products leads to economic growth, abd the reduction in the cost of exported nanoproducts to its slowdown [13];

– an international industrial and technological partnership in the creation, production and sale of high-tech products increases the innovative activity of participating firms [14–16];

– an international industrial and technological partnership has a positive impact on the development of human capital in developing countries [17, 18].

2. On the impact of the production and technology partnership on the country's sustainable development:

– trade in intermediate goods demonstrates participation in the international division of labor on the basis of fragmentation of production and positively affects the economy of the country [19];

– an international industrial and technological partnership that positively influences the country's economy can have a negative impact on the environment [20];

– industrial and technical partnership in the form of investment of material assets of non-resident companies in the economy has a significant impact on the competitiveness of the national industry [21];

– for each country there are critical areas in partnerships [22];

– the disintegration of partnership agreements negatively affects the economy and social sphere of the participating countries [23].

The above conclusions of experts in the world economy are important for the correct interpretation of the results obtained on the basis of the model proposed by the authors of this article for choosing the best ways to develop an international production and technology partnership.

3. The Result of Research

Networks that characterize the interaction of participants in the international production and technology partnership raise a lot of questions, the answers to which can deepen our understanding of how it should develop. The further assessment of the degree of entropy of Russia's foreign economic relations in three important areas for its economy will enable us to answer two questions. The first – with which partners it is expedient to cooperate in the chosen direction. The second, what is the expected macroeconomic effect of expanding the international production and technology partnership in the chosen direction with these partners.

Illustration of Bayesian networks for international trade in high-tech products is presented in Figure 1 (based on UNCTAD 2017 data), which is the main object of modern international production and technology cooperation.

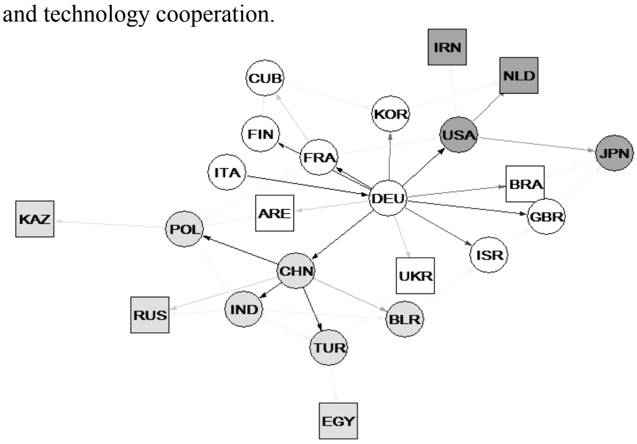

Fig. 1: Bayesian network of international trade in high-tech products

Bayesian networks discarded all random information and preserved probabilistic relationships between exporting countries in relation to importing countries that correspond to the proximity of the deterministic trends of international cooperation hidden in the network.

It is interesting to analyze the hierarchical interactions of nodes: between the core of the network, between the core and the periphery with the membership of one or different groups, between the network drivers, etc. In our networks, we discovered the possibility of monitoring through the core network countries and through the nodes-drivers. The core represents the most influential exporters of high-tech products (in Figure 1, the US and Japan). At the same time, the drivers are often countries that do not have large amounts of export-import operations but have a significant impact on international production-technological cooperation (in Figure 1, one of these countries is Russia). From the theory of complex networks, it is known that the impact drivers can be sufficient to fully control the dynamics of the system.

For high-tech products and for two other areas of economic activity affecting the macroeconomic situation in Russia (coal, oil, gas and engineering products), based on the network models obtained in the above way, we will present key characteristics reflecting the potential for the development of international industrial and technological integration (Table 1) (built on the basis of UNCTAD 2017 data).

Table 1: Characteristics of complex networks of three key sectors of the Russian economy

Structural, topological and functional characteristics of complex networks	Industries		
	Coal, oil, gas	Engineering products	High-tech products
Density of bonds	0.116	0.210	0.130
Coefficient of flow	0.060	0.116	0.064
Maximum grouping factor	0.824	2.097	5.141
A country	RUS	USA	POL
Global Efficiency	0.211	0.379	0.237
Assortative mixing	-0.075	-0.124	0.008
Number of independent cycles	55	101	64
Maximum node height	14	18	15
Country	USA	FRA ITA	IND
Number of drivers	14	9	15
Number of control combinations	2	1	2
Modularity of the graph	0.599	0.507	0.631
Relative entropy of motive 3	0.582	0.804	0.667
Relative entropy of motive 4	0.566	0.771	0.640

In Table 1 the following resultant characteristics are presented:
– the density of relations between countries – the ratio of the number of observed connections to the number of the most possible edges of the graph, and it can be noted that the highest density in the compared group for the production of machine building, which is explained by the large volumes of mutual trade in this industry, due to the most significant division of labor;
– the average coefficient of flow of the graph – the ratio of the number of connections involved between the node, its nearest neighbors and with each other in all combinations to the number of all possible connections between the same vertices, shows the share of realized directions of the relationship, in their total number, which in engineering products is also maximal;
– the maximum grouping factor or coefficient of local clustering is a measure of how well the neighboring countries of the given node are related, in the presented group, is the maximum in high-tech products, the basis of which is integration in the sphere of innovations;
– global efficiency – the average number of the reciprocal length of the shortest path between all vertices of the graph, is the maximum in engineering products, which indicates a more significant advantage in this area of global industrial and technological integration, compared with integration processes in the other two areas;
– assortative mixing – preference for network nodes to connect to other similar nodes – the correlation between vertices has a positive value only for high-tech products, which indicates an exclusive preference for interaction with leaders in this field of activity, while in the other two areas of research prevail other motives;
– coefficient of assortative mixing – correlation coefficient of Pearson. Positive values indicate a link between nodes of the same degree, while negative values indicate the strength of the relationship between nodes of different degrees;
– the number of independent cycles – the number of non-pairwise common edges of closed chains of vertices of different lengths, that is, the number of possible interaction scenarios that are not related to each other, as far as mechanical engineering is concerned, since there are the largest number of countries participating in trade and industrial integration in this area;
– the maximum degree of the node or valency corresponds to the vertices of the graph with the largest number of incident edges, reflects the number of possible combinations of the interaction organization, and the maximum among the studied industries for engineering;
– the number of drivers and their control combinations refer to the functional characteristics associated with monitoring network processes. The number of drivers, as well as the number of control combinations, in the engineering sector is significantly lower than in the other two areas under consideration. Manageability is the ability to drive a dynamic system from any initial state to any desired final state in a finite time, with a suitable choice of inputs. Thus, among the systems under consideration, the process of integration in the production of engineering products is less manageable;
– the modularity of a graph is the fraction of edges that are within the given groups minus the expected similar fraction if the edges were randomly distributed with the same number of vertices where each country (node) retains its importance. The value of modularity lies in the range from (-1/2) to 1. In our case, the modularity of the graph in all the considered branches is positive. This means that the number of edges within the groups exceeds the number of random or short-term production links;
– the relative entropy of the motives for the considered options is the maximum for engineering, slightly lower for high-tech products and slightly lower for the coal, oil and gas industry.
In this paper, when analyzing foreign economic networks between countries, network motives are used (Table 1) of the three (motive 3) and four (motive 4) vertices and their interrelations, consisting of 13 (Figure 2).

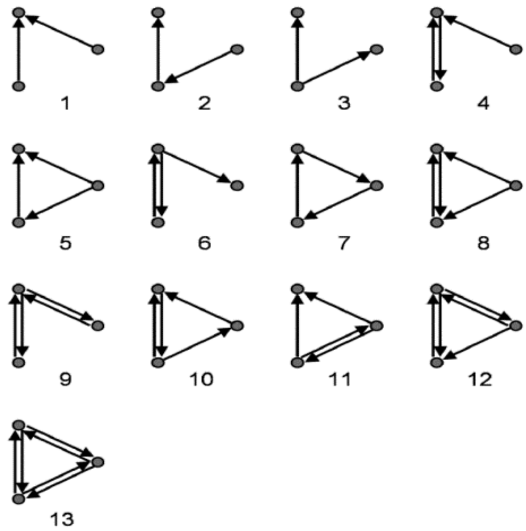

Fig. 2: A complete set of network motifs with three vertices

According to the calculated frequency spectra of the motifs, the relative entropy is calculated:

$$H = -\sum_{i=1}^{n} P_i \log_2 P_i / \log_2 n, \tag{2}$$

where P_i is the frequency of appearance of the motif i = 1, 2, ... n, n – number of variants of motives.
The higher the value, the greater the structural and functional diversity of the industrial network and the number of countries and production links between them. Zero means that the network has only one network motive (that is, one partner).
A higher entropy indicator indicates a more significant level of diversification of foreign economic relations, which also means lowering risks and increasing competitiveness.
In general, the range of entropy in these industries is average across Russia. In other countries it is much higher, in China it is about 0.8, in the United States it is about 0.9.

This suggests that for the time being Russia is interested in maximizing the number of production links and expanding industrial and technological integration in the sectors examined, with the coal, oil and gas industry showing the greatest need for integration. This is understandable because the Russian economy is losing part of the added value, realizing these minerals in an under-processed form, which is hindered by the low level of industrial and technological integration in this field of activity.

4. Discussion

Let us consider what can be explained and how to overcome the relatively low, in comparison with developed countries, entropy of industrial and technological ties in the three reviewed sectors of the Russian economy. The reason lies in the fact that the existing type of relations developed spontaneously and largely due to the country's heritage. In order to optimally develop Russia's production links, in certain circumstances it is necessary to incur certain costs in connection with the expansion and reformatting of these links, as well as take into account the risks associated with the volatility of commodity markets.

The contradiction between the increase in the entropy of production ties as a factor of their competitiveness and reliability, revealed at the result of the analysis, while concurrently enlarging the individual production links leading to its reduction, finds its solution in the optimum of such links. To determine the optimum of relationships within the framework of an industrial and technological partnership, an analysis of network models for the development of production and technological links from the perspective of the management theory of complex networks is conducted to reveal the asymmetry of distribution.

The network characterizing the production and technology partnership was presented in the form of a graph, which includes a wide range of sub-graphs. One of the important local properties of networks are the so-called network motifs – repetitive and statistically significant subgraphs or patterns (that is, the stability of the links). Motives are important because their spectrum can reflect the functional properties of the network [6].

When studying more complex networks, the structure of the association, in which the nodes of the network-countries, can be easily grouped together so that each set of vertices is tightly interconnected within the group, is important. That is, node pairs (two-way links) are more likely to interact if they are members of the same union, and less likely if they belong to different groups. The structure of the association is essential in analyzing the dynamics of the entire network. Obviously, a closely related group has a higher information transfer rate than weakly connected network clusters. In this paper, to identify groups in complex networks, the iterative algorithm of Louvain was implemented, which implements the "collecting optimization method", which proved to be successful in the detection of small associations [8].

Summarizing the discussion, we note that the unevenness in the networks is explained by the specific features of the development of industrial and technological ties in various industries of countries with unequal levels of economic development: on the one hand, the degree of entropy (disorder), inertia, differentiation and diversification, and on the other hand, the existing economic relations and interests of countries, the tightness of their production ties.

5. Conclusion

Despite the urgency of the issue of choosing the best ways of the international production and technology partnership of Russia, the variety of factors influencing this process has not been sufficiently studied yet. In this paper, we estimate the degree of entropy of foreign economic relations to determine the level and most appropriate directions for the development of industrial and technological partnership.

Bayesian networks were characterized by three key sectors of the Russian economy: oil and gas, machine building and high-tech products. To quantify the characteristics of networks used indicators: the density of bonds; coefficient of flow; maximum grouping factor; global effectiveness; assortative mixing; number of independent cycles; the maximum degree of the node; number of drivers; number of control units.

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