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Research paper

Multivariable Classification of Countries of the World in Terms of Innovation Development

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Abstract

The article makes an attempt to contribute to the scientific literature on the issues of directions of intercountry integration from the point of innovative development and understanding of a new structure of integration associations of countries, leaders of innovation development, which will determine the top level of development. The results of the multivariable classification of 189 countries in terms of innovative development show that the countries are divided into five clusters. Moreover, the leading countries that form the "core" of the cluster are identified within each group. Also, there is a high differentiation in all indicators characterizing innovation development of the countries as evidenced by the calculated coefficients of variation.

Keywords: *innovations, grand challenges, multidimensional group, cluster, leading countries*

1. Introduction

The modern development strategy of countries is based on the principles of ensuring national interests in the long term. In this regard, the problem of a new quality of economic development, from the point of view of achieving strategic development goals and narrowing the gap with the leaders of economic development becomes most relevant in the face of grand challenges and building new contours of the world economic system. The main fundamental task for countries is their readiness for the existing and emerging "grand challenges" in the conditions of the specific arrangement of the leading countries and the formation of a separate group of countries possessing advanced technologies. In fact, we are talking about institutional innovations - finding modern forms of interaction. Within the framework of multilevel and interconnected phenomena, changing conditions and new challenges for modern economies "country challenges" and "regional challenges" have a special sound.

The studies of the "grand challenges" are mostly based on the identification of problem zones in the world, for example, climate change [1], the aging of society [2], natural resources [3]. The concept of "grand challenges" is interpreted differently in different countries. The differences of "grand challenges" in different countries exist because each of the countries has its own specificity of socio-economic development.

The concept of GC research comes from a notion that in the process of globalization of economic relations, a qualitatively new modified economic system of any country is being formed. In the context of the integration of countries into the global world economy, the previous forms are overcome and new forms of economic relations are inherent in both the internal environment of national economic systems and the external environment of transnational economic interaction.

GC is something that will change the system of organization, values (of various kinds), create the need for a transition to a new level of technological development, and create the threat of backwardness in the economies of many countries. They create causes of threats to the entire global economy; create barriers and gaps that determine the segmentation of the world economic system. Countries which are not ready to respond to GC recoil from market transformations and begin to lag behind innovative breakthroughs. Since there is country specificity, the positions of different countries with respect to GC do not necessarily coincide, which, accordingly, limits or even excludes the possibility of cooperation to overcome common problems. This creates a fundamental problem of the world economy - the practical impossibility of a coherent global response to "grand challenges".

We can state that at the present stage the emergence of a powerful regulator of economic development – GC – dramatically changes the distribution of the world's countries according to clusters depending on the level of innovative development and the formation of a new "core" - the leading countries of innovative development. In the context of reducing the life cycle of processes in the economy and society as a whole, putting forward the ability to innovate to the forefront forces the world economic system, each of its subjects, to react quickly to the current changes in the leading countries of innovation development.

Therefore, it is necessary to determine the gap between the absolute and current market potential, taking into account both quantitative and qualitative indicators, which will help to understand the directions of intercountry integration from the point of innovative development and understanding of the new structure of integration associations of countries, leaders of innovative development that will determine the top level of development.

This conclusion determined the need for the study on 189 countries worldwide.

At present, various approaches to assessing the level of innovative development of the country and its regions have been developed in the world practice. In the conditions of formation of the innovation economy, the main factors of the country's socio-economic development are scientific and technological progress, the process of creating and using innovations, and intellectual property. To determine the potential opportunities and directions for the growth of the economic system, the idea of searching for a methodology for a comprehensive assessment of the country's innovative development was widely disseminated.

The researchers from various international schools and scientific organizations are occupied bythe problem of measuring and evaluating the innovation potential. In particular, they include the Organization for Economic Co-operation and Development (OECD), the European Commission for Innovation, the scientific units of the World Economic Forum and the World Bank, the United Nations Industrial Development Organization (UNICTAD), etc. The methods and approachesfor assessing innovation development developed by these organizations are widely used for various purposes.

The development of approaches to assessing innovation can be represented as follows:

The first generation (1950-1970) - the cost of research (costs of research, the number of scientists, and the cost of purchasing new equipment). Indicators of the first generation of measurements are a consequence of the linear concept of the innovation process, in which investing at the beginning of the process (fundamental and applied research) yields more or less predictable output results (new products, markets, etc.). The second generation (1970-1990) - indicators of the results of research (patents, publications, high-tech products, technology sales). Indicators of the second generation of measurements reflect the results of research and development work, in particular, obtained patents and created high-tech products. Third generation (1990-2000) –indicators of system innovation and innovation activity indices (integration of various indicators, comprehensive description of the innovation sphere). The indicators of the third generation of measurements are the result of an attempt of a comprehensive description of innovative activity by methods of system analysis. The fourth generation (2000-present time) - indicators of the ability of the organization's processes to create and adopt innovations (knowledge and knowledge management systems, management technologies, business processes and value networks, risk / return, system dynamics). Indicators of the fourth generation are little used in Russia. In general, they are based on modeling the structure of the organization, its climate and evaluation, primarily its ability to create and implement innovations [4].

The conducted research has shown that existing methods of research of innovation processes can be grouped into three groups.

The first group includes index methods. This group includes methods based on the evaluation of variables that interpret the quantitative and qualitative characteristics of innovation processes. The basis of the methods of this group is Western models, which have proved their effectiveness in practice. Among them we can distinguish: The Boston Consulting Group Index (2018) and a global index of innovation [5].

The second group is the methods of scoring, rating evaluation. The methods of this group include the definition of coefficients (weights) and particular indicators of innovative development of the territory. For example, the regional competitiveness model [6].

The basis of the third group consists of matrix methods. These methods are based on a quantitative assessment of the relationship between elements of innovative development of regions within the types of economic activity. For example, the methodology for assessing the innovative potential of the regions [7].

Considering the international specifics, it should be noted that the international community is practicing the evaluation and comparison of innovative development of individual countries and their regions. For example, there is a two-tier system for measuring innovative development in the European Union: at the country level, the European Innovation Scoreboard (EIS) and at the regional level - the Regional Innovation Scoreboard (RIS) [8]. This system has been applied since 2000, and in 2002, based on it, a system for assessing the innovative development of the EU regions was created, which included some of the indicators from the country survey. Currently, innovation activity at the level of the European Union countries is measured on the basis of twenty-nine indicators, and sixteen indicators are used to assess the innovative development of regions. This is due to the fact that fewer statistical data are available at the regional level than at the country level. Imperfection of statistics at the regional level is the reason that RIS does not apply the absolute ranking of individual regions, but groups of regions with a similar level of innovative development are allocated and ranked.

The system for measuring the innovative development of territories in the United States is somewhat different from the European. A composite index of innovation development (PII, Portfolio innovation index) of the American regions (states and counties) was developed by a number of American research centers according to the initiative of the Department of Economic Development of the US Department of Commerce [9, 10; 11, 12]. This index consists of four blocks; each of the blocks has different weighting factors: human capital (30%), economic dynamics (30%), productivity and employment (30%) and welfare (10%). Each block includes from 5 to 7 indicators reflecting its content. Based on PII, more than 3,000 US regions are analyzed and five groups of territories are allocated based on their relative level of innovation development.

The survey conducted by the consulting group Boston is also a very common measure. The group developed the International innovation index for ranking states of the US and countries [13]. The index is built on the basis of two blocks - resources for innovation (innovation inputs) and innovative behavior (innovation performance). It assesses the state's ability to stimulate and support innovation through public policy. The index is based on the method of interviewing company executives (in-depth interviews).

The integral indicator of innovative development of the Organization for Economic Cooperation and Development is used to analyze the level and dynamics of the development of the innovation economy of developed and a number of developing countries. The OECD methodology presents the following indicators: the share of the high-tech sector of the economy in manufacturing products and services; innovative activity; the amount of investment in the knowledge sector (public and private); development and release of information and communication equipment, software products and services; number of employees in the field of science and high technology, etc.

In general, classifying the most famous international systems for assessing innovation development by territorial criteria we get the following measures at the level of countries: The Global Competitiveness Index (GCI) [14], The Global Innovation Index (GII) [5], The European Innovation Scoreboard (EIS) [15], The International Innovation Index (III) [16]. Also, if we focus on the regional level, we can see Regional Innovation Scoreboard [17], RISin the European Union and Portfolio innovation index (2012), PII in the USA [18].

The above international methods for assessing the innovative development of the territories are scientifically validated and sufficiently approved, which allows them to be considered for application, with appropriate adaptation, to domestic specifics.

In the Russian practice, the Russian Regional Innovation Index (HSE) has become wide spread. The index is compiled by the Higher School of Economics (HSE) in cooperation with the Institute of Statistical Studies and the Knowledge Economy [19]. The index is based on the following sections: socio-economic conditions of innovation, the scientific and technical potential of the regions, innovative activity in the regions, and the quality of the region's innovation policy.

The system of innovative activity of the subjects of the Russian Federation, developed by V.N. Kiselev [6] (Center for Research and Statistics of Science of the Ministry of Education and Science of the Russian Federation), includes three sections: 1. Innovative capacity (indicators of human resources, creation and dissemination of knowledge). The section includes eight indicators, for example, the number of staff with higher education, raising qualifications, engaged in research and development, etc.; 2. Innovative infrastructure and innovative climate (indicators characterizing the management of innovation activities). The section includes four indicators related to the number of organizations of material innovation and supporting infrastructure, the number of innovative projects and the share of investments that have entered the territory of the region; 3. Effectiveness of innovation (indicators of intellectual and economic performance). The section contains eight indicators related to the creation, delivery and use of advanced production technologies, shares of innovative products, etc. [6].

The methods used to assess the country's innovative development have certain shortcomings that limit their practical use. Among the shortcomings we can note the imperfection of regional statistics, as a number of indicators at the regional level are not calculated; therefore, the differentiation factor is not taken into account. National indices take into account the specific characteristics of the country as priority. The indices of international organizations are more comparable, since they apply a common methodology.

Quantitative assessment of the volume and effectiveness of innovative development is quite difficult because of the limited statistical information in the regional and country aspects. The main measure of innovation activity in foreign economic literature is the number of applications for patents; for comparison: in some Russian studies the indicator "number of innovative-active enterprises" is used. Thus, the choice of the indicator as a measure of innovation activity remains as the discretion of the researcher.

We agree with the opinion of foreign researchers that patents more accurately reflect the state of the research sector as the main source of new knowledge and innovations than the number of innovation-active enterprises. It is the number of filed patent applications that reflects the efficiency of the activity of innovation-active enterprises. Undoubtedly, their innovative activity has an impact on the innovative development of the country and its regions and is determined by a huge number of factors.

The approach we propose in the study is used to determine the current trends of innovative development, taking into account the development of human potential in countries with different levels of socio-economic development. Particular attention is paid to the formation of a system of indicators informatively reflecting the level of innovative development of the country.

2 Methods

Innovations are one of the mechanisms for ensuring the economic growth of the country at present time. Innovations lead to the renewal of markets, the improvement of quality and the expansion of the range of goods and services, the creation of new methods of production, the marketing of products, and the improvement of management efficiency. Ensuring quality growth is possible in the presence of special conditions that would activate and strengthen the innovative component. The influence of innovations on the development of national economies has become an incentive for developed countries to create a set of measures focused on the development of innovative activities.

In the framework of this study, a multivariable classification of the countries of the world has been implemented in order to identify similar groups of countries in terms of the level of innovative development. First, we define the range of indicators that characterize the country's innovative development.

1. Grants for technical cooperation (Grants), in US dollars. There are two main types of technical cooperation: autonomous technical cooperation (FTC), which is the provision of resources aimed at the transfer of technical and managerial skills or technologies to create a common national capacity without reference to the implementation of any specific investment projects; and investment-related technical cooperation (IRTC), which means providing the technical services necessary to implement specific investment projects.

2. Articles in scientific and technical journals (SAJ), units. The calculation of the indicator takes into account articles in scientific and technical journals published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, technology and technology, and earth and space sciences. This indicator characterizes the results of scientific activity, as well as the progress of science by presenting new research.

3. Expenditure on R & D (RnD_Exp), in percent of GDP. The indicator reflects the amount of R & D financing. R & D expenditures cover fundamental and applied research in various fields of science.

4. Researchers in the R & D sector (RgD_RES), per 1 million people. The indicator reflects the quality of human capital and is an important indicator for characterizing the level of innovative development.

5. Internet users, for 100 people (IT_US). The indicator characterizes human access to information resources.

6. Government spending on education, as a percentage of public expenditure on education (Exp_Ter). Governments of many countries consider improving the competitiveness of the economy as one of the main tasks at the expense of developing the quality of educational services. This is due to the fact that the level of education of society and scientific potential is an important condition for economic growth and characterizes the quality of human capital as the main factor of the country's innovative development.

7. Exports of high-tech goods, as a percentage of industrial exports (HT_Exp). High-tech exports are products with a high level of research and development included, such as the aerospace industry, computers, pharmaceuticals, scientific and electrical appliances. The indicator characterizes the impact of foreign economic activity on the country's innovation and technological development.

8. Patents received by residents and non-residents of the country, calculated for 100 thousand people (Patent). The indicator reflects the state of the research sector as the main source of new knowledge and innovations.

9.Public expenditure on education, in percent of GDP (EDU_GDP). The indicator reflects the socio-economic development of the country. A high share of expenditures in the country's GDP indicates a high priority in the field of education, which certainly has an impact on the country's innovative development through the effective formation of human capital.

10.Import of ICT (ICT_Im), as a percentage of total imports. New information and communication technologies (ICTs) provide wide opportunities for progress in all spheres of life in all countries - opportunities for economic growth, better health, better services, distance education, and social and cultural successes.

11. ICT exports (ICT_Ex), as a percentage of total exports. Export of goods for information and communication technologies includes computers and peripheral equipment, communication equipment, consumer electronic equipment, electronic components and other information technology products.

12.Secure Internet servers (Sec_Serv), for 1 million people. The quality of infrastructure is an important element of the country's innovative development. In telecommunications competition in the market, an important role is played by improving the quality and security of access to information around the world.

Based on the proposed set of indicators characterizing the level of innovative development of the country, a multidimensional grouping of 189 countries was implemented using the IBM SPSS Statistics package according to the hierarchical scheme by the Ward's method (Ward`smethod), the criterion of unification, in which is the metric of the city (City-block (Manhattan) distances).

The economic and mathematical formulation of the problem comes to the following: let the set N = {n1, n2, ..., nn} denote countries of the world (189 countries participated in the analysis). Suppose that there exists a set of exponents X = {x1, x2, ..., x12}

that characterize the innovative development of each country in the sample. For each country, the vector of measurements of Y is a set of characteristics of X. The task of cluster analysis is to divide the set N into clusters (homogeneous groups of countries) based on the data of the set Y so that each country belongs to only one subset, and that objects, located in the same cluster, were similar, while the objects belonging to different clusters were heterogeneous.
In the process of cluster analysis, each country participating in the analysis was represented by a vector in the 12-dimensional space of the vector X. Thus, using the indicators characterizing the innovative development in the country, similar territorial zones were identified for the analyzed period. As a result of the cluster analysis, the countries of the world will be divided into homogeneous groups according to the level of innovative development.
For a comprehensive study of the level of innovation development already in homogeneous groups of countries and understanding of the structure of each cluster, it is necessary to identify countries that dominate in terms of innovative development and form a kind of "core" of the cluster. The authors propose an approach to determining the "core" of the cluster consisting of three main stages.
At the first stage, each indicator characterizing the country's innovative development is compared to the average value for a specific cluster. Thus, all the indicators become relative, and show how many times the value of the indicator for the country is larger, or less than the average for the cluster (1):

$$Z_{ij} = {x_{ij}}\Big/{\overline{x_i^{cl}}} \qquad (1)$$

where Zij is the coefficient showing the ratio of the i-th indicator in
j-th country with the value of the i-th index in the cluster;
xij - the value of the i-th indicator in the j-th country;
The average value of the i-th index in the cluster.
In the second stage, each calculated coefficient Zij for each country is assigned points according to the following scheme (2):

$$q_{ij} = \begin{cases} 0, if\ Z_{ij} < 0{,}5 \\ 1,\ if\ 0{,}5 \le Z_{ij} < 0{,}9 \\ 2, if\ 0{,}9 \le Z_{ij} \le 1{,}1 \\ 3, if\ 1{,}1 < Z_{ij} \le 1{,}5 \\ 4, if\ Z_{ij} > 1{,}5 \end{cases} \qquad (2)$$

where qij is the score assigned to the j-th country by the i-th indicator.
In the third stage, all the j-th country credits received (qij) are summed up, the total amounts are divided by the maximum possible score, which the country can collect. As a result, we get an assessment of the country's position in the cluster by the level of innovation development (3):

$$R_j = \frac{\sum_{i=1}^{12} q_{ij}}{\sum_{i=1}^{12} \max q_{ij}} \cdot 100\% \qquad (3)$$

where Rj is an estimate of the level of innovation development in the j-th country in the cluster,
max qij - the maximum possible score that can be typed
j-th country by the i-th indicator.
The obtained value of Rj is in the range from 0 to 100, the closer it is to the upper boundary, the higher the values of the innovative development indicators of the country in a particular cluster. Obviously, for any given set of indicators, any country cannot simultaneously have the highest values. Thus, we will adhere to the view that if the country in the cluster has the value of Rj greater than or equal to 50%, then it can be argued that it is in the "core" of the cluster and is the leader among the countries of this group.

3. Results

World experience shows that the development of an innovative economy within a single country is uneven. Today, we need a clear understanding of how the development and deployment of innovative centers of the world is taking place. Taking into account the current trends, today it is very important to single out an innovative core, where a high concentration of scientific, industrial and financial resources is concentrated. In this regard, there is a need to identify homogeneous regional zones in terms of indicators that characterize innovative development in the countries of the world. Descriptive statistics and indicators of variation by indicators characterizing innovative development (Table 1) show a rather heterogeneous structure of the countries of the world. The study was conducted in 189 countries.

Table 1 Indicators characterizing the variation of the countries of the world according to the indicators of innovation development.

Indicators	Mean	Mean square deviation	Coefficient of variation
Grants	121526877,20	611617579,90	5,03
SAJ	11329,40	44897,58	3,96
RnD_Exp	0,63	0,85	1,36
RgD_RES	1044,73	1798,94	1,72
IT_US	46,56	28,61	0,61
Exp_Ter	20,21	10,23	0,51
HT_Exp	8,09	9,80	1,21
Patents	164,15	481,18	2,93
EDU_GDP	4,53	2,03	0,45
ICT_Im	6,04	5,53	0,92
ICT_Ex	3,58	7,48	2,09
Sec_Serv	336,72	770,69	2,29

As can be seen from Table 1, absolute differentiation is observed for absolutely all indicators characterizing innovation development in the countries of the world, as evidenced by the calculated coefficients of variation. It should be noted that all variables are measured by a quantitative scale; therefore, they can participate in a cluster analysis. According to the calculations, abnormal values (emissions) were observed for such variables as grants, scientific journal articles (SAJ), researchers in the R & D sector (RgD_RES), patents (patents), secure Internet servers (Sec_Serv) high values for these indicators were observed in the following countries of the USA, Japan, Germany, China, Great Britain, South Korea, etc. This fact is confirmed by high values of standard deviations.
Based on the proposed set of indicators that characterize the level of innovative development of the country, a multidimensional grouping of countries of the world (189 countries) is done. Due to the high differentiation of the countries in terms of innovative development, the initial values of the variables were normalized in the range from 0 to 1. The results of the hierarchical cluster analysis are shown in Fig.1 in Table 2.

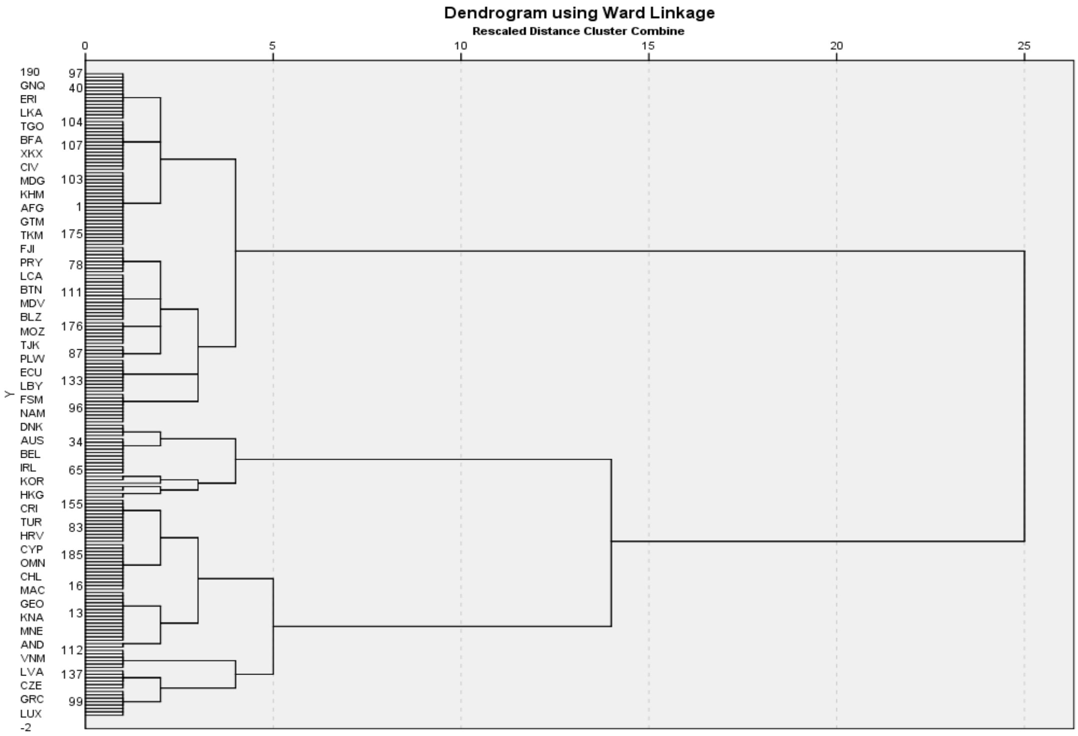

Fig.1 The results of clustering of the countries in terms of innovation development indicators hierarchical method.

Table 2 The order of agglomeration of observations (countries).

Stage	The cluster is integrated with		Coefficient of agglomeration	Absolute increase in the agglomeration coefficient	Stage of the first appearance of the cluster		Next stage
	Cluster 1	Cluster 2			Cluster 1	Cluster 2	
1	97	150	0,068	–	0	0	39
2	31	84	0,142	0,074	0	0	25
3	93	184	0,219	0,077	0	0	73
…	…	…	…	…	…	…	…
182	2	3	94,016	3,438	180	175	185
183	47	105	97,991	3,975	169	166	186
184	10	37	102,305	4,314	174	179	187
185	1	2	107,293	4,988	177	182	188
186	4	47	112,870	5,577	181	183	187
187	4	10	130,112	17,242	186	184	188
188	1	4	161,112	31,000	185	187	0

Visual analysis of the dendogram made it possible to identify 5 clusters. We analyzed the change in the values of the agglomeration coefficient presented in Table 2 in order to determine the optimal number of clusters. Based on the results of calculating the absolute increase in the agglomeration factor, we can distinguish the stages under the numbers 182, 183 and 184, where the value of the indicator under consideration increases sharply, and consequently at these stages we cease to unite similar objects and begin to attach to each other qualitatively different. Thus, it is potentially possible to model cluster models containing 4, 5, and 6 clusters (according to the rule (N-k), where k is the step number at which the agglomeration jump occurs, N is the total number of steps). In the next step, we analyze the conjugacy tables and choose the best model with the optimal number of clusters. Pairwise comparisons for the 4, 5 and 6-cluster models are presented in Tables 3-5.

Table 3 - Conjugence table for the four-cluster and five-cluster models.

Clustering		five-cluster model					Total
		1	2	3	4	5	
four-cluster model	1	51	52	0	0	0	*103*
	2	0	0	44	0	0	*44*
	3	0	0	0	22	0	*22*
	4	0	0	0	0	20	*20*
Total		*51*	*52*	*44*	*22*	*20*	*189*

Table 4 - Conjugence table for the four-cluster and six-cluster models.

Clustering		six-cluster model						Total
		1	2	3	4	5	6	
four-cluster model	1	51	52	0	0	0	0	*103*
	2	0	0	44	0	0	0	*44*
	3	0	0	0	15	7	0	*22*
	4	0	0	0	0	0	20	*20*
Total		*51*	*52*	*44*	*15*	*7*	*20*	*189*

Table 5 - Conjugence table for the five-cluster and six-cluster models.

Clustering		six-cluster models						Total
		1	2	3	4	5	6	
five-cluster	1	51	0	0	0	0	0	*51*
	2	0	52	0	0	0	0	*52*
	3	0	0	44	0	0	0	*44*
	4	0	0	0	15	7	0	*22*
	5	0	0	0	0	0	20	*20*
Total		*51*	*52*	*44*	*15*	*7*	*20*	*189*

Analyzing tables 3-5, we can conclude that the five-cluster model is optimal from the point of view of the fullness of the groups of countries in comparison with the four- and six-cluster. In the case of four clusters, the first group is filled with more than 50% of the total number of countries, which will make it difficult to determine the characteristics of countries in homogeneous groups according to the level of innovative development. With an increase in the number of clusters from four to six, small groups are allocated; the number of countries in them does not exceed 10%, which makes it difficult to qualitatively analyze the country characteristics of innovative development. The optimized coefficients of determination shown in Fig.2 also testify to the optimality of the choice of the five-cluster model.

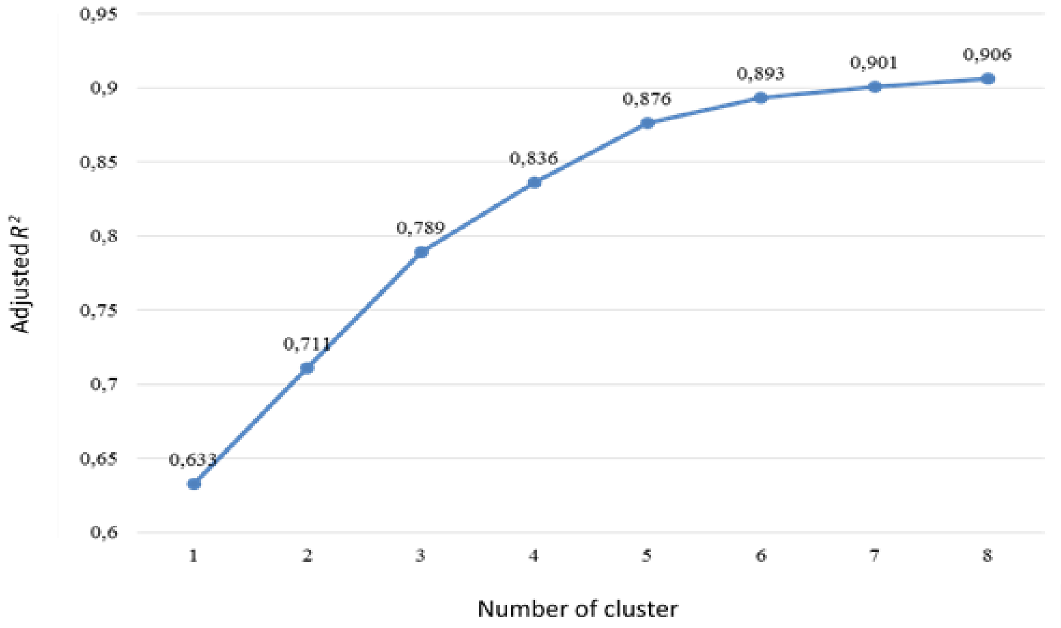

Fig.2 - Adjusted R2 values for different models.

Fig.2 shows that a sharp change in the value of the adjusted determination coefficient ends at the transition from the five-cluster model to the six-cluster model. Thus, it can be noted that the model with five homogeneous groups of countries in terms of innovative development in this case is more optimal. The results of the five-cluster model are presented in Table 6 and in Fig.3.

Table 6 - Distribution of countries according to clusters, depending on the level of innovation development.

Group of countries	Number of countries	Country
Cluster*A*	51	Afghanistan, Angola, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Cameroon, Chad, Comoros, Congo Dem. Republic of the Congo, Cote D'Ivoire, Djibouti, El Salvador, Equatorial Guinea, Eritrea, Gambia, Guatemala, Guinea, Guinea-Bissau, Guyana, Iraq, Kenya, Kosovo, Liberia, Madagascar, Malawi, Mali, Mauritania, Mongolia, Myanmar, Nauru, Nepal, Nicaragua, Pakistan, Samoa, San Marino, Sierra Leone, Solomon Islands, South Sudan, Sri Lanka, Sudan, Tanzania, Togo, Turkmenistan, Uganda, Uzbekistan, Yemen, Zambia
Cluster*B*	52	Albania, Algeria, Belize, Bhutan, Bolivia, Botswana, Cape Verde, Colombia, Cuba, Dominica, Ecuador, Egypt, Ethiopia, Fiji, Gabon, Ghana, Grenada, Honduras, India, Indonesia, Iran, Jamaica, Kazakhstan, Kiribati, Kirghiz Lesotho, Libya, Maldives, Marshall Islands, Mauritius, Micronesia, Mozambique, Namibia, Niger, Nigeria, Palau, Papua New Guinea, Paraguay, Peru, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Saint Lucia, Saint Vincent and the Grenadines, Swaziland, Tajikistan, Timor Leste, Tonga, Tuvalu, Vanuatu, Zimbabwe
Cluster*C*	44	Andorra, Antigua and Barbuda, Argentina, Armenia, Aruba, Azerbaijan, Bahamas, Bahrain, Barbados, Belarus, Bermuda, Bosnia and Herzegovina, Brazil, Brunei, Bulgaria, Chile, Costa Rica, Croatia, Cyprus, Dominican Republic, Georgia, Italy, Jordan, Kuwait, Lebanon, Macau, Macedonia, Moldova, Montenegro, Morocco, Oman, Panama, Qatar, Romania, Saudi Arabia, Serbia, South Africa, Saint Kitts and Nevis, Trinidad and Tobago, Tunisia, Turkey , Ukraine, Uruguay, Venezuela
Cluster*D*	22	Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Hong Kong, Ireland, Israel, Japan, South Korea, Netherlands, New Zealand, Norway, Singapore, Sweden, Switzerland, United Kingdom, USA
Cluster*E*	20	Czech Republic, Greece, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malaysia, Malta, Mexico, Philippines, Poland, Portugal, Russia, Slovakia, Slovenia, Spain, Thailand, UAE, Vietnam

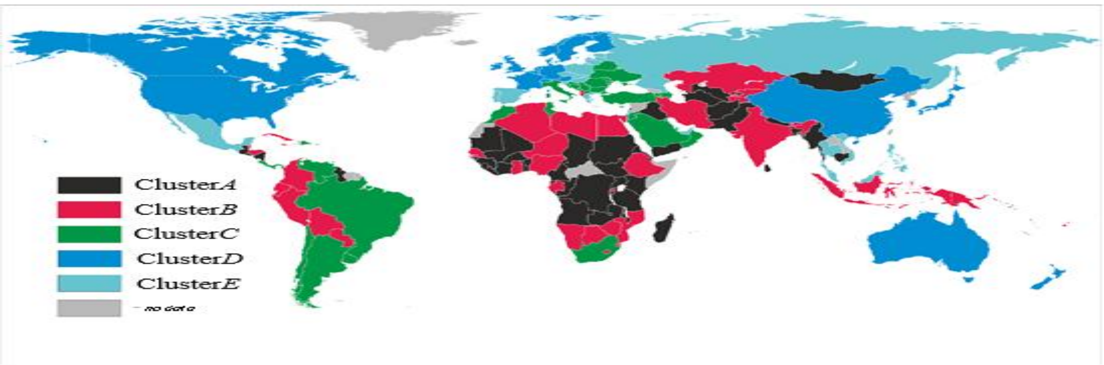

Fig.3 - Distribution of countries in the world according to clusters at the end of 2015.

We use the Kruskal-Wallis criterion, which is based on hypothesis testing (Table 7) to determine the extent to which qualitatively presented variables differentiate countries according to the level of innovative development.

Table 7 - Checking the equality of the means in the clusters by the variables participating in the analysis, based on the Kruskal-Wallis criterion.

Indicator	Statistics of the criterion	Degrees of freedom	p-value
Grants	11,005	4	0,027
SAJ	82,386	4	0,000
RnD_Exp	96,285	4	0,000
RgD_RES	115,219	4	0,000
IT_US	149,132	4	0,000
Exp_Ter	17,413	4	0,002
HT_Exp	81,106	4	0,000
Patents	110,017	4	0,000
EDU_GDP	48,164	4	0,000
ICT_Im	69,267	4	0,000
ICT_Ex	91,985	4	0,000
Sec_Serv	115,438	4	0,000

The basic hypothesis H0 suggests that the average values for the indicator under test in each group are equal, and, consequently, there are no significant differences between the groups and the indicator has no significant effect in the process of isolating homogeneous groups. The competing hypothesis H1 implies that there are at least two groups (two clusters) of countries, the average values for the considered indicator in which significantly differ from each other.

According to the data in Table 7, the achieved level of significance (p-value) does not exceed 0.05, therefore, the null hypothesis is rejected and with a probability of 95% it can be asserted that for each of the twelve indicators presented in the analysis, there are at least two clusters significantly different from each other. Graphical representation of clusters differentiation by variables is shown in Fig.4.

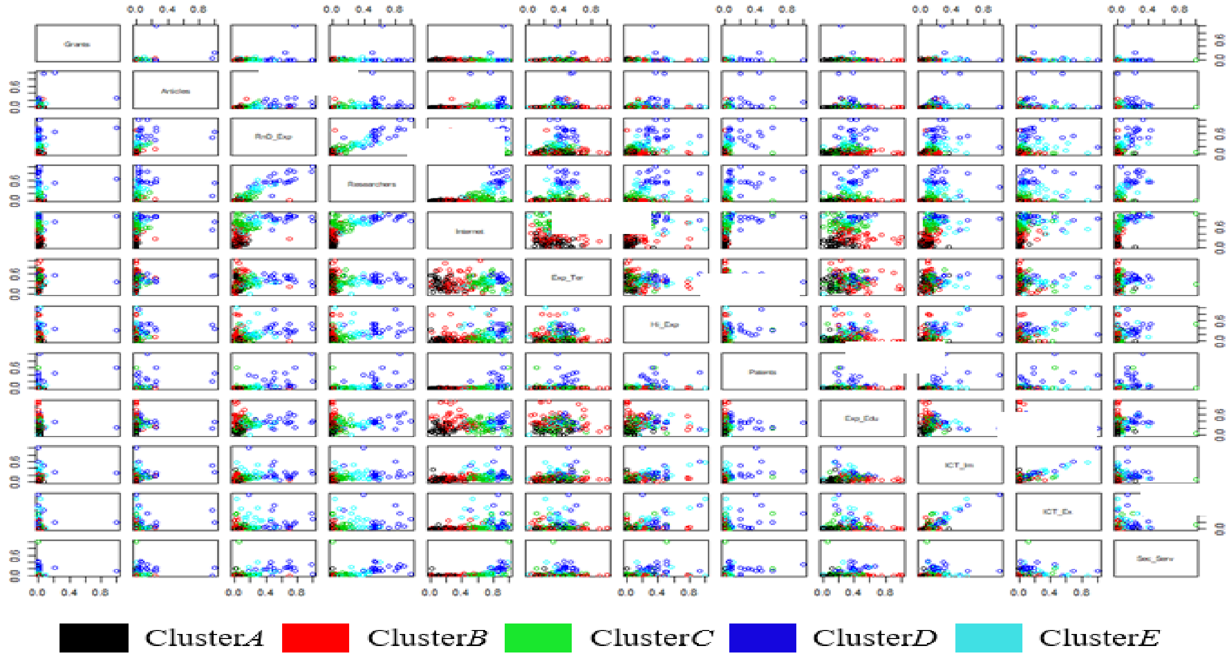

Fig.4 - Cluster differentiation by selected indicators.

We will determine the features of the selected clusters of countries in terms of the level of innovative development. Table 8 shows the results of calculating the average values for the variable set of indicators for clusters for 2015.

Table 8 - Average values for indicators in clusters.

Indicator	Cluster				
	A	B	C	D	E
Grants	82152252,90	72563076,90	52813677,60	1762130342,70	88081399,00
SAJ	332,90	3023,60	5125,80	69123,00	11039,70
RnD_Exp	0,18	0,27	0,42	2,51	1,07
RgD_RES	61,86	115,80	610,93	5122,28	2435,34
IT_US	14,59	34,41	67,57	85,04	71,14
Exp_Ter	17,46	20,80	19,53	26,55	20,17
HT_Exp	2,30	7,40	6,03	19,47	16,61
Patents	8,45	23,82	136,78	948,17	123,85
EDU_GDP	3,24	5,71	4,10	5,50	4,60
ICT_Im	3,31	4,68	5,32	12,11	11,41
ICT_Ex	0,31	1,52	2,58	9,93	12,46
Sec_Serv	44,65	58,56	347,60	1448,67	557,67

In 2015, 51 countries (27% of the total number of countries) entered Cluster A, and it should be noted that this cluster is formed mainly countries of Africa (55% of the total group). The peculiarity of the countries of this cluster is a low level of innovative development, as evidenced by the lowest values of indicators in comparison with the other selected groups. The effectiveness of innovation activity is characterized by the number of issued patents; the average value of the indicator for 2015 in the countries of this cluster was marked at the level of 8.45 per 1 million people. The number of engineers and researchers in the R & D sector is 61.86 per 1 million people on average. In total only 2.3% of high-tech goods and 0.3% of ICT were exported from the cluster A countries, while ICT imports amounted to 3.3%. As for opportunities for innovative development in cluster A countries, there is a low share of spending on research and development in GDP - an average of 0.2%, as well as a low share of public expenditure on education - 3.2% on average for the group.

Cluster B in 2015 included 52 countries, which accounted for 28% of the total number of countries. The group consisted mainly of the countries of Africa and Oceania. The peculiarity of this cluster is the highest share of education expenditures - 5.7% of GDP, while the share of spending on higher education is 20.8% of the total national expenditure in this area. For all other indicators, the countries of this group occupy the penultimate places among the remaining clusters.

At the end of 2015, cluster C united 44 countries, which accounted for 23% of the total number of countries participating in the analysis. The peculiarity of this group is the fact that the countries occupy a "middle" position according to the indicators of innovative development among the other groups. The average number of patents granted here are 136.8 units for 1 million people. At the same time, the lowest level of grants for technical cooperation is observed in this group, which is 33 times less than the corresponding figure for cluster D.

Cluster D in 2015 included 22 countries (12% of the total number of countries participating in the analysis). This cluster is formed by the developed countries of the Asia-Pacific region, the European Union and Israel. According to the analyzed indicators, the countries of this group are leaders - the cluster can be characterized as the most innovative-developed. There is a high potential for innovative development in the countries of this group, conditions for its implementation are created, which is confirmed by high performance indicators by the number of issued patents and published articles in scientific and technical journals. These countries actively import and export high-tech goods and new information and telecommunication technologies.

The cluster E included 20 countries (10% of the total number of analyzed countries). According to the average characteristics of most of the analyzed indicators, the countries of this group are the second in terms of the level of innovative development and differ from the other groups by high values of exports and imports of information and telecommunications services. In this cluster, there are fairly high average values for indicators of expenditure on R & D and the number of researchers. It should be noted that Russia has become part of this cluster. In general, this cluster can be characterized as innovative and developing.

For a deeper analysis and understanding of the structure of each cluster, it is necessary to identify countries that dominate in terms of innovative development and form a kind of "core" of the cluster. The results of calculating the level of innovative development of countries in clusters are presented in Table A.1. As a result, countries that form the "core" of the cluster were identified in each group (Table 9).

Table 9 - The most innovative-developed countries in clusters.

Cluster	Country (R_j, %)
«Core» inclus-ter*A*	Kosovo (79.17), Kenya (75.00), Sri Lanka (58.33), Uganda (56.25), Pakistan (56.25), Mongolia (52.08), Tanzania (50.00)
«Core» inclus-ter*B*	India (64.58), Egypt (64.58), Colombia (62.50), Iran (58.33), Ecuador (56.25)
«Core» inclus-ter*C*	Brazil (64.58), Romania (60.42), Tunisia (58.33), Turkey (58.33), Argentina (56.25), Italy (56.25), South Africa (56.25), Ukraine (56,25), Bulgaria (54,17), Croatia (52,08), Cyprus (52,05), Barbados (50,00), Costa Rica (50,00), Serbia (50,00)
«Core» inclus-ter*D*	USA (66.67), South Korea (64.58), Singapore (56.25), Japan (52.08), China (50.00)
«Core» inclus-ter*E*	Malaysia (66.67), Czech Republic (54.17), Russia (50.00), Estonia (50.00), Poland (50.00)

It should be noted that the value of Rj cannot be compared in countries that do not belong to the same cluster because of the specifics of the methodology.

4. Conclusion

As a result, the multivariable classification of the countries in terms of innovative development indicators was implemented in the framework of the study. The presented 189 countries were divided into five clusters and within each group the leading countries that form the "core" of the cluster were identified. As can be seen from the research results, there is a high differentiation in all indicators that characterize innovation development in the countries. It was confirmed by the calculated coefficients of variation. The most powerful group of countries is cluster D, in which the “core” consists of the United States (66.67), South Korea (64.58), Singapore (56.25), Japan (52.08), and China (50.00). Despite the fact that the developed countries of the world retain their leading positions in the field of creation and commercialization of innovations, the effectiveness of the innovative way of development of national economies in the context of globalization and impressive growth rates are demonstrated by developing countries. Strengthening innovation capacity and building an innovative economy is a strategic goal for each of these countries. However, the “core” of these integration interactions is a very limited number of countries. In the future, we will determine the degree of closure of the countries that constitute the "core" of innovative development.

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