DOI: 10.17747/2618-947X-2021-4-335-343

Identification of the national innovation system in a globalized environment

S.I. Kravchenko[1]

[1] Financial University under the Government of the Russian Federation (Moscow, Russia)

Abstract

The activation of innovation processes always requires the presence of an appropriate enabling environment - an effective national innovation system (NIS), which determines the country's ability to generate and implement various kinds of innovations. However, the formation of a full-fledged country's innovation system is quite difficult, at least for two reasons: the presence of purely national features of the functioning of the main agents of change, as well as the specifics of the modern world, when many important processes for innovation go beyond individual countries, forming a globalized environment, the presence and the specifics of which determine the potential and strategic directions for the further development of each NIS. The scientific and methodological approach proposed in the paper is generally based on the hypothesis of the expediency of regulating a particular national innovation system development, taking into account its belonging to a certain basic type, which determines the specific features of development. For its implementation, the methods of genetic algorithms, cluster analysis, and neural network training were used. Within the framework of the study, four basic types of NIS were identified and qualitatively interpreted, which have characteristic features in the context of the quadruple helix concept of development. To identify the national innovation system, a neural network, which simplifies the modeling of its development, was built. As a demonstration of the additional possibilities of the toolkit, four supranational associations of countries have been identified and analyzed. The practical significance of the results lies in the possibility of conducting variable analytical and predictive studies in the course of substantiating the optimal directions for the further development of the national innovation system in terms of global and cluster trends.

Keywords: national innovation system, genetic algorithm, clustering, neural network model, basic type, regulation, modeling.

For citation:

Kravchenko S.I. (2021). Identification of the national innovation system in a globalized environment. *Strategic Decisions and Risk Management,* 12(4): 335-343. DOI: 10.17747/2618-947X-2021-4-335-343. (In Russ.)

Introduction

The effectiveness of any national innovation system is largely due to the state of its four main complexes: scientific and educational (SE), state-political (SP), production and economic (PE) and socio-cultural (SC), which form a single ecosystem within the framework of the concept of the quadruple helix of development [Carayannis, Grigoroudis, 2016]. A change in the functioning parameters of any of them as a result of national policies, of course, affects both the state of others and the overall result, since mutualism takes place - a situation in which the effectiveness of interaction is important both for joint functioning and separately. At the same time, the interdependent development of NIS complexes is accompanied by the formation of a set of multilateral adaptations (co-adaptations) that optimize these stable interactions.

The ontological complexity of the problem of increasing the efficiency of the NIS is exacerbated by the fact that in the modern integrated world, many processes important for innovation go beyond the boundaries of individual countries, forming a globalized environment, the presence and specifics of which determine the potential and strategic directions for the further development of each individual system. That is, while maintaining a significant degree of independence, the NIS of each country evolves not only within this environment, but also along with it. Thus, the hypothesis about the existence of several characteristic basic types (images) of national innovation systems is updated, which can be identified and to which, with a certain degree of approximation, all innovation systems of national economies in the world can be attributed. At the same time, each such type has its own stable and unique features which to a large extent determine the behavior parameters and capabilities of the corresponding NIS. Based on this, the development of each individual national innovation system, on the one hand, is multi-vector due to its own identity, and on the other hand, it can be significantly limited by intertype features.

Taking into account the above mentioned, any impact on the development of the national innovation system should take into account not only the features of the transformation of its constituent complexes but also the characteristic features of the corresponding basic type. They are also transformed in time and space in a specific way due to the influence of geographical, economic, sociocultural and other factors. It is the consideration of type affiliation that makes it possible to correctly determine the strategic directions for the development of the NIS and improve the efficiency of its regulation.

The study of national innovation systems has been a popular trend in recent years. Thus, the founders of the NIS concept [Freeman, 1982; Metcalfe et al., 1988; Lundvall, 2007] believe that each such system is unique and inimitable, despite a number of universal features. A similar point of view is shared by researchers who focus more on national specifics and its dynamics (see, for example, [Datta et al., 2019]). In addition, the focus of research has extended to other levels, including subnational (Silicon Valley) [Saxenian, 1994], sectoral [Malerba et al., 2004], technological [Carlsson, Jacobsson, 1997], regional [Asheim et al. , 2004], supranational [Jackson, 2014]. There are also studies that identify clusters of supranational innovation systems that go beyond administrative boundaries [Proksch et al., 2019]. Of no less interest in scientific and practical terms are taxonomies [Godinho et al., 2005; Balzat, Pyka, 2006]: the first paper analyzes 69 countries with different regions of location and economic development, the second one analyzes the international features of the NIS of eighteen advanced high-tech countries of the Organization for Economic Cooperation and Development. The approaches that form the conceptual basis for global innovation systems should be singled out separately [Binz, Truffer, 2017].

In general, the analysis of a number of works in this area proves that, despite the differences in the approaches and tools of different authors, the hypothesis of the existence of basic types of innovation systems is objectively justified and confirmed by empirical observations.

Paying tribute to the results of existing studies on the taxonomy of national innovation systems, due to the complexity, comprehensiveness and breadth of problem understanding, the theoretical and practical aspects of solving this issue are not universal, since in most cases they are limited by the specifics of researchers' goal setting. In this regard, the purpose of this work is to propose a scientific approach to the typology of national innovation systems, which contributes to the solution of a number of problems related to the identification of national innovation systems, clarification of the composition of their basic types, analysis of functioning supranational formations for type affiliation, as well as development modeling.

1. Description of the research methodology

Based on the stated goal and expected results, the research methodology involves the use of a number of economic and mathematical methods that, according to the initial set of indicators, allow:

1) to establish the similarity of national innovation systems and form stable clusters that correspond to certain types of NIS, which are considered as basic (parent);

2) to develop tools for classifying new objects of research to the corresponding types of NIS.

In a general approximation, the process of recognizing the basic types of the national innovation system can be represented as follows (for more details, see [Kravchenko, 2019; Kravchenko, Zanizdra, 2019]):

1.1) substantiation of the classification features of the national innovation system (based on the concept of the quadruple helix of development);

1.2) formation of a representative sample of indicators (the study is based on databases of world rankings for different years: the Global Innovation Index, the Global Competitiveness Index, the Human Development Index). Valdai and the All-Russian Public Opinion Research Center), data from the UNESCO Institute for Statistics, the Travel Weather Averages Internet resource, the International Energy Agency, the World Bank's Energy Sector Management Assistance Program, etc. The initial sample consists of 136 countries whose national innovation system parameters characterize 148 qualitative and quantitative indicators in the context of four classification features: SE, SP, PE and SC);

1.3) the normalization of the sampling parameters (for further correct comparisons) was carried out according to the rule: a higher value of the standardized indicator means a more efficient functioning of the national innovation system. Thus, the indicators were brought into the range [0, 1] (for the subsequent construction of a neural network with a binary data type);

1.4) each analyzed indicator received a number based on classification group (attribute) it belongs to. Further, the resulting series was used as an objective function in the selection of the most significant countries for the formation of clusters (the method of genetic algorithms was applied). That is, an inverse problem was solved: with a certain division of objects into groups, indicators were selected that had the greatest impact on this division. Thus, the primary matrix has been streamlined (reduced to 95 countries);

1.5) cluster analysis of a truncated/optimized sample (using the Ward method). The measure of distance is the square of the Euclidean distance. The number of clusters was refined using the quality functional - the sum of the squared distances to the center of the clusters. At the same time, when divided into four clusters, the functional amounted to 255, into five - 235, into six - 254.

To solve the problem of assigning new objects to the basic types of national innovation systems, a neural network was built (for more details, see [Kravchenko, Zanizdra, 2019]). The algorithm for its formation is as follows:

2.1) collection, analysis and standardization of input data (the previously described sample of 136 countries and 148 indicators was used);

2.2) choice of architecture and definition of the structure of the neural network (multilayer perceptron with one hidden layer: 148-60-5);

2.3) training of the neural network (70% of the primary parameters were used, optimized by the methods of genetic algorithms, the definition of the training set - 100% result);

Table 1
Representatives of NIS's basic types

NIS of type A Developed countries with predominantly inclusive institutions	
1. Australia	14. The Netherlands
2. Austria	15. New Zealand
3. Belgium	16. Norway
4. UK	17. The USA
5. Germany	18. Finland
6. Denmark	19. France
7. Israel	20. Switzerland
8. Ireland	21. Sweden
9. Iceland	22. Estonia
10. Canada	23. Japan
11. Republic of Korea	
12. Luxembourg	
13. Malta	

NIS of type B Developing countries with mixed extractive-inclusive institutions with a strongly pronounced socio-cultural component (mainly Muslim and Buddhist-Hindu types)	
1. Azerbaijan	11. Malaysia
2. Bahrain	12. Oman
3. Butane	13. Panama
4. Brunei Darussalam	14. Rwanda
5. India	15. Saudi Arabia
6. Indonesia	16. Tajikistan
7. Jordan	17. Thailand
8. China	18. Chile
9. Kuwait	
10. Mauritius	

NIS of type C Developed and developing countries with mixed extractive-inclusive institutions with a strongly pronounced informal component (including the post-Soviet type)	
1. Albania	15. Mongolia
2. Armenia	16. Poland
3. Bulgaria	17. Portugal
4. Bosnia and Herzegovina	18. Russian Federation
5. Hungary	19. Romania
6. Greece	20. Serbia
7. Georgia	21. Slovakia
8. Spain	22. Slovenia
9. Italy	23. Ukraine
10. Kazakhstan	24. Croatia
11. Cyprus	25. Montenegro
12. Latvia	26. Czech Republic
13. Lithuania	
14. Moldova	

NIS of type D Developing countries with predominantly extractive institutions	
1. Algeria	33. Malawi
2. Argentina	34. Liberia
3. Bangladesh	35. Lebanon
4. Benin	36. Mauritania
5. Botswana	37. Mali
6. Brazil	38. Morocco
7. Burundi	39. Mexico
8. Venezuela	40. Mozambique
9. Vietnam	41. Namibia
10. Haiti	42. Nepal
11. Gambia	43. Nigeria
12. Ghana	44. Nicaragua
13. Guatemala	45. Pakistan
14. Guinea	46. Paraguay
15. Honduras	47. Peru
16. Dominican Republic	48. Republic of Chad
17. Egypt	49. Salvador
18. Zambia	50. Seychelles
19. Zimbabwe	51. Senegal
20. Iran	52. Sierra Leone
21. Yemen	53. Tanzania
22. Cape Verde	54. Trinidad and Tobago
23. Cambodia	55. Tunisia
24. Cameroon	56. Turkey
25. Kenya	57. Uganda
26. Kyrgyzstan	58. Uruguay
27. Colombia	59. Philippines
28. Congo	60. Sri Lanka
29. Costa Rica	61. Ecuador
30. Laos	62. Eswatini
31. Lesotho	63. Ethiopia
32. Madagascar	64. South Africa
	65. Jamaica

Source: compiled by the author.

2.4) testing and verification of the neural network (breakdown of the initial data: 15% for testing and 15% for verification, while the definition of the test sample corresponds to 92.9% of the result, the verification sample - 85.7%, which indicates a fairly high quality of network formation).

2. Theoretical and calculated parts

Cluster analysis of an optimized sample of 95 countries with different geographical locations and levels of development of national innovation systems (scientific-educational, industrial-economic, state-political and socio-cultural complexes characterized by 148 indicators) made it possible to identify five clusters. However, an in-depth analysis of their composition showed that one of them, the smallest one, includes countries in which high performance indicators are achieved through rental income. Therefore, this cluster (United Arab Emirates, Hong Kong SAR (China), Singapore, Qatar) was excluded from the taxonomy in the study. Thus, in the end, four basic types of national innovation systems were identified.

Using the constructed neural network for countries previously recognized as insignificant for clustering and screened out by the genetic algorithms method, the basic type of NIS was established. Full information on the grouping of 132 countries is presented in Table 1.

The study analyzes the degree of development/efficiency of the national innovation system in terms of the above four elements of the development spiral. In this regard, further, in order to objectify the analysis of the achievements of different countries, the generalized results of three world rankings were additionally used: the Global Innovation Index (GII), the Global Competitiveness Index (GCI), and the Human Development Index (HDI). The data of these ratings are adapted to the respective samples of countries: they are standardized and summarized into an integral indicator (Ni) for each country (Table 2):

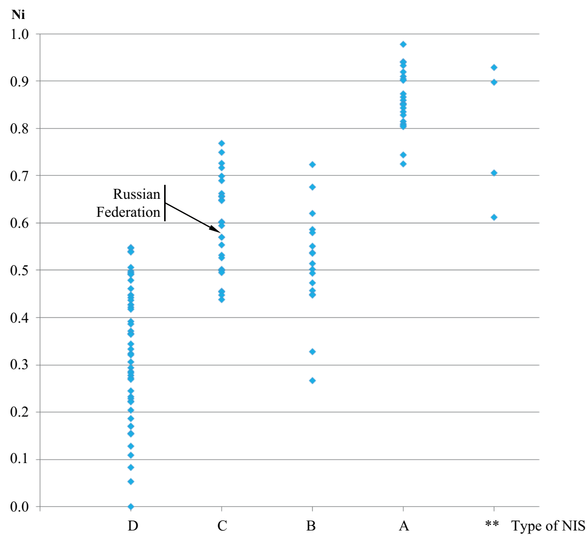
$$N_i = \sqrt[3]{GII_i^* \times GCI_i^* \times HDI_i^*},$$

where GII^*_i is the standardized value of the GII rating for the i-th country, GCI^*_i is the standardized value of the GCI-rating for the i-th country, HDI^*_i is the standardized value of the HDI-rating for the i-th country.

This approach is designed to provide a certain balance in assessing the achievements of different countries in the field of innovation, paying attention not only to the effectiveness of efforts in this direction, but also to the degree of public satisfaction with the achieved results.

The measure of the validity of using the integral indicator (N_i) was confirmed by the closeness of the relationship between it and the values of the “Most Innovative Countries in the World” rating (according to Bloomberg) using the Spearman rank correlation coefficient in 60 countries. This non-parametric method characterizes relationships between variables measured by a rank scale (the sample size is determined by the availability of data published by the specified agency). Taking into account the above mentioned and the fact that the analyzed sample includes more than 130 countries, and individual ratings (for example, Bloomberg) are less, further in the comparative analysis of economies the results of the integral indicator (N_i). were mainly used. A graphical interpretation of the results of clustering and ranking countries based on it is shown in Fig. 1.

Fig. 1. Graphical interpretation
of the countries ranking results by NIS’s basic types



Notes: 1. Countries are ranked according to the indicator (N_i) as of 2020.

2. ** – rich countries with rental economy (represented for reference only).

Source: developed by the author.

Summarizing the information obtained, we can draw general conclusions:

- within the selected types of NIS (except for countries excluded from the typology), there is a close homogeneity of economies;
- the top third of the rating is mainly represented by developed countries of type A, which are “supported” from below by the leaders of the NIS countries of type B and C;
- The bottom third of the ranking is almost completely represented by developing countries with predominantly extractive type institutions (NIS of type D).

For further in-depth analysis of the specifics of individual clusters, the following data from the Global Innovation Index [Global Innovation Index, 2021] were additionally used:

Table 2

Characteristics of the NIS's basic type C «Developed and developing countries with mixed extractive-inclusive institutions with a strongly pronounced informal component (including the Post-Soviet type)»

Country	Country position in the ranking			N_i	Innovation efficiency ratio	Innovation productivity
	GII-2020 (totally 132 countries)	GCI-2019 (totally 141 countries)	HDI-2019 (totally 189 countries)			
Spain	30	**23**	**25**	**0.916**	0.663	2
Czech Republic	**24**	**32**	**27**	**0.900**	**0.823**	1
Italy	**29**	**30**	29	**0.845**	0.738	2
Slovenia	32	35	**22**	0.841	0.617	2
Cyprus	**28**	44	33	0.767	0.759	2
Portugal	31	34	38	0.753	0.673	2
Poland	40	37	35	0.686	0.607	2
Lithuania	39	39	34	0.682	0.594	3
Latvia	38	41	37	0.638	0.626	2
Hungary	34	47	40	0.630	0.701	2
Slovakia	37	42	39	0.629	0.722	2
Bulgaria	35	49	56	0.546	**0.833**	1
Greece	47	59	32	0.527	0.494	3
Russian Federation	45	43	52	0.497	0.569	2
Croatia	42	63	43	0.486	0.585	2
Romania	48	51	49	0.456	0.611	3
Montenegro	50	73	48	0.402	0.591	2
Serbia	54	72	64	0.360	0.563	2
Georgia	63	74	61	0.313	*0.443*	2
Armenia	69	69	*81*	0.289	0.707	2
Ukraine	49	85	74	0.254	**0.798**	1
Kazakhstan	*79*	55	51	0.185	*0.346*	3
Moldova	64	*86*	*90*	0.139	0.687	1
Bosnia and Herzegovina	*75*	*92*	73	*0.119*	0.447	2
Mongolia	58	*102*	*99*	*0.000*	0.626	1
Albania	*84*	81	69	*0.000*	*0.404*	2
Mean value	47	56	50	0.495	0.624	–

Notes: 1. The ranking of countries is carried out according to the indicator (N_i), the three highest values of the indicators are in bold, three lowest values are in italics.
2. Productivity of innovations: 1 – above expectations, 2 – in line with expectations, 3 – all the rest.
The source: calculated and built by the author based on [Global Competitiveness Report, 2020; Human Development Index, 2020; Global Innovation Index, 2021].

- Innovation performance at different income levels in terms of expectations of innovative development level of the country's economy and income level (Income);
- Innovation Efficiency Ratio – the ratio of the Innovation Output Sub-Index indicator to the Innovation Input Sub-Index value.

In accordance with the developed taxonomy, the national innovation system of Russia belongs to the type "Developed countries with strong informal institutions, including those of the post-Soviet type". This cluster includes other 25 different countries - both economically developed and innovative (for example, Spain, Czech Republic, Italy, etc.), as well as with an average and below average level of development, as well as with weak NIS (Albania, Mongolia, etc.). (Table 2).

Analyzing the data in Table. 2, a number of points should be noted that additionally characterize the NIS of type C:

- the basic type is characterized by relatively good productivity of innovations by the level of development (in the context of the Global Innovation Index rating data): about 2/3 of the representative countries, including the Russian Federation, have productivity at the level of “in line with expectations”, five countries (Bulgaria, Moldova, Mongolia, Czech Republic and Ukraine) – “above expectations” and only four – below (see column 7 of Table 2);
- the performance of national innovation systems representing this type is lower in terms of the “innovation efficiency ratio” than in countries with NIS of type A, while half of the countries included in the cluster have a value of this indicator below the average for the cluster – 0.624 (see column 6 Table 2);
- Top 60 from Bloomberg 2021 Innovation Index [Jamrisko et al., 2021] includes 17 countries out of 26, while 6 of them (including Russia) have above-average performance;
- The leaders of the analyzed cluster of countries as a whole can be considered Spain, the Czech Republic and Italy (based on the generalization of the obtained results of the ranking, taking into account the balance of the considered parameters of innovative development).

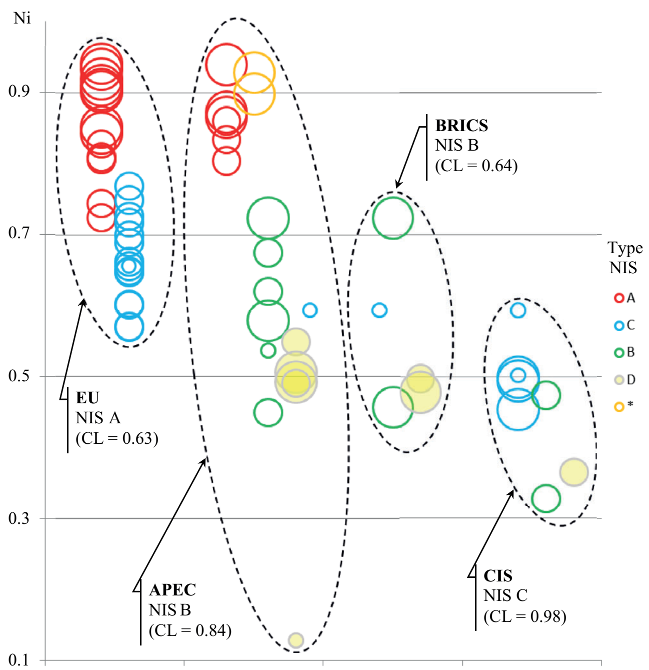
In all three ratings under consideration (GII-2020, GCI-2019, HDI-2019), in the global context, Russia is included in the first third of the lists (Table 2, columns 2-4). However, in the cluster context (among countries of the basic type C with a similar type of innovative development) demonstrates positions at the level of averages, including the generalized indicator (N_i) (Table 2, column 5). Obviously, this situation is due to the presence of obviously weaker countries in the world rankings. Among the important directions for further development in the innovation sphere, the need to adjust the ratio of "contribution/result from innovation" (Innovation Output and Innovation Input) should be noted, since the value of the indicator "innovation efficiency ratio" in Russia is below the average for the cluster (Table 2, column 6).

Thus, in order to increase the degree of validity of the results from modeling innovative development, of particular interest is not only the distribution of individual countries into leaders and outsiders in the global context, but also in each basic type of NIS. It is the understanding of the full picture of what is happening, which will allow us to assess the current real state of the NIS. At the same time, for any country, two possible approaches to innovative development in the future can be considered: either a focus on the experience of leaders of their NIS basic type (having similar development specifics), or striving for world leaders (the conditions and development nature of which differ significantly). Obviously, the second case will require much more resources (including temporary ones).

In general, the use of the described scientific and methodological approach makes it possible to solve the problems of modeling such multidimensional phenomena as the features of the functioning of individual national innovation systems, and to predict the evolution of their types. Information refined in the global and typical/cluster context may be of scientific and practical interest in identifying the characteristic features of various types of NIS, as well as substantiating strategic directions for their further development.

Separately, it should be noted that the proposed tools also make it possible to analyze existing supranational formations

Fig. 2. The neural network identification results of countries individual supranational formations



Notes: 1. Countries are ranked by integral indicator (N_i).
2. CL – the level of confidence (confidence level) of the neural network.
3. Bubble diameter – productivity of innovative development: from “below the expected level” (small diameter) to “above the expected level” (large diameter).
Source: developed by the author.

and predict the features of the new ones. For example, several supranational associations/unions were characterized during the study[1]:

- The European Union (EU) is an international formation of 28 European states that combines signs of inter- and superpower, but legally is neither one nor the other (the EU has about 500 million citizens, its share in world GDP, PPP in 2018 was about 23 %);
- Asia-Pacific Economic Cooperation (APEC) - unites 21 economies of the respective region with the aim of ensuring economic growth and strengthening the trade community, as well as facilitating investment processes (participating countries account for about 40% of the world population, share in world GDP, PPP in 2018 was about 53%);
- BRICS – includes five countries: Brazil, Russia, India, China, South Africa (share in world GDP, PPP in 2018 was about 33%).
- The Commonwealth of Independent States (CIS) is an international treaty that regulates cooperation between individual states from the former USSR (about 300 million people live in the participating countries, the share in world GDP, PPP in 2018 was about 4%).

For this purpose, based on the data sample used for clustering, averaged parameters of the functioning of these associations (according to 148 indicators) were formed, which were further identified by the neural network. Visualization of the results is shown in fig. 2.

The obtained results can be summarized as follows:

- all countries of the European Union are quite successful in their innovative development, since the integral indicator (N_i) does not fall below 0.57 (the average value is 0.75). This is the most successful result among the analyzed objects. Almost all EU countries are characterized by high productivity of innovative development - at the level of expectations and above (about 30%). According to the study, the EU largely has the characteristics of the basic type A, despite the fact that the NIS of many countries are of type C;
- APEC (includes countries with all types of NIS) is generally less successful than the European Union: the range of (N_i) is wider, from 0.13 to 0.94, with an average value of 0.67. Most of the countries have innovative development productivity at the levels “in line with expectations” and “above expectations”. With a high level of confidence, the union is recognized as the basic type B;
- BRICS - the value of the average integral indicator (N_i) for this association of countries is 0.55 (with a slight spread). Virtually all countries have innovation productivity at or above expectations. With an acceptable level of confidence, the neural network defines the object as the basic type B. Most likely, this is due to the presence of the economies of China and India, which, together with South Africa (according to the GII index), have a higher level of productivity of innovative development than expected;
- The integration of the CIS countries is less successful: the N_i indicator is at the level of 0.46, the level of innovation productivity in a third of the countries is lower than expected. The neural network recognizes it as an object with explicit features of type C.

Conclusion

The modern regionalization of political gravity centers is of a cultural and technological nature, which leads to the formation of transnational innovation ecosystems that do not necessarily occupy adjacent territories in space. Such ecosystems can cover different regions of the world, as they unite people and territories that historically have common values, sociocultural features, and technical and technological norms. For example, as a result of colonization, Australia became cultural and technological part of the Western world, although geographically it is significantly distant from Western Europe and North America. In this regard, the concept of a four-link helix of innovations, which, along with science, industry and government, also takes into account the evolutionary and socio-cultural aspects of society development, is of fundamental importance for understanding the features of national innovation system development.

The scientific and methodological approach proposed in the paper as a whole is based on the hypothesis of the expediency of regulating the development of a separate national innovation system, taking into account its belonging to a certain basic type that has specific features of development. In this regard, the paper identifies four basic types of NIS, which have characteristic features (spatial-historical, resource, etc.) that determine the capabilities and behavior of countries in relation to innovations.

The contours of a particular type of national innovation system are quite real, but they are wide and flexible (allow for intersection with others) and, thus, allow for case scenario. In this regard, the NIS vector development of a particular country are naturally diverse, but can be significantly limited by the typical specifics of functioning. This feature must be taken into account when developing individual national strategies aimed at enhancing innovation activity.

An elaborated toolkit is intended to analyze and model NIS development, taking into account typical features, its use is aimed at increasing the degree of validity of strategic decisions. With its help, it was established that the national innovation system of Russia belongs to the basic type "Developed and developing countries with mixed extractive-inclusive institutions with a strongly pronounced informal component (including the post-Soviet type)". The results of

[1] Major Alliances of the World (2020). EconomicData.ru. https://www.economicdata.ru/union.php?menu=world-unions.

its functioning (according to the analyzed statistical data) can be improved. At the same time, two approaches to adjusting innovative development are possible: either strengthening positions, focusing on the experience of countries of their own NIS type (they have similar development specifics), or following world leaders (their conditions and nature of development differ significantly). Obviously, in the second case, much more resources and efforts need mobilizing.

Four supranational associations of countries (EU, APEC, BRICS and CIS) have been identified and analyzed as a demonstration of additional possibilities of the toolkit. The relative effectiveness of the EU as a supranational formation against the background of others is noted.

The characteristic features that distinguish the author's approaches from the existing ones are the combination of genetic algorithms and cluster analysis methods to obtain a representative sample of national innovation systems, different in terms of economic development, geographical location and dominant institutions. However, their limitation is the need to involve big data for analysis, as well as blurry (moving) boundaries between different basic types of NIS, which are unstable in the long term. In this regard, further identification and distribution of specific national innovation systems between certain basic types is proposed to be carried out on the basis of neural network modeling. The resulting network model is capable of accumulating experimental knowledge, learning from it, and with high quality assigning new objects of analysis to the corresponding clusters.

The practical significance of the presented results of the study lies in the possibility of conducting variable analytical and predictive studies in the course of substantiating the optimal directions for the further development of the national innovation system in the context of global and cluster trends.

References

1. Kravchenko S.I. (2019). Regulation of the national innovation system in the glocalization aspect. *Economy of Industry*, 4(88): 58-74. (In Russ.)
2. Kravchenko S.I., Zanizdra M.Yu. (2019). Typology of basic supranational innovative systems. *Economy of Industry,* 1(85): 5-29. (In Russ.)
3. Asheim B., Gertler M., Fagerberg J., Mowery D., Nelson R. (2004). *Regional systems of innovation. The Oxford Handbook of Innovation.* Oxford, Oxford University Press.
4. Balzat M., Pyka A. (2006). Mapping national innovation systems in the OECD area. *International Journal of Technology and Globalisation,* 2(1-2):158-176.
5. Binz C., Truffer B. (2017). Global innovation systems - A conceptual framework for innovation dynamics in transnational contexts. *Research Policy*, 46(7): 1284-1298.
6. Carayannis E., Grigoroudis E. (2016). Quadruple innovation helix and smart specialization: Knowledge production and national competitiveness. *Foresight and STI Governance,* 10(1): 31-42.
7. Carlsson B., Jacobsson S. (1997). *In search of a useful technology policy - general lessons and key issues for policy makers. Technological Systems and Industrial Dynamics.* Boston, Kluwer Academic Publishers.
8. Datta S., Saad M., Sarpong D. (2019). National systems of innovation, innovation niches, and diversity in university systems. *Technological Forecasting and Social Change,* 143: 27-36.
9. Freeman C. (1982). *Technological Infrastructure and International Competitiveness.* http://redesist.ie.ufrj.br/globelics/pdfs/GLOBELICS_0079_Freeman.pdf.
10. *Global Competitiveness Report* (2020). World Economic Forum. *http://reports.weforum.org/.*
11. *Global Innovation Index* (2021). Geneva, World Intellectual Property Organization. https://www.wipo.int/global_innovation_index/en/2021/.
12. Godinho M., Mendonça S., Pereira T. (2005). Towards a taxonomy of innovation systems. *Working Papers Department of Economics,* 2005/13. Lisbon, ISEG - Lisbon School of Economics and Management, Department of Economics, Universidade de Lisboa.
13. *Human Development Index* (2020). United Nations Development Programme. http://hdr.undp.org/en.
14. Jackson P.C. (2014). Towards a regional (supra-national). *Innovation System for CARICOM Countries*. Kingstown, Vincent and the Grenadines: Science and Technology Unit, Government of St. Vincent and the Grenadines. https://www.academia.edu/2473274/Towards_a_ Regional_Supra-national_Innovation_System_for_CARICOM_Countries.

15. Jamrisko M., Lu W., Tanzi A. (2021). South Korea leads world in innovation as U.S. exits top ten. *Bloomberg.* https://www.bloomberg.com/news/articles/2021-02-03/south-korea-leads-world-in-innovation-u-s-drops-out-of-top-10.

16. Lundvall B.-A. (2007). National innovation systems - Analytical concept and development tool. *Industry and Innovation*, 14(1): 95-119.

17. Malerba F., Fagerberg J., Mowery D., Nelson R. (2004). *Sectoral Systems: How and Why Innovation Differs Across Sectors. The Oxford Handbook of Innovation.* Oxford, Oxford University Press.

18. Metcalfe S., Dosi G., Freeman C., Nelson R. (1988). The Diffusion of Innovations: An Interpretative Survey. *Technology and economic theory.* London, Pinter.

19. Proksch D., Busch-Casler J., Haberstroh M.M., Pinkwart A. (2019). National health innovation systems: Clustering the OECD countries by innovative output in healthcare using a multi indicator approach. *Research Policy,* 48(1): 169-179.

20. Saxenian A. (1994). *Regional advantage: Culture and competition in Silicon Valley and route 128.* Cambridge, MA: Harvard University Press.

About the author

Sergey I. Kravchenko

Doctor of economics, professor, Financial University under the Government of the Russian Federation (Moscow, Russian Federation). SPIN-code: 8606-3176, Author ID: 110508, ORCID ID: 0000-0001-8391-0445, Researcher ID: E-1397-2017, Scopus Author ID: 57208315814.

Research interests: investment and innovation, national innovation systems, science and education management, change management.

SKravchenko@fa.ru

The article was submitted on 10.10.2021; revised on 28.10.2021 and accepted for publication on 7.11.2021. The authors read and approved the final version of the manuscript.