

**SIMULATION OF THE NATIONAL INNOVATION SYSTEMS DEVELOPMENT:
A TRANSNATIONAL AND COEVOLUTION APPROACH**

Sergey Kravchenko

Abstract. The current state of scientific and technological development of the world economy is quite specific, because advanced technologies already known are too complicated for simple mechanical copying and borrowing, and most of the technologies of Industry 4.0 are in the making. Thus, the development and further exploitation of all kinds of innovations today, more than ever, require an appropriate environment - an effective national innovation system (NIS), which determines the country's ability to generate innovation, which is the key to high competitiveness and world leadership. However, the formation of a full-fledged innovation system of the country is quite complicated, for at least two reasons: first, there exist purely national features of functioning and cooperation of the main agents of change, and secondly, in the modern globalized world many of the most important for innovation processes go beyond the borders of individual countries, creating a unique transnational "ecosystem" with its distinctive features, which, undoubtedly, must be considered. The article proposes the scientific approach of reliable identification of national and transnational (supranational, global) innovation systems (TNIS) and the corresponding toolkit for simulating their development in the context of the quadruple helix concept. Identification of innovative systems is based on the methods of cluster analysis, genetic algorithms and neural network training. As a result, there have been identified and qualitatively interpreted four basic types of TNIS, which have stable characteristics determining the behavioural parameters and capabilities of the NIS included. A neural network has been built to identify NIS, which simplifies the process of simulating their development within the characteristic features of basic TNIS. It is established that the NIS of Ukraine belongs to the basic type of TNIS – “developed and developing countries with mixed extractive-inclusive institutions with a strong informal component (including the post-Soviet type)”. The results of its functioning against the background of global and relevant cluster leaders are not satisfactory and necessitate the adjustment of the further development vector. In order to demonstrate the capabilities of the neural network built, four supranational associations have been identified and analysed. The proposed approaches and tools will facilitate variant analytics and forecasting studies in substantiating the optimal directions for the individual NIS further development in the context of global and cluster trends.

Keywords: national and transnational innovation systems, cluster, quadruple innovation helix, identification, simulation, neural network

JEL Classification: O1, O30, P00

Sergey Kravchenko

Virtual Economics, Vol. 2, No. 3, 2019

Author(s):**Sergey Kravchenko***Institute for International Cooperation Development, 24/26/1 Kazimierza Wielkiego Street, Poznan, Poland, 61-863**E-mail: sergey.iv.kravchenko@gmail.com**<https://orcid.org/0000-0001-8391-0445>*

Citation: Kravchenko, S. (2019). Simulation of the national innovation systems development: a transnational and coevolution approach. *Virtual Economics*, 2(3), 41-54. [https://doi.org/10.34021/ve.2019.02.03\(4\)](https://doi.org/10.34021/ve.2019.02.03(4))

Received: February 23, 2019. Revised: April 17, 2019. Accepted: June 25, 2019.

© Author(s) 2019. Licensed under the [Creative Commons License - Attribution 4.0 International \(CC BY 4.0\)](https://creativecommons.org/licenses/by/4.0/)

1. Introduction

The effectiveness of NIS is largely due to the state of science-education (SE), state-political (SP), production-economic (PE) and socio-cultural (SC) complexes that form a single ecosystem within the concept of "quadruple helix" (Carayannis & Grigoroudis, 2016). Changing the functioning parameters of any of them, as a result of national policies, will certainly affect both the status of others and the overall result, since there is a mutualism – a situation in which the effectiveness of interaction is important for the functioning of all together and separately.

However, on the other hand, in order to understand the specific features of the national innovation systems functioning (Vishnevsky & Knjazev, 2018), it is important to take into account the fact that in today's globalized and integrated world many of the most important processes for innovation go beyond individual countries (Dalevska et al., 2019; Kwilinski et al., 2019a; 2019b), forming a unique transnational (supranational) "ecosystem" with its characteristic features, which, in turn, determine the possibilities for further development. That is, regulating the development of national economies in isolation is conceptually incomplete and limited, which does not give a complete picture of their effectiveness, preconditions and potential for further functioning.

Given the abovementioned, the article is based on the scientific hypothesis that each NIS, while maintaining a considerable degree of independence, evolves within the framework of TNIS and together with it. That is why simulating an individual NIS development should cover not only the transformation of its complexes' constituents, but also the characteristic features of the corresponding "maternal" TNIS, which is also transformed in time and space in a specific way, due to the influence of historical, geographical, economic, socio-cultural and other factors.

2. Literature review

NIS research has been a popular trend in recent years. The founders of the NIS concept (Freeman, 2004; Lundwall, 2007; Metcalfe et al., 1988) generally consider that each NIS is

unique and inimitable, despite a number of universal features. This view is shared by researchers who focus more on national specificities and their dynamics (Datta, Saad, & Sarpong, 2019). In addition to several versions of the basic NIS concept, the focus of research is extended to levels other than national, including: sub-national realities - Silicon Valley level (Saxenian, 1994), sectoral (Malerba et al., 2006) or technological (Carlsson & Jacobsson, 1997), regional (Asheim & Gertler, 2004; Pająk et al., 2016), supra-national (Jackson, 2014). Some researchers (Prokschet et al., 2019) identify specific clusters of supranational innovation systems that go beyond administrative boundaries. It is of the scientific and practical interest to study the three-tier taxonomy of NIS-2005 (includes 69 countries of different economic development and location (Godinho et al., 2005) and NIS-2006 with empirical identification of cross-national specificities in the structure and activity of innovative systems of high-tech advanced economies (includes 18 OECD member countries (Balzat & Pyka, 2006). Also, there are works that form the conceptual framework for global innovation systems (Blinz & Truffer, 2017).

In general, the analysis of a number of works in this area proves that despite the differences in different authors' approaches and tools, the hypothesis of the existence of typical transnational (supranational) innovative systems is objectively substantiated and confirmed by empirical observations.

Paying tribute to the scientific experience of the TNIS taxonomy, it should be noted that due to the complexity and dynamism of national innovation systems as a socio-economic phenomenon, theoretical and practical issues of innovation development, previously disclosed, are restricted by the specificity of the authors' goal setting and are not universal. Therefore, in the context of this study, we propose the author's approach to classifying transnational innovation systems, which will help solve a number of tasks related to identifying individual NIS and specifying the composition of TNIS, analysing already functioning supranational entities for belonging to one or another type of TNIS, as well as acquiring future scenarios within NIS foresight.

The purpose of the article. Given that each NIS evolves within and along with a certain basic supranational system, the purpose of the article is to propose a scientific approach to authentic identification of national and transnational innovation systems and appropriate simulating tools for their development in the context of the quadruple helix concept.

3. Methods

Based on the stated purpose and expected results, the research methodology involves using a number of economic and mathematical methods, which, from the initial set of indicators, allow:

- 1) establishing the kinship of national innovation systems and creating stable clusters corresponding to certain types of transnational innovation systems that are considered as basic;
- 2) developing a toolkit for assigning new objects to appropriate types of TNIS.

The overall algorithm for identifying the basic types of transnational innovation systems can be summarized as follows:

1.a) substantiation of the TNIS classification features (based on the concept of "quadruple helix", which combines all four elements of the developmental spiral);

1.b) formation of a representative set of indicators (used Global Integration Index Database: The Global Innovation Index (GII) of INSEAD International Business School (Global Innovation Index, 2019), Human Development Index – HDI developed by UNDP (Human Development Index, 2018), The Global Competitiveness Index (GCI) issued by the World Economic Forum (2019), the Readiness Index for the Future, the Valdai International Debating Club and the All-Russian Centre for the Study of Public Opinion, information other bases of the UNESCO Institute for Statistics, the International Energy Agency and the World Bank's Energy Sector Management Program, the Travel Weather Averages, etc. The sample contains 136 countries, whose innovative systems state is determined by 148 quantitative and qualitative indicators, divided between the four classification traits (SE, SP, PE and SC);

1.c) parameters standardization for correct comparisons (carried out according to the rule: the higher the value of the standardized indicator, the more effective is the functioning of the country's innovation system). The normalization allowed to bring the indicators to the range [0, 1], which is caused by the construction of a neural network that works with a binary data type;

1.d) Each of the indicators analysed has been assigned a number, depending on which classification attribute (group) it refers to. Using the resulting series as a target function, the countries that are most relevant for cluster formation based on the selected indicators were chosen by genetic algorithms. In fact, the reverse task has been performed: given that the objects are divided into groups, to select those indicators that influence the given partition most significantly. As a result, the output matrix was reduced to 95 countries, characterized by 148 indicators;

1.e) optimized sampling clustering (using the Ward method that minimizes intragroup dispersion. The measure of distance is the Euclidean squared distance. To accurately determine the number of clusters the quality functional - the sum of the squared distances to the cluster centre - is used. The calculations show that for splitting into 4 clusters the functional equals 255, for 5 clusters - 235, for 6 clusters - 254. Therefore, splitting the original set of countries into 5 clusters is optimal.

In order to solve the problem of assigning new objects to the TNIS groups, a neural network was built. The overall algorithm for its formation can be summarized as follows:

2.a) collection, analysis and standardization of input (an earlier described sample of 136 countries and 148 indicators was used as data);

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

2.c) neural network training (70% of the original data optimized by genetic algorithms were used, and the training sample definition corresponds to 100% of the result);

2.d) neural network testing and verification (baseline breakdown: 15% for testing and 15% for verification, with the determination of the test sample corresponding to 92.9% of the result, the validation - 85.7%, indicating a sufficiently high-quality network formed).

4. Results and Discussion

As a result of the cluster analysis of a sample from 95 countries of the world with different economic development and location, according to 148 indicators characterizing the NIS in terms of scientific, educational, industrial, economic, political and socio-cultural characteristics, five clusters were selected. However, SAR Hong Kong, China, Qatar, Singapore and the United Arab Emirates are atypical examples of national innovation systems in which high performance is achieved through rental income. Therefore, this cluster was excluded from the taxonomy of basic types of transnational innovation systems (Godinho, Mendonça, & Pereira, 2005). So, as a result, four basic types of TNIS were defined.

Using a built neural network for countries that were previously found to be insignificant for clustering and screened by genetic algorithms, as well as for Ukraine, which was deliberately withdrawn from the initial sample under the experimental conditions, the basic type of TNIS was determined. The complete grouping of all 136 countries analysed is given in *Table 1a* and *Table 1b*.

Table 1a. Contents of TNIS Basic Types (countries are ranked within individual clusters (TNIS types) by value N_i (bold indicates leaders and outsiders), (part 1).

TNIS "A"		TNIS "B"	
Developed countries with predominantly inclusive institutions		Developing countries with mixed extractive-inclusive institutions with a strong socio-cultural component (predominantly Muslim and Buddhist-Hindu types)	
1. Switzerland	17. Iceland	1. China	15. Jordan
2. Sweden	18. Australia	2. Malaysia	16. Tajikistan
3. Netherlands	19. Austria	3. Chile	17. Rwanda
4. United States	20. Belgium	4. Thailand	
5. United Kingdom	21. New Zealand	5. Saudi Arabia	
6. Germany	22. Estonia	6. Kuwait	
7. Denmark	23. Malta	7. Brunei Darussalam	
8. Finland		8. Bahrain	
9. Ireland		9. Oman	
10. Japan		10. Mauritius	
11. Canada		11. Panama	
12. Korea, Rep.		12. India	
13. Norway		13. Azerbaijan	
14. Israel		14. Indonesia	
15. France			
16. Luxembourg			

Source: own research.

Table 1b. Contents of TNIS Basic Types (countries are ranked within individual clusters (TNIS types) by value Ni (bold indicates leaders and outsiders), (part 2).

TNIS "C"	TNIS "D"	
Developed and developing countries with mixed extractive-inclusive institutions with a strong informal component (including the post-Soviet type)	Developing countries with institutes of predominantly extractive type	
1. Spain	1. Mexico	29. Guatemala
2. Czech Republic	2. Turkey	30. Honduras
3. Italy	3. Costa Rica	31. Cambodia
4. Slovenia	4. Uruguay	32. Nicaragua
5. Cyprus	5. Vietnam	33. Ghana
6. Portugal	6. Brazil	34. Bangladesh
7. Poland	7. Colombia	35. Nepal
8. Lithuania	8. Philippines	36. Pakistan
9. Latvia	9. Peru	37. Tanzania
10. Slovak Republic	10. South Africa	38. Senegal
11. Hungary	11. Iran, Islamic Rep.	39. Uganda
12. Greece	12. Argentina	40. Nigeria
13. Bulgaria	13. Tunisia	41. Cameroon
14. Russian Federation	14. Jamaica	42. Zambia
15. Croatia	15. Trinidad and Tobago	43. Zimbabwe
16. Romania	16. Sri Lanka	44. Madagascar
17. Montenegro	17. Morocco	45. Benin
18. Georgia	18. Dominican Rep.	46. Malawi
19. Serbia	19. Lebanon	47. Ethiopia
20. Armenia	20. Ecuador	48. Guinea
21. <i>Ukraine</i>	21. Botswana	49. Mali
22. Kazakhstan	22. Egypt, Arab Rep.	50. Mozambique
23. Bosnia and Herzegovina	23. Algeria	51. Burundi
24. Moldova	24. Kyrgyz Rep.	52. Yemen, Rep.
25. Mongolia	25. Paraguay	
26. Albania	26. Kenya	
	27. Namibia	
	28. El Salvador	

Source: own research.

In this study, the measure of NIS development / efficiency is analysed in terms of all four elements of the helix. In this regard, in order to objectify the process of analysing different countries' achievements, we have used the generalized results of three generally world-recognized ratings: (GII), (GCI), (HDI). The data of these ratings are adapted to the respective sample of countries: standardized and summarized in the integral index (Ni) for each country (separate results are presented in *Table 2*):

$$N_i = \sqrt[3]{GII_i^* \times GCI_i^* \times HDI_i^*} \quad (1)$$

where: GII^*i – the standardized value of the GII rating (2019) for the i -th country;
 GCI^*i – the standardized value of the GCI rating (2019) for the i -th country;
 HDI^*i – the standardized value of the HDI rating (2018) for the i -th country.

Table 2. Rating of developed and developing countries with mixed extractive-inclusive institutions with a strong informal component (including the post-Soviet type) *

No	TNIS Type	Country	Normalized index value				Bloomberg, pts	Innovation efficiency ratio	Productivity of innovation **	The level of income***
			GII-2019	GCI-2019	HDI-2018	Ni				
1	C	Spain	0.9172	1.0000	0.9745	0.9633	64.52	0.6702	2	H
2	C	Czech Republic	1.0000	0.8062	0.9592	0.9179	68.09	0.7834	2	H
3	C	Italy	0.8360	0.8326	0.9184	0.8614	72.85	0.6929	2	H
4	C	Slovenia	0.7810	0.7753	1.0000	0.8460	64.1	0.6728	2	H
5	C	Cyprus	0.9429	0.6079	0.8622	0.7906	52.1	0.7405	2	H
6	C	Portugal	0.7496	0.7841	0.7500	0.7611	62.79	0.6325	2	H
7	C	Poland	0.5746	0.7181	0.8418	0.7030	69.1	0.6216	2	H
8	C	Lithuania	0.5825	0.6960	0.8061	0.6888	59.7	0.6383	3	H
9	C	Latvia	0.6752	0.6344	0.7500	0.6849	55.46	0.6862	2	H
10	C	Slovak Republic	0.6134	0.6256	0.7908	0.6720	58.03	0.7340	2	H
11	C	Hungary	0.7423	0.5507	0.7041	0.6602	63.05	0.7694	2	H
12	C	Greece	0.4484	0.4405	0.8673	0.5554	62.05	0.5498	2	H
13	C	Bulgaria	0.5244	0.5419	0.5765	0.5472		0.6778	2	UM
14	C	Russian Federation	0.3814	0.6211	0.5918	0.5195	66.81	0.5316	3	UM
15	C	Croatia	0.3918	0.4097	0.6684	0.4752	54.98	0.5970	2	H
16	C	Romania	0.3363	0.5198	0.5663	0.4626	64.78	0.6154	2	UM
17	C	Montenegro	0.3855	0.3612	0.5816	0.4327		0.6608	1	UM
18	C	Georgia	0.3478	0.3524	0.4082	0.3685		0.5353	1	LM
19	C	Serbia	0.2813	0.3656	0.4439	0.3574	51.35	0.6045	2	UM
20	C	Armenia	0.1907	0.3833	0.2806	0.2737		0.7259	1	UM
21	C	Ukraine	0.3698	0.1938	0.2602	0.2652	48.05	0.8378	1	LM
22	C	Kazakhstan	0.0361	0.4537	0.5102	0.2030		0.4188	3	UM
23	C	Bosnia and Herzegovina	0.0561	0.0925	0.3469	0.1216		0.4811	2	UM
24	C	Moldova	0.2713	0.1806	0.0000	0.0000		0.7426	1	LM
25	C	Mongolia	0.3117	0.0000	0.2092	0.0000		0.7180	1	LM
26	C	Albania	0.0000	0.2203	0.4337	0.0000		0.4316	2	UM

* - The five largest values for each indicator are indicated in red, and the five smallest in blue.

** - "1" - higher than developmental expectations,

"2" – corresponds to developmental expectations,

"3" - lower than developmental expectations.

*** - "H" - High income, "UM" - Upper-middle income, "LM" – Low-middle income, "L" - Low income.

Source: own research.

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

The measure of validity of using the specified integral indicator (Ni) was proved by the close connection between this indicator and the values of the most innovative countries' rating according to Bloomberg (2019) using Spearman's rank correlation coefficient in 60 countries.

For further in-depth analysis of both the aggregate countries and individual clusters, the available information is supplemented by other supporting data from the Global Innovation Index (2019):

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

According to the TNIS taxonomy, Ukraine belongs to the cluster "Developed countries with strong informal institutions, including the post-Soviet type", which includes another 25 countries (*Table 2*). Traditionally interpreted by the World Bank, they are comparable to economically developed and innovative countries (Italy, Spain, etc.), and to middle-income countries, as well as to countries with lower-middle-class development and weak innovation systems (Georgia, Armenia, etc.).

In order to increase the validity of the results of innovative development simulation, the division of individual countries into leaders and outsiders, both globally and in each type of TNIS, is of particular interest. It is the understanding of the complete picture of what is going on that will allow evaluating correctly the current state of NIS and choosing the vector of further development – world- or cluster- oriented.

So, by the overall rating, Ukraine ranks 66th out of the 136 countries analysed. Its middle position is driven not so much by its achievements but by its presence in the ranking table of other deliberately weaker countries. Against the background of the countries in its cluster, Ukraine looks less efficient - it is stated among the bottom six of the list from 26 countries.

Moreover, Ukraine, being in the same cluster with countries such as Spain, Czech Republic, Italy, which are close to developed countries with predominantly inclusive institutions, not only occupies one of the last places, but is also inferior to many developing countries with mixed extractive-inclusive institutions with a strong socio-cultural component (predominantly Muslim and Buddhist-Hindu types) and even a number of countries with predominantly extractive-type institutions (such as Mexico, Turkey, Costa Rica, Vietnam, Argentina) (Kravchenko, 2018).

Thus, two possible vectors of innovative development can be considered for Ukraine: either strengthening of position among countries of their own TNIS type (having similar specificity of development) or aspiration for world leaders (conditions and nature of development differ significantly). Obviously, in the second case, it will be necessary to mobilize much more resources and efforts, which is extremely difficult at the current stage of Ukraine's making.

It should be specially noted that the proposed simulation tool allows analysing already existing supranational formations and predicting the specific features of forming new ones. As a demonstration of a built neural network application, the paper characterizes several supranational associations / alliances:

- The European Union (EU) is an international formation of 28 European states that combines the features of inter- and superpower, but legally it is neither. There are 500 million inhabitants in the EU (third place in the world), the share as a whole in world GDP, PPP in 2018 accounted for about 23% (second place in the world);

- Asia-Pacific Economic Cooperation – (APEC) – is included as the 21st economy of the Asia-Pacific region. The purpose of the countries' forum is to boost economic growth in the region and strengthen the Asia-Pacific trade community, as well as facilitate and liberalize investment. About 40% of the world's population resides in the participating countries, with a share of 53.34% in world GDP and PPPs (2018);

- a group of five countries: Brazil, Russia, India, China, South Africa - (BRICS). A share in world GDP, PPP (2018) – 32.68%;

- commonwealth of Independent States (CIS) is an international organization (international treaty) that regulates the relations of cooperation between some states that previously composed the USSR. About 286.5 million of the world's population live in the participating countries, the share of world GDP, PPP (2018) - 4.35%.

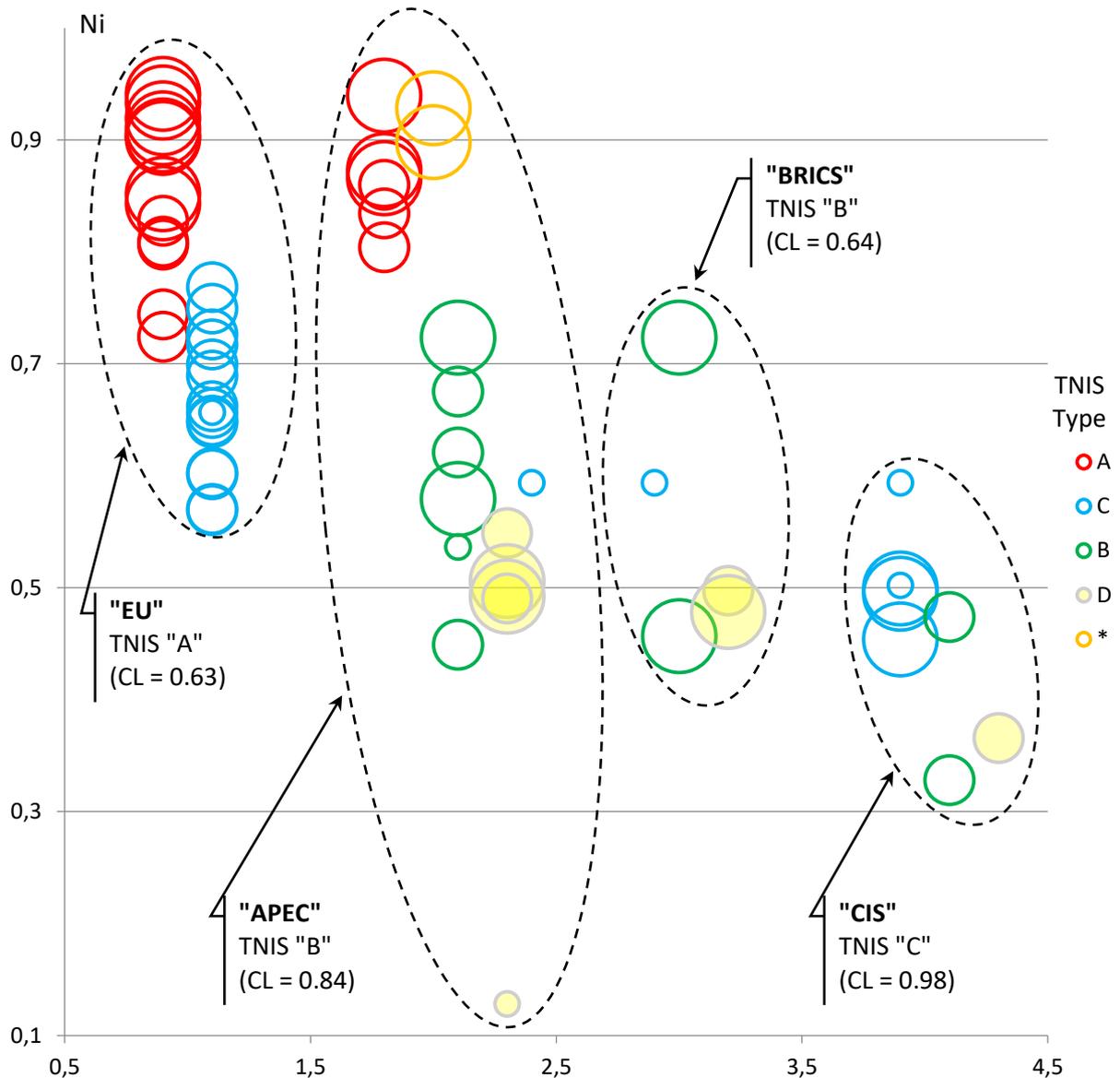
For this purpose, on the basis of the sampling data that was used for clustering, the averaged parameters of these associations' functioning (by 148 indicators) were formed and further identified by the neural network. The situation is shown in *Fig. 1*.

The results obtained can be summarized as follows:

- (a) All EU countries are quite successful in their innovative development, since the N_i integral is on average 0.75 and does not fall below 0.57, which is the most successful result among all the associations analysed. Almost all one hundred percent of countries have high productivity of innovation development - at the level of expectations and above (the number of the latter reaches 30%). The EU as a whole (trust level is 0.63) has A-type TNAs, that is, developed countries with predominantly inclusive institutions, even though just over half of the countries are C-type TNIS, i.e. developed countries and developing countries with mixed extractive-inclusive institutions with a strong informal component (including the post-Soviet type);

- APEC, represented by countries of all TNIS types, is, on the whole, less successful than the EU (N_i averages 0.67), with a variation of more than 0.13 in Guinea to 0.94 in the US. About 40% of the countries have innovative development productivity at the level of expectations and 45% at the level above expectations. A high-confidence neural network ($CL = 0.84$) is

recognized as an object with clear features of type B TNIS, that is, developing countries with mixed extractive-inclusive institutions with a strong socio-cultural component (predominantly Muslim and Buddhist-Hindu types);



CL is the neural network confidence level.

The diameter of the bubble is the productivity of innovative development: from "below the expected level" - small diameter, to "above the expected level" - large.

Figure 1. Results of neural network identification of individual countries' supranational entities ranked by integrated Ni index

Source: own research.

- BRICS is the smallest grouping of countries with an average N_i integral of 0.55 and the smallest variation. All countries except Russia meet or exceed an innovation performance level of expectations. With a valid level of confidence (CL = 0.63), the neural network recognizes this cluster as an object with clear features of type B "TNIS", that is, developing countries with mixed extractive-inclusive institutions with a strong socio-cultural component (predominantly Muslim and Buddhist-Hindu types). Obviously, this is due to the presence of economies such as India and China, which, together with South Africa (according to the GII), show innovation performance at a level higher than expected;

- the cluster of CIS countries is the least successful of the countries analysed (the integral indicator N_i is at the level of 0.46). About a third of countries have below-expected innovation performance. With a high level of confidence (CL = 0.98), the neural network recognizes it as an object with clear features of C-type TNIS, that is, developed and developing countries with mixed extractive-inclusive institutions with a strong informal component (incl. post-Soviet type).

5. Conclusions

The new regionalization of political gravity centres is of a cultural and technological character, leading to forming innovative ecosystems - transnational entities that do not necessarily occupy adjacent territories. Such an ecosystem can span several different regions of the world because it brings together people and territories that have historically shared values, socio-cultural traits and technical and technological standards. For example, Australia, located in the southern hemisphere of the Earth and occupying a separate continent, but as a result of colonization, culturally and technologically became part of the Western world – Western Europe and North America, although geographically i.e. is far removed from them. In this regard, in order to understand the characteristics of NIS development, the concept of the quadruple innovation helix, which encompasses not only science, industry and power, but also society, that is, evolutionary and socio-cultural aspects of development, is of fundamental importance.

In general, the proposed scientific and methodological approach is based on the hypotheses about:

- the expediency of simulating the national systems' development within transnational - basic or maternal - entities that go beyond the administrative boundaries of individual countries;
- the need to take into account the co-evolutionary relationship of science, production, power and society - the main elements of the helix.

The paper identifies four basic types of transnational innovation systems that have persistent characteristics, in some cases unique due to different circumstances (resource, spatial, historical, etc.) that determine the behaviour parameters and capabilities of the national innovation systems that are part of them.

The contours of each TNIS type are, of course, real, but extremely wide and flexible, allowing for an intersection with others and thus creating many versions for each national innovation system. In this regard, the motion vectors of the NIS of an individual country, on the one hand, are diverse and, on the other, may be substantially restricted by the features of the specific type of TNIS to which it belongs. This fact should be taken into account when developing specific national strategies based on the activation of innovative activities.

An effective toolkit is proposed – a neural network, the use of which greatly simplifies the process of simulating the development of NIS within the characteristic features of the basic TNIS development and increases the degree of strategic decisions' validity.

It is established that the national innovation system of Ukraine belongs to the basic type of TNIS - "developed and developing countries with mixed extractive-inclusive institutions with a strong informal component (including the post-Soviet type)". The results of its functioning against the background of global and relevant cluster leaders are not satisfactory, which necessitates the adjustment of its further development vector.

As a demonstration of the built neural network capabilities, four supranational associations / unions have been identified and analysed. The relative effectiveness of the EU as a supranational entity against the background of APEC, BRICS, CIS was noted.

Characteristic features that distinguish the author's approach from those available are the combination of genetic algorithms and cluster analysis to obtain a representative sample of national innovation systems, different in economic development, geographical location and dominant institutions.

A limitation of the method is the need to attract "big data" for analysis, as well as blurred moving boundaries between different types of TNIS, which are unstable in the long run. That is why it is proposed to perform further identification and allocation of specific national innovation systems among the identified basic types on the basis of neural network simulation. The obtained network model is able to accumulate experimental knowledge, learn from them and with high quality to assign new objects of analysis to the relevant clusters.

The practical significance of the proposed results (typology of supranational innovation systems based on the concept of quadruple helix and neural networks) lies in the possibility of carrying out variant analytical and predictive studies in the part of justification of the optimal directions of further development of individual NIS in the context of global and cluster trends.

References

Asheim, B. T., Gertler, M. S. (2009). The Geography of Innovation: Regional systems of innovation. *The Oxford Handbook of Innovation*. <https://doi.org/10.1093/oxfordhb/9780199286805.003.0011>

- Balzat, M. & Pyka, A. (2006). Mapping national innovation systems in the OECD area. *International Journal of Technology and Globalisation*, 2(1-2), 158-176.
- Blinz, C. & Truffer, B. (2017). Global Innovation Systems – A conceptual framework for innovation dynamics in transnational contexts. *Research Policy*, 46(7), 1284-1298. <https://doi.org/10.1016/j.respol.2017.05.012>
- Bloomberg. (2019). *These Are the World's Most Innovative Countries*. Retrieved from <https://www.bloomberg.com/news/articles/2019-01-22/germany-nearly-catches-korea-as-innovation-champ-u-s-rebounds>
- Carayannis, E., & Grigoroudis, E. (2016). Quadruple Innovation Helix and Smart Specialization: Knowledge Production and National Competitiveness. *Foresight and STI Governance*, 10(1), 31–42. <https://doi.org/10.17323/1995-459x.2016.1.31.42>
- Carlsson, B., & Jacobsson, S. (1997). In search of a useful technology policy – general lessons and key issues for policy makers. In B. Carlsson (Ed.), *Technological Systems and Industrial Dynamics. Economics of Science, Technology and Innovation* (Vol. 10), (pp. 299-315). Boston, MA: Springer. https://doi.org/10.1007/978-1-4615-6133-0_11
- Dalevska, N., Khobta, V., Kwilinski, A. & Kravchenko, S. (2019). A model for estimating social and economic indicators of sustainable development, *Entrepreneurship and Sustainability Issues*, 6(4), 1839-1860. [https://doi.org/10.9770/jesi.2019.6.4\(21\)](https://doi.org/10.9770/jesi.2019.6.4(21))
- 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. <https://doi.org/10.1016/j.techfore.2019.02.005>
- Freeman, C. (2004). Technological Infrastructure and International Competitiveness. *Industrial and Corporate Change*, 13(3), 541-569. <https://doi.org/10.1093/icc/13.3.541>
- Global Innovation Index*. (2019). INSEAD, WIPO. Retrieved from <https://www.globalinnovationindex.org>
- Godinho, M., Mendonça, S. & Pereira, T. (2005). Towards a taxonomy of innovation systems. *Working Papers Department of Economics*, 2005/13, 1-43. Retrieved from <https://depeco.iseg.ulisboa.pt/wp/wp132005.pdf>
- Human Development Index. (2018). *United Nations Development Programme*. Retrieved from: <http://hdr.undp.org/en>
- 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. Retrieved from https://www.academia.edu/2473274/Towards_a_Regional_Supra-national_Innovation_System_for_CARICOM_Countries
- Kravchenko, S. (2018). Nacional'naya innovacionnaya sistema Ukrainy v kontekste modeli „Quadruple Helix” [Ukraine's National Innovative System in the Context of the “Quadruple Helix”]. *Modern Economics*, 12, 112-119. [https://doi.org/10.31521/modecon.V12\(2018\)-17](https://doi.org/10.31521/modecon.V12(2018)-17) [in Russian].
- Kwilinski, A., Dalevska, N., Kravchenko, S., Hroznyi, I., Kovalenko, I. (2019a). Formation of the entrepreneurship model of e-business in the context of the introduction of information and communication technologies. *Journal of Entrepreneurship Education*, 22(SI1), 1528-2651-22-S1-337: 1-7. Retrieved from <https://www.abacademies.org/articles/Formation-of-the-entrepreneurship-model-of-e-business-1528-2651-22-S1-337.pdf>

- Kwilinski, A., Ruzhytskyi, I., Patlachuk, V., Patlachuk, O., & Kaminska, B. (2019b). Environmental Taxes as a Condition of Business Responsibility in the Conditions of Sustainable Development. *Journal of Legal, Ethical and Regulatory Issues*, 22(SI2) 1544-0044-22-SI-2-354: 1-6. Retrieved from <https://www.abacademies.org/articles/Environmental-taxes-as-a-condition-of-business-responsibility-in-the-conditions-of-sustainable-development-1544-0044-22-SI-2-354.pdf>
- Lundvall, B.-A. (2007). National Innovation Systems - Analytical Concept and Development Tool. *Industry and Innovation*, 14(1), 95-119. <https://doi.org/10.1080/13662710601130863>
- Malerba, F., (2006). Sectoral Systems: How and Why Innovation Differs Across Sectors. *The Oxford Handbook of Innovation*. Oxford: Oxford University Press. <https://doi.org/10.1093/oxfordhb/9780199286805.003.0014>
- Metcalf, S. (1988). The Diffusion of Innovations: An Interpretative Survey. In G. Dosi, C. Freeman, R. R. Nelson, L. Silvelberg, and L. Soete (Eds.), *Technology and Economic Theory* (pp. 560-589). London: Pinter.
- Paják, K., Kamińska, B., & Kvilinskyi, O. (2016). Modern trends of financial sector development under the virtual regionalization conditions. *Financial and Credit Activity: Problems of Theory and Practice*, 2(21), 204-217. <https://doi.org/10.18371/fcaptp.v2i21.91052>
- 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. <https://doi.org/10.1016/j.respol.2018.08.004>
- Saxenian, A. (1994). *Regional advantage: Culture and competition in Silicon Valley and route 128*. Cambridge, MA: Harvard University Press.
- Vishnevsky, V.P. & Knjazev, S.I. (2018). How to Increase the Readiness of Ukraine's Industry to Smart Transformations. *Science and Innovation*, 14(4), 55-69. <https://doi.org/10.15407/scin14.04.055>
- World Economic Forum. (2019). GCI Report. Retrieved from <https://www.weforum.org/reports>