Computer Cognitive Modeling of the Innovative System for the Exploration of the Regional Development Strategy*

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Abstract. The purpose of this research is to propose a methodology for cognitive modeling decision making and establishing a set of control actions to develop and strengthen the sustainability of the regional innovation system. The subject of the study is the functional interrelationships of the elements of the regional innovation system. The scientific hypothesis of the research is based on the need for a correlating synergetic interaction between the regional system of higher education and the innovation system of the region to stimulate and develop innovative activity and commercialize innovation. The novelty of the approach consists in applying the methodology of cognitive modeling, which allows modeling the consequences of decisions taken on the interaction of all factors of the regional innovation system: state, science and business at the regional level and lays the foundation for the effective use of higher education institutions potential in promoting opportunities for region development. The authors proposed a model for analyzing the relationship between the regional system of higher education and the regional innovation system and developed a cognitive map of their interrelationships based on scenario impulse modeling of possible development scenarios. The results of the study provide an opportunity to show a detailed and objective assessment of the interrelationship between the regional system of higher education and the regional innovation system, which has great potential in assessing the effectiveness and quality of innovative development of the regions for monitoring their investment prospects and public administration objectives.

Keywords: computer modeling, cognitive modeling, impulse modeling, decision-making, regional development, regional innovation system

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1 Introduction

According to the concept of regional innovation systems, the specific socio-economic conditions of the region have a decisive influence on its innovative development and the development of companies located in it. The territorial distribution of innovation, the presence of inter-sectoral differences and the power of the influence of various factors on the processes of innovative development of the regions attract a lot of attention and are studied in foreign and domestic scientific works to find potential mechanisms by which they can stimulate regional innovation activity and economic growth. The questions of determining the composition of factors, the methodology for measuring this influence and the development of tools are debatable. The present research is devoted to the substantiation of approaches to solving these problems.

The special individual characteristics of the region and the spatial proximity of certain factors of the regional innovation system contribute to the creation of innovations, the effect of the spillover effect and the "overflow" of knowledge in innovative systems which serves as a catalyst for their dissemination, the degree of involvement of regional structures in innovative processes stimulates the transfer of information, reduces costs and risks associated with innovations.

The problem of indicators search for modeling the innovative development of the region is relevant in the context of the need to build an innovative economy. The phenomenon of regional economic growth, the positive impact of academic institutions on it through the transfer of R&D results from universities to other factors in the regional innovation system and the emerging spillover effects have been actively discussed in foreign and domestic scientific papers for a long time [3, 14]. In general, a lot of attention is paid to domestic and foreign research in developing a criteria system for assessing the innovative development of regions and a set of indicators that make it possible to produce such an assessment.

Foreign researchers [1, 4, 5, 7, 8, 11] distinguish and analyze such economic factors as human capital, the existence of individual institutions, the activities of local authorities, the interaction between different factors, and others. Most studies are based on measurable indicators of the number of scientific personnel and patent activity as an indicator and measure of the level of effectiveness of innovation activity in the region.

Domestic research is mainly focused on the innovative development of the region through the HR component and education system, such aspects of the regionalization of innovation development as personnel support are singled out; social and environmental problems of innovation; innovative infrastructure development; predominantly regional character of small innovative entrepreneurship; social and legal issues of innovation activity regulation; quantitative and qualitative composition of employment [2].

Given the importance, complexity and multidimensionality of the interrelationships between the regional system of higher education and the regional innovation system, it is necessary to develop a system of effective measures, weighted management decisions with a view to building a strategy for innovative development of the region. In this case, it is possible to use the tools for researching problems and methods for providing conditions for the rational development of socio-economic systems, methods for system analysis of possible instruments and ways to achieve goals at different levels of the socio-economic system. Today, the most common tools for researching and modeling complex systems are various methods of mathematical linear programming for solving optimization problems; statistical regression methods for solving problems of identification of the object under study and forecasting its future states; cybernetic models for solving the problem of "input-output" type in management.

2 Theoretical Analysis

To assess the role of regional higher education system institutions in regional development, various models are used in foreign studies that allow a multilateral analysis of the contribution of universities to the socio-economic and innovative development of regions. Methods for analyzing the impact of universities on regional development and assessing their contribution to the socio-economic development of the region, depending on the indicators used, are divided into qualitative and quantitative, theoretical and empirical methods for investigating the university's interaction with other subjects of the region economy [14].

The influence degree of the universities activities on regional innovation development, as a rule, is estimated in the long run and by measurable indicators: the number of scientific personnel, the number of patents, the level of university developments sales to the direct amount of scientific development costs; the number of patents granted and dissertations defences; the number of scientific articles published annually; number of university graduates. The main aspect of the assessment is the significant relationship between the effects of university research and corporate patent activity [15].

In Russia, these models are applicable with significant limitations. Special methods for estimating and predicting irregular chaotic and quasiperiodic stationary time series generated by complex nonlinear systems, such as regional innovation systems, have not been sufficiently developed in Russian practice, including, due to the lack of specific data for analyzing the performance of the higher education system and the regional innovation system (for example, the specifics of procedures for patenting and the application of patent law). The general methodology for quantitative and qualitative assessment of the higher education effectiveness and the degree of its impact on the region innovative development, as well as the study of the relationship between the regional system of higher education and the regional innovation system has not yet been developed.

To explore such relationships, it is possible to use the cognitive approach which allows formulating and refining hypotheses about the functioning of the education system viewed as a complex, semistructured system that consists of separate but interconnected elements and subsystems. These approaches can complement methods for assessing the effectiveness of innovation activities in the regions in the field of research processes of regional innovation development in the Russian conditions.

In this work, the authors used the method of cognitive modeling to study the problems of complex systems and compiled a cognitive map for a semistructured system of interrelations between the regional system of higher education and the regional innovation system.

3 Research Methodologyate

3.1 Cognitive modeling

Under cognitive modeling, the authors mean solving a set of system tasks: identifying an object in the form of a cognitive model, analyzing ways and cycles of a cognitive map, impulse modeling (scenario analysis), analyzing the observability, stability, controllability, optimization, the problem of analyzing the characteristics of adaptivity, self-organization, decision making, structural analysis of systems (analysis of connectivity and complexity), analysis of the relationship between the structural properties of the system and the nature of the impulse processes. The solving possibility of these problems is supported by the software system of cognitive modeling [12].

When using the cognitive approach, it is necessary to compile a cognitive model for analyzing relationship between the regional system of higher education and the regional innovation system:

$$G = \langle V, E \rangle,$$

where G is the sign oriented graph (digraph) in which: V is the set of nodes $V_i \in V$, $i = 1, 2, \ldots, k$ are elements of researched system; E is the set of edges, where edges $e_{ij} \in E$, $i, j = 1, 2, \ldots, N$ reflect the relations between the nodes V_i and V_j (positive if the increase (decrease) of one factor leads to an increase (decrease) of the other, negative, when the increase (decrease) of one factor leads to a decrease (increase) in another factor) [9].

The set E can be represented in the form $E = E^+ \cup E^-$, in which E^+ is a subset of positive constraints, and E^- is a subset of negative constraints.

The exponent e_{ij} characterizes the direction and intensity (force) of the influence of the e_i factor on e_j.

$$e_{ij} = E(e_i, e_j)$$

where: e_{ij} is the norm indicator of the force influence of e_i concept on e_j. The estimate e_{ij} has the following properties:

1. The estimate e_{ij} is assigned in the interval from -1 to 1.
2. $e_{ij} = 1$, if e_i has the greatest positive effect on e_j.
3. $e_{ij} = 0$, in the absence of influence between e_i and e_j factors.
4. $e_{ij} = -1$, if e_i has the largest negative influence on the e_j factor.

Obviously, the education system and the innovation system are interconnected at the regional level. To construct the initial cognitive map, a model is constructed that reflects the current state of the education system and the regional innovation system and their impact on the region's innovative development.

3.2 Cognitive mapping

In the model under consideration [10], the variables recommended by the Ministry of Education will be used to assess the impact of the education system, including indicators of educational activities, scientific and innovative activities, human resource development, international activities, infrastructure, graduate employment and financial indicators.

In addition to the main factors, the subjects of regional innovation system interaction: the state (in the name of federal regulatory systems – node B1), business (providing the production of goods, works, services and the entire process of regional economy reproduction – node B2) and science (education system – node B3), on the innovative development of the region – the node B0 is influenced by the following groups of indicators.

The first group of indicators named "economic development of the region" (node B4) includes GRP per capita, investment in fixed assets per capita and consumer expenses per capita. This group depends on the investment from the federal regulatory systems and production, and influences innovative development of the region (node B0).

The second group of indicators "financial indicators of innovation activity" (node B5) is divided into internal costs for research and development (R&D), costs for technological innovation of enterprises and costs for radical innovation of enterprises.

The third group of indicators "innovative and industrial potential of the region" (node B6) unites innovative activity of enterprises, the share of innovative goods and services in the total volume of shipped goods and services, and the innovative attractiveness of the region.

The fourth group of indicators "intellectual potential of the region" (node B7) includes the advanced production technologies used, the number of patent applications, the number of personnel engaged in research and development, and directly related to the education system (node B3).

Risks group (node B8) include market risk which is determined by the probability of investment loss due to changes in supply and demand for innovative products; business or production risk which is expressed in mistakes of the innovation evaluation, the duration of the investment period, the selection and training of personnel engaged in research and development; financial risk associated with the depreciation of money and assets during the period of investment and commercial implementation of innovations, as well as the risk of lack of the necessary finance amount for investment. This group has a negative impact on the education system and the regional innovation system, so they need to be taken into account when building an innovative development strategy for the region.

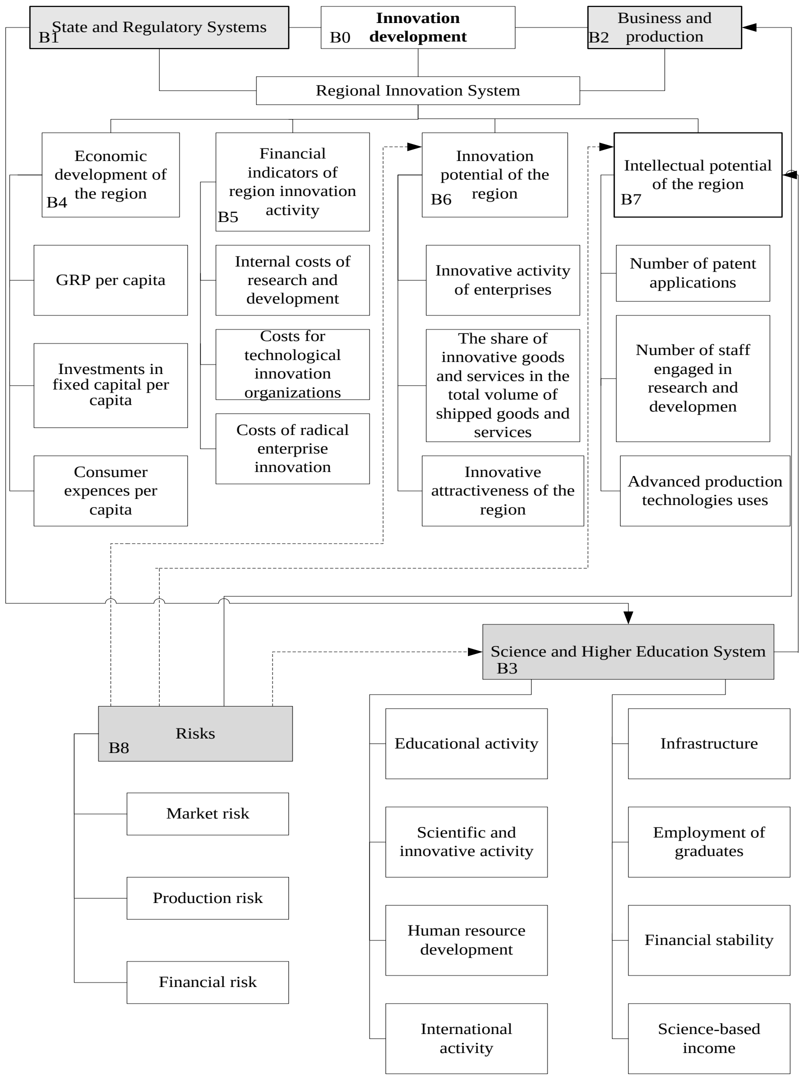

Fig. 1. Model of interrelation between higher education system and regional innovation system for building the region strategy of innovative development (G1)

An enlarged cognitive map of the interrelationship between the regional system of higher education and the regional innovation system for building the region strategy of innovative development is constructed.

The results of the analysis of such an "aggregated" cognitive model (G2) are easier to interpret without distorting the conclusions outlined above.

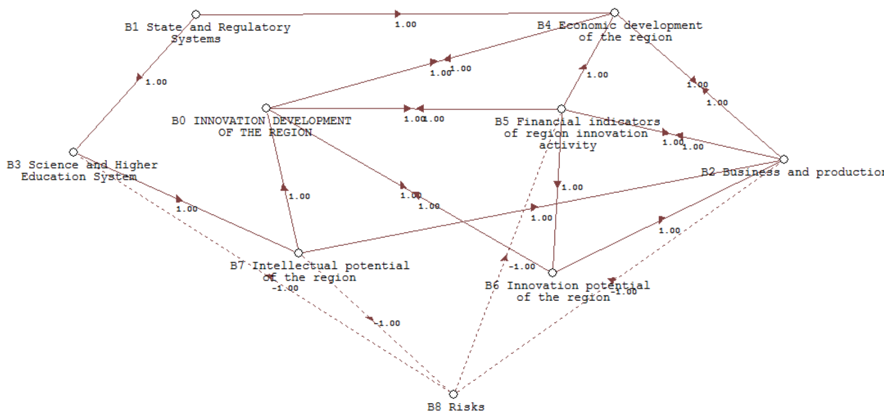

Fig. 2. Cognitive map (G2) of the interrelationship between the higher education system and the regional innovation system for building the strategy of innovative development

In this cognitive map (G2), all edges between nodes are positive and there are sixteen (even number) interconnected positive feedback cycles, which indicates the structural instability of this system. This model scenario and analysis of its variants can supplement the conclusions drawn and show possible ways of overcoming the indicated problems.

3.3 Interrelations Establishment between Factors

There are four blocks of factors affecting the innovative development of the region as a whole, allocated in this research. A heuristic meaning description of individual parameters and the relationships between them is presented below in the form of cognitive block models. The fact that there are causal relationships (or lack thereof) between the sources of risk factors – the nodes of cognitive maps, as well as the nature of the mutual influence of such nodes on each other – has been established by expert methodology.

Block 1: 1) Innovation development of the region; 2) Financial indicators of innovation activity; 3) Innovative-industrial potential (Fig. 3). Improving the financial performance of innovative activities $\xrightarrow{+}$ for innovation and industrial potential, there is an increase in the number of industrial innovations, a growing share of innovative goods and services in the total volume of goods and services shipped, which affects the innovative development of the region.

Block 2: 1) Innovation development of the region; 2) Economic development; 3) Financial indicators of innovation activity (Fig. 4). The increase in the fi-

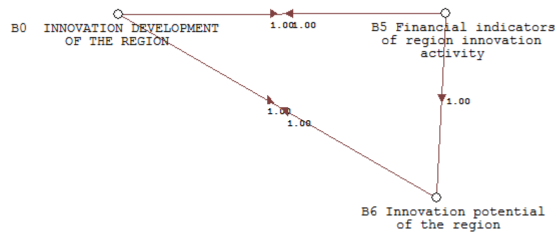

Fig. 3. Cognitive map of the innovation-industrial potential and financial indicators of innovative activity of the region innovation development

nancial indicators of innovation activity $\xrightarrow{+}$ for economic development, which causes the growth of investments in fixed capital per capita and consumer expenses per capita, creates favorable conditions for the innovation development of the region.

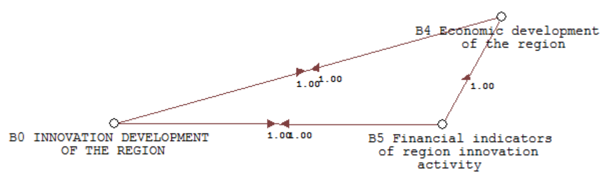

Fig. 4. Cognitive map of the impact of financial indicators of innovation and economic development on the innovation development of the region

Block 3: 1) Innovation development of the region; 2) Production; 3) Economic development; 4) Innovation-industrial potential (Fig. 5). The positive influence of the innovation and industrial potential $\xrightarrow{+}$ on the production of goods, works, services and the entire process of reproduction of the regional economy, combining the innovative activity of enterprises, the share of innovative goods and services in the total volume of goods and services shipped, increasing the region's innovative attractiveness.

Block 4: 1) Innovation development of the region; 2) Production; 3) Economic development; 4) Financial indicators of innovation activity (Fig. 6). The positive impact of financial indicators $\xrightarrow{+}$ on economic development leads to an increase in GRP per capita, investment in fixed capital per capita and increases consumer expenses per capita, which has a positive effect on the region's innovative attractiveness.

If you carefully review the chains and cycles of the cognitive map (G2) in Fig. 2, then it is possible to combine a number of indicators of the society and the higher education system state into larger blocks (Fig. 7). The results of the analysis of such an "enlarged" cognitive model (G3) are easier to illustrate without distorting the above-mentioned conclusions.

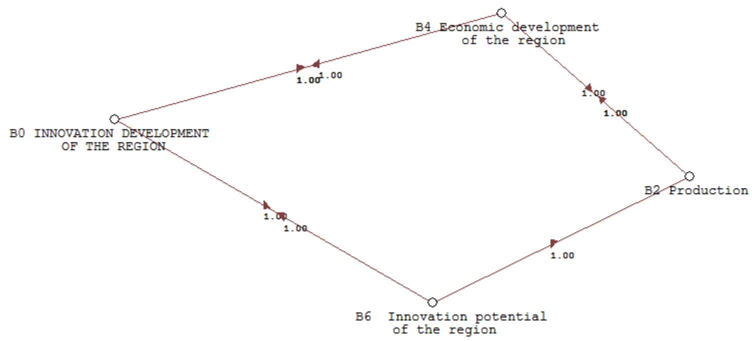

Fig. 5. Cognitive map of the influence of production, economic development and innovation-industrial potential on the innovation development of the region

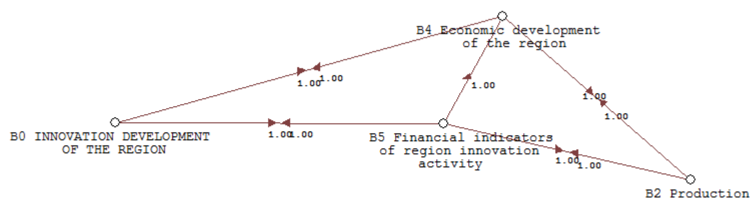

Fig. 6. Cognitive map of the impact of production, economic development and financial performance of innovative activities on the innovation development of the region

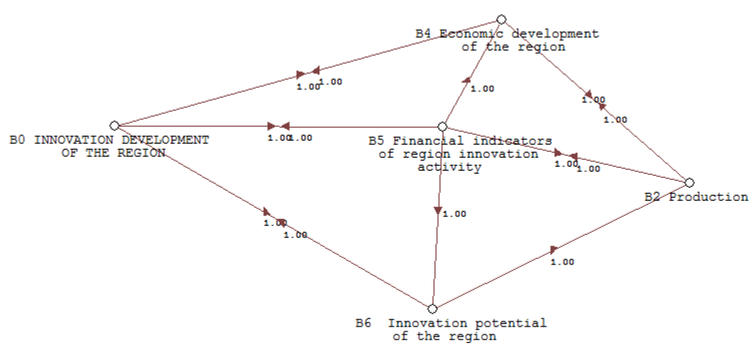

Fig. 7. The enlarged cognitive map (G3) of the interrelationship of the regional innovation system for building the strategy of innovative development of the region

The next stage of cognitive analysis operation is the scenarios construction for the development of situations based on impulse modeling, which will allow us to substantiate the main results of this study.

4 Impulse Modeling

Carrying out a computational experiment by impulse simulation requires preliminary planning which consists in identifying among the early cognitive maps the ones that will be managers, target and indicative. The chosen will be those nodes into which perturbing (control) impacts must be introduced; target will be those whose specified change is necessary to achieve; edges-indicators will be those that characterize the development of the economic processes of the model.

On the constructed cognitive map of the interrelation of the regional innovation system for building the strategy of innovation development of the region (Fig. 7), an impulse simulation of possible scenarios of the system development was carried out.

In our research we use the model of the impulse process, known in the theory of automatic control, proposed by F. Roberts [13] for modeling the behavior of complex systems identified by the graph, as well as used in [6], in the form (1):

$$x_i(n+1) = x_{vi}(n) + \sum_{j=1}^{k-1} f_{ij} P_j(n) + Q_i(n) \tag{1}$$

It should be noted that the impulse (control action) in the impulse process on cognitive maps during theoretical investigation is represented by an ordered sequence of values $x_i(n), x_i(n+1), \ldots$ in i nodes without time-bound, which may be given in interpreting the results of a computational experiment.

As a result of the computational experiment, it became possible to construct, in accordance with the experimental plan, 15 scenarios for the development of situations in the region – the modeling object obtained by successively introducing perturbations into one, two, three nodes of the cognitive map.

The number of simulation cycles was determined from the observation of the processes development trend until the changes in trends ceased to be observed, and their character became quite obvious.

There are examples of the three most characteristic scenarios of the system development (based on the factors of region sustainable development) and their analysis is given. These results give grounds to recommend the appropriate mechanism of decision making and set of control actions with the aim of enhancing the sustainability of the development of the regional innovation system.

4.1 Scenario 1

The impulse enters one node of the financial indicators of innovation activity (B5).

The growth of financial indicators of innovation activity after the third tact leads to an increase in production, economic development and innovative and industrial potential, and after $n > 5$, all factors rapidly grow (Fig. 8).

Results. The growth of financial indicators of innovation activity also affects production (B2), economic development (B4) and innovative and industrial potential of the region (B6).

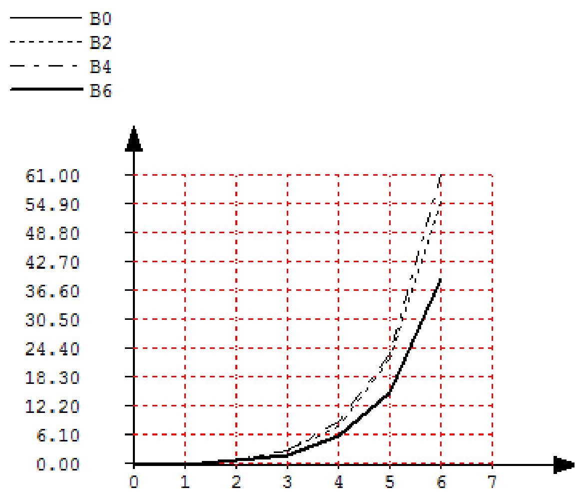

Fig. 8. Impulse processes in node financial indicators of region innovation activity (B5), $Q = \{q_1 = 0, 0, 0, +1, 0\}$

4.2 Scenario 2

The impulse arrives at two nodes. Growth of financial indicators of innovation activity (B5) +1 and −1 decrease in economic development (B4).

The increase in the growth of financial indicators of innovation activity due to the reduction of economic development also leads to positive results (Fig. 9).

Results. The growth of financial indicators of innovation activity due to the reduction of economic development leads to sustainable development of the region due to factors of production and innovative industrial potential.

4.3 Scenario 3

The impulse comes in two nodes. Growth of financial indicators of innovation activity (B5) +1 and −1 decrease in innovation-industrial potential (B6).

The growth of financial indicators of innovation activity, with a decrease in innovation – industrial potential, entails multidirectional impacts at the first stages of the simulation. At $n > 2$, a sharp decrease in all indicators is observed (Fig. 10).

Results. The reduction of innovation-industrial potential negatively affects the innovation development of the region.

5 Conclusion

In order to find the most effective management tools and tools for interaction between the regional higher education system and the regional innovation system, it is possible to analyze their mutual influence through cognitive analysis.

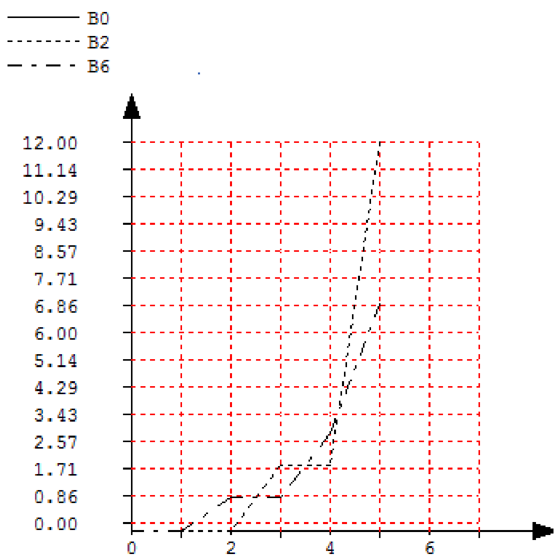

Fig. 9. Impulse processes in two nodes: financial indicators of region innovation activity (B5), economic development (B4) $Q = \{q_1 = 0, 0, -1, +1, 0\}$

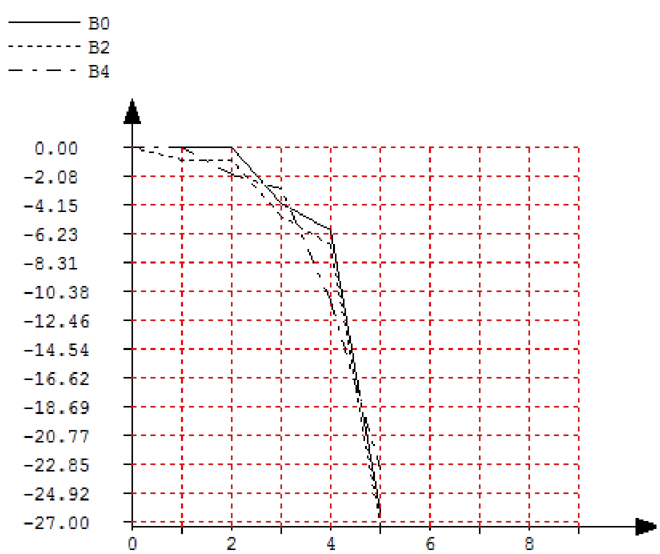

Fig. 10. Impulse processes in two nodes: financial indicators of region innovation activity (B5), innovation-industrial potential (B6) $Q = \{q_1 = 0, 0, 0, +1, -1\}$

Using impulse modeling on the basis of the cognitive model, the basic prerequisites of the concept of sustainable development on the influence of the higher education system and the regional innovation system for building the strategy of innovative development of the region were tested.

The innovative and industrial potential of the region unites innovative activity of enterprises; the share of innovative goods and services in the total volume of shipped goods and services, the innovative attractiveness of the region directly affects the innovative development of the region.

References

1. Arbo, P., Benneworth, P.: Understanding the regional contribution of higher education institutions. OECD Education Working Papers 9, Organisation for Economic Co-operation and Development (Jul 2007), http://www.oecd-ilibrary.org/education/understanding-the-regional-contribution-of-higher-education-institutions_161208155312
2. Asheim, B., Boschma, R., Cooke, P.: Constructing regional advantage: Platform policies based on related variety and differentiated knowledge bases. Regional Studies 45(7), 893–904 (2011)
3. Autant-Bernard, C.: Science and knowledge flows: evidence from the French case. Research Policy 30(7), 1069–1078 (2001)
4. Benneworth, P.: The engaged university in practice? In: Benneworth, P. (ed.) University engagement with socially excluded communities, pp. 329–344. Springer (2012)
5. Broekel, T., Brenner, T.: Regional factors and innovativeness: an empirical analysis of four German industries. The Annals of Regional Science 47(1), 169–194 (2011)
6. Casti, J.L.: Connectivity, complexity, and catastrophe in large-scale systems. Wiley IIASA international series on applied systems analysis, John Wiley and Sons, Chichester – New York – Brisbane – Toronto (1979)
7. Doran, H.C., Lockwood, J.R.: Fitting value-added models. Journal of Educational and Behavioral Statistics 31(2), 205–230 (2006)
8. Etzkowitz, H., Leydesdorff, L.: The triple helix – university–industry–government relations: A laboratory for knowledge based economic development. EASST Review 14(1), 14–19 (1995)
9. Firsova, A., Makarova, E.: Cognitive modelling the impact of a regional system of higher education in the innovative development of the region. Izvestiya of Saratov University. New series. Series: Economics. Management. Law 15(4), 411–417 (2015)
10. Firsova, A., Makarova, E.: Factors affecting the innovative development of the region. Izvestiya of Saratov University. New series. Series: Economics. Management. Law 17(2), 141–147 (2017)
11. Goddard, J.B., Chatterton, R.: The response of universities to regional needs. European Journal of Education 35(4), 475–496 (2000)
12. Gorelova, G., Makarova, E.: Simulation of socio-economical system and high education system problem correlation by means of cognitive approach. Large-scale Systems Control 30.1, 431–452 (2010)
13. Roberts, F.: Graph theory and its applications to problems of society. Society for Industrial and Applied Mathematics, Philadelphia (1978)
14. Tödtling, F., Trippl, M.: One size fits all?: Towards a differentiated regional innovation policy approach. Research Policy 34(8), 1203–1219 (2005)
15. van Vught, F., Westerheijden, D.F.: Multidimensional ranking: a new transparency tool for higher education and research. Higher Education Management and Policy 22(3), 6–11 (2010)