

Olena Sergienko

*PhD in Economics, Associate Professor, National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine
orcid.org/0000-0002-9796-9218*

Maryna Tatar

*PhD in Economics, Associate Professor, National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine
orcid.org/0000-0002-1111-7103*

Oleksandr Bilotserkivskiy

*PhD in Technical, Associate Professor, National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine
orcid.org/0000-0003-4707-7964*

Valeria Baranova

*PhD in Economics, Associate Professor, Karazin Kharkiv National University, Kharkiv, Ukraine
orcid.org/0000-0002-8163-881X*

APPLIED ASPECTS OF PROACTIVE MODELING OF INNOVATIVE-INVESTMENT PROCESSES OF COMPLEX HIERARCHICAL SYSTEMS: ENTERPRISE–REGION–STATE

***Abstract.** The paper proposed a proactive mechanism of innovative activity management of complex hierarchical systems (CHS), consisting of successive stages of assessment, analysis, planning, forecasting and innovative activities regulation at the levels of an enterprise - a region – the state. Specific tasks of the proposed mechanism require model support, in connection with which the author has developed a set of models for the proactive innovation management SYSTEM. The valuation models and analysis of the innovation capacity and innovation outcomes of socio-economic system of a region (SESR), which allow, in contrast to the existing models, to compare the results of innovation activities and innovation potential and to make a conclusion about the effectiveness of the existing potentia use are built. The model of evaluation of innovative projects of business-industrial structures (BIS) efficiency based on the use of fuzzy set theory and methods of multicriteria problems solution, which allow to consider the risks arising at each stage of the innovation life cycle. The set of models of economic evaluation of SESR innovative activities based on panel data, which allows to estimate the resource use efficiency in the implementation of innovative activities and to predict the consequences of managerial decisions on stimulation of innovative activities is proposed. The simulation model scenarios of stimulation of SESR innovative activity, which allowed the simulation of scenarios to stimulate and assess their performance in order to select the best scenario of innovation regional systems according to the criteria of profit maximization, maximizing the number of innovative-active BIS and maximize the gains integrated assessment of SESR innovative activity results are designed. The simulation results allowed to determine the best scenario for promoting regional systems and the state as a whole.*

Introduction.

While implementing reformation and European integration processes in Ukraine, taking into account the rapid development of the information society, the formation of innovative economy and innovative development where the role of the state is a key one, acquire special importance. The government should ensure the transition to the innovative model of development based on the use of SIFferent means of innovative processes stimulation at all levels of management. One of the most important factors that influences the acceleration of innovative processes development in the country, is a budget support of innovation at all levels.

Limited sources of innovative projects financing with own funds business-industrial structures (BIS) and with the help of domestic or foreign investors can lead to the disproportionate development of some industries compared to others, less profitable, but strategically important state industries. However, the activation of innovation activity (IA) will accelerate the development of high-priority industries, lead to an increase in the number of innovation-active BIS, the growth of profit due to the implementation of innovative activities, which in turn will affect the improvement of life quality and will meet the population needs. The issues of activation of innovation activity management at the level of regional systems are of a special importance. The socio-economic system of the region (SESR) as a territorial unit is characterized by definite managerial and financial resources and a certain innovative potential of business entities located on the territory of a regional system. The role of the state is to support management influence on innovation activities of BIS, taking into account the industrial sector they operate in to ensure the promotion of innovation development of SESR in Ukraine.

The purpose of the study is development a set of models for managing innovation activity of complex hierarchical systems (IACHS) based on existing potential, goals and results of innovation, which will accelerate the development of particular business structures, economies of regional systems and countries to improve the quality of life. To achieve this goal, the following tasks were set:

1. To analyze the development of innovation in Ukraine and the problems of its management.
2. To develop a mechanism for managing the innovation of complex hierarchical systems.
3. To build models to stimulate innovation of regional systems and business-industrial structures.
4. To improve models for assessing the innovation potential of regional systems, business-industrial structures and the results of their innovation activities.
5. To improve models for evaluating the effectiveness of innovative projects.
6. To build models for assessing the economic efficiency of innovation in regional systems.
7. To develop a model of innovative activity of business-industrial structures of regional systems.
8. To develop a simulation model of realization of innovative activity stimulation of complex hierarchical systems and to define the best scenarios of stimulation.

1. Theoretical and methodological base of research of innovative activity management problems in Ukraine

Among the researches in the scientific literature there is a significant part which deals with various aspects of functioning of innovative activity management system at the level of business-industrial structures and approaches to its modeling.

Also, most of the researches are focused on dealing with the issues of national and regional innovation management. At the level of regional innovative activity management the study is mainly related to the definition of the innovation strategy of regional systems or the development of innovation infrastructure of regions and interregional comparison of innovation performance of regional systems based on the use of integrated indicators.

The authors [1-4] focus on the "production capabilities" component and form a set of indicators of a region industrial potential estimatio. Particular attention of other researchers [5] is paid to labour and capital resources for the implementation of innovation. Therefore, the set of indicators mainly consists of those that characterize the cost of labor and capital.

The authors [6-9] propose to evaluate the following components of a region potential: scientific and technical, innovative potential, resources and results, each of which is determined by many parameters.

A special attention should be paid to the consideration of many issues relating to innovation activity and innovation policy in the current legislation of Ukraine, in particular in normative legal acts [10-17].

However, the issues of forming an effective mechanism for managing innovation at the level of regional systems and model support of such a mechanism remain out of consideration. Existing approaches to innovation management do not take into account the individual characteristics of regional innovation development and are insufficiently substantiated. Problems of innovation management of complex hierarchical systems require a comprehensive, systematic solution due to the complexity of innovation processes, individual characteristics of each regional system and business-industrial structures engaged in innovation, operating in conditions of uncertainty and the impact of many destabilizing factors, the need to take into account various conditions and criteria of management efficiency.

The complexity of the studied issues requires the use of new, modern mathematical methods and models that will assess the individual characteristics of innovative development of SESR in Ukraine and build a mechanism for managing innovation in each region, taking into account the sectoral focus of business structures, existing innovation potential, which will increase efficiency of regional systems innovation activities, increase the number of innovation-active structures, the volume of innovative products and profits from innovation.

As the research methods the following ones were used:

- theory of active systems to describe the innovation activities management system of a region socio-economic system ;
- cluster analysis to analyse regional systems according to the level of potential development and results of innovation activity;
- taxonomy method to determine the integrated indicators of potential and results of innovation activity of SESR and BIS;
- correlation-regression analysis to build models of dependence of innovation results on a potential;
- fuzzy set theory for risk assessment of an innovation project;
- method of panel data analysis for construction of econometric models of economic efficiency estimation from the realization of innovative activity of SESR;
- dynamic probabilistic model of the development of fast social and economic processes to design a model of innovative activity of BIS;
- method of system dynamics to build the simulation model of stimulation scenario of regional systems innovative activity ;
- method of simulation modeling of scenarios for the analysis of all possible ways of stimulation of regional systems innovative activity and choosing the best scenarios.

The calculations were performed using Microsoft Excel, Statistica, Eviews and Vensim.

2. The formation of a mechanism of innovation activity management in complex hierarchical systems

The statistical analysis of innovation processes in Ukraine conducted in recent years has allowed to ascertain the decline in innovation. In particular, the cost of innovation is increasing annually, but the share of business-industrial structures undertaking innovation activities decreases. This indicates the rising cost of labor, material and other resources for the implementation of innovative activities in the country, so not every company has the opportunity to implement new processes and upgrade their products. Among the reasons of this slow development of innovative processes in Ukraine it is necessary to highlight the low innovation activity of industrial enterprises, the absence of the state's stimulation of innovative activity of business entities, because the main sources of financing innovative activities of industrial enterprises (over 70%) are funds of enterprises, whereas the share of the state financing is about 2%. Also among the reasons for the slowdown of innovative development should also be mentioned the presence of disparities in regional funding of IA systems. So, the analysis indicates the necessity of improvement of state and regional innovation management mechanism, based on the use of interconnected, logically complete complex of economic and mathematical methods and models which will allow to increase the efficiency of IA management of SESR in Ukraine.

Fig. 1 shows the proposed mechanism of innovation activity management of complex hierarchical systems: an enterprise – a region – the state. The first block of the mechanism combines the problem of determining goals, objectives and implementation strategy of innovation activity of SESR. The second block is the unit of analysis of innovation activity – provides for the assessment of innovative potential of SESR and business-industrial structures, the results of their IA and assesses the compliance of results and capabilities. According to the set goals, objectives, chosen strategy, innovation potential analysis and ID results planning of IARS management is realized (block 3). Block 4 provides the assessment of the effects of IA implementation by regional authorities performing the following tasks: assessment of funded innovative projects effectiveness; assessment of economic efficiency of IARS and evaluation of the effect of BIS innovation activity. Block 5 provides a solution to the problem of making decisions on IARS management. Based on the formed set of management actions (block 3) and their forecasts (block 4) the simulation of control and possible IARS management scenarios are realized. Block 6 of the mechanism provides a solution of monitoring the results of IA implementation and regulation of IARS.

The complexity of the tasks of IARS management requires the use of a wide range of economic and mathematical methods and models. Therefore, modeling tools of support of the proposed mechanism of IARS management play a special role in ensuring the effectiveness of its operation. The complex of economic-mathematical methods and models that are interrelated, has consistently supported the implementation of blocks 2-5 of the constructed mechanism, and assess the results of various scenarios of regional systems innovative activity management, depending on the goals of the state. The problem of the mechanism of SESR innovation activity management requires an increased interaction with regional and state authorities as a single system [18, 19, 20]. Such a system of regional systems innovative activity management is considered as an active system of a certain type, within which the state authorities are considered as the top-level element, the regional authorities – as the subjects of management of the second level and business and industrial structures as the active elements that interact with each other in the process of innovations implementation [21].

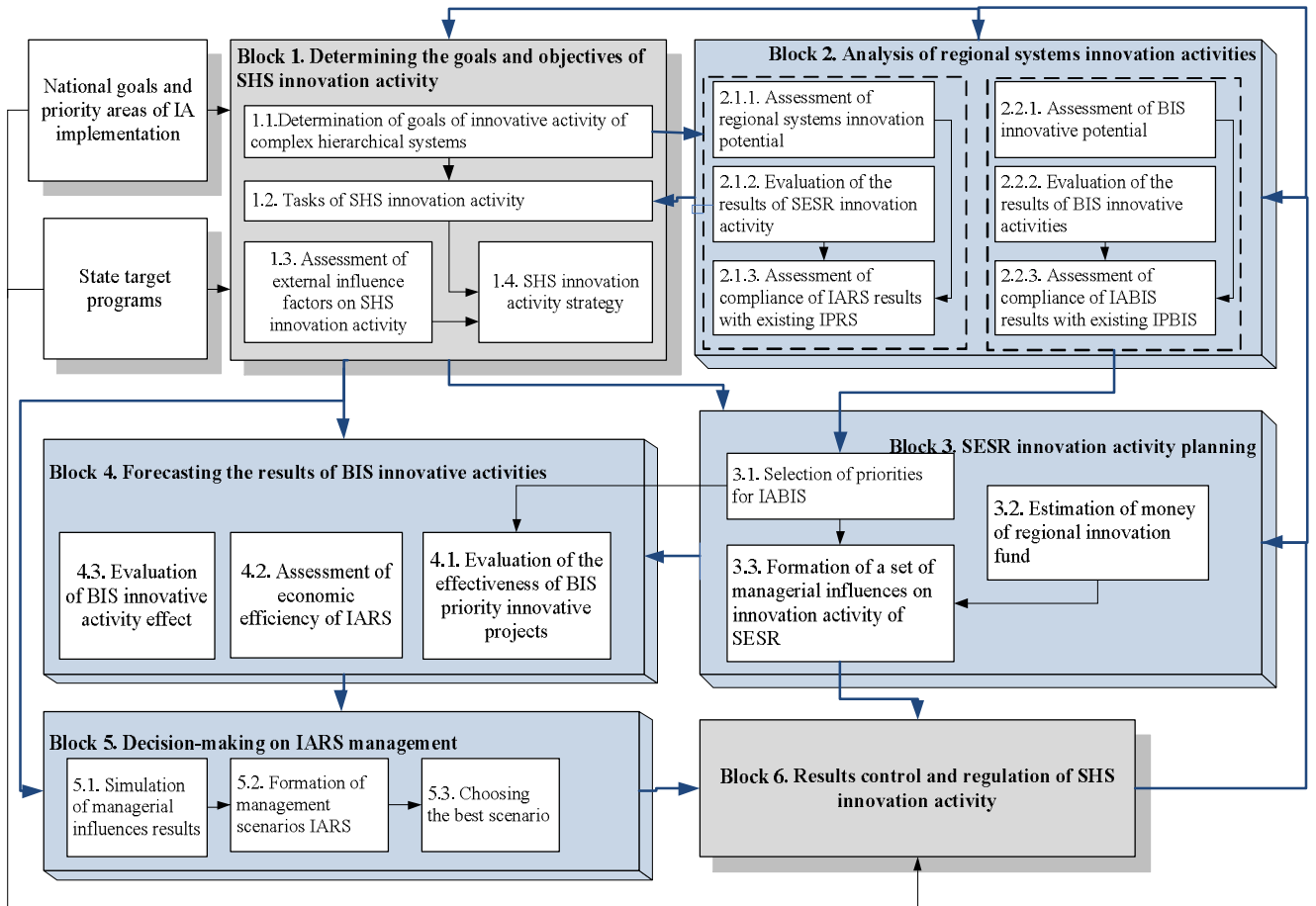


Fig. 1. SHS innovation management mechanism: enterprise - region - state

Financial impact, which finds its expression in the formation of an effective system of stimulation of SESR innovation activity granted by regional (national) innovation Funds is proposed to consider among the vast variety of managerial actions for the implementation of SESR innovation activity.

Using the theory of active systems [22-27] allowed us to build the nonlinear dynamic optimization models to stimulate innovation at the level of regional systems and the state, which take into account both regional features of innovation processes and features of innovation development of BIS and to optimize the distribution of funds to ensure a maximum profit from innovations.

The model of stimulating SESR innovative activity out of the proceeds of the State Innovation Fund (SIF) is as follows:

it is necessary to find the amount of funds allocated to stimulate the IA of the region

$$\sigma_k^t > 0, \quad (1)$$

where $k = 1, \dots, 25$, is that one maximizing the profit function:

$$\Phi^t = \sum_{k=1}^{25} H_k^t(\sigma_k^t, \Delta(\tau, t - \tau)) - \sum_{k=1}^{25} \sigma_k^t \rightarrow \max \quad (2)$$

and meet the conditions:

$$\left\{ \begin{array}{l} \sum_{k=1}^{25} \sigma'_k \leq \Theta^t, \\ \sum_{k=1}^{25} \sigma'_k \geq 0; \\ \Theta^t \geq 0. \end{array} \right. \quad (3)$$

$$\Theta^t = \Theta^{t-1} + \sum_{k=1}^{25} \alpha_k \cdot \Phi_k^{t-1}(\sigma_k^{t-1}) \quad (4)$$

where σ'_k – is the amount of funds aimed at stimulating innovation in the region in the t period, thousand UAH; Φ^t – is total income from innovation activities in the country in t period, thousand UAH; $H_k^t(\sigma_k^t, \Delta(\tau, t - \tau))$ – is an income of the region from the implementation of innovation activities in t period, thousand UAH; $\Delta(t - \tau, \tau)$ – is a function that takes into account the degree of uncertainty of the internal and external parameters; Θ^t – the amount of funds of the state innovation fund in t period, which is formed from the deductions from profits from the innovation activities implementation by k region in the previous period, thousand UAH, α_k – is a weighting factor that reflects the share of funds from the profit from the implementation of the IA of the region, which is transferred to SIF, and is determined by public administration bodies; $\Phi_k^{t-1}(\sigma_k^{t-1})$ – is a profit from innovation activities in the k region in $(t - 1)$ period, thousand UAH.

Therefore, for the effective functioning IARS management it is proposed to improve the mechanism of management of IARS due to the realization of the complex of economic-mathematical methods and models, based on the use of the theory of active systems and optimization techniques. As the management actions it is proposed to use the most effective financial actions. Also, as a part of the study the models for evaluation of innovative capacity, models for evaluation of SERS innovative results, models of dependence of regional systems innovation activity results on innovation potential have been built.

The model of estimation of innovative projects efficiency has been improved and models for assessing the economic efficiency of innovative activities have also been developed.

For the realization of block 2 of the control mechanism of IARS (Fig.1) the system of indicators that comprehensively characterize innovation potential and the results of regional systems innovative activities of business-industrial structures is proposed. Based on a set of indicators in dynamics for 2013-2019 cluster analysis of the regions of Ukraine, the results of which allowed us to distinguish three groups of regional systems in terms of development of innovation potential and the level of development of the innovative results according to high, medium and low levels has been carried out. For analysis of dynamics of innovative processes development in the regional system on the basis of taxonomy defined, the integral indicators of the level of innovative potential and level of SESR innovation, the results of which coincide with the results of clustering have been determined. This is the evidence of the uneven development of innovation activity of regional systems in Ukraine: the occurrence of several leading regions (Kyiv, Kharkiv, Dnipropetrovsk and Donetsk regions) that attract all the financial and intellectual resources when the outsider regions (Vinnytsia, Volyn, Zakarpattia regions) also need the support.

At the same time, the analysis allowed us to conclude that the results of the implementation of IA are directly proportional to the existing innovation potential of a regional system.

The use of correlation-regression analysis allowed to put forward and confirm the hypothesis that the results of SESR's innovation activity depend on the innovation potential: the results of the region's innovation activity in t period (R_t) are proposed to be considered as a consequence of using its innovation potential (P_{t-1}) accumulated by the end of the $(t-1)$ period, i.e. $R_t = f(P_{t-1})$. The hypothesis was tested and confirmed by designing a number of adequate econometric models according to the data of 2013-2019. So, for the last considered period the following dependence was got:

$$R_{2006} = \frac{1}{1 + e^{2.28 - 4.94 * P_{2005}}} \quad (5)$$

The criteria for evaluating the quality of the model confirm the assumptions about the type of relationship between the indicators (Student's criterion was and exceeded the critical value $t_{kp} = 1.71$, Fisher's criterion was $F = 1037.1$, that is more than critical value $F_{kp} = 4.27$, the coefficient of determination equal $R^2 = 0.975$ confirmed the adequacy of the model).

The evaluation of the results of SESR innovation activities (block 4, Fig. 1) begins with an assessment of the effectiveness of specific innovation projects (IP), for which a model that allows the selection of an innovation project as a result of solving a multi-criteria problem based on the previous estimation of IP effectiveness using methods of analysis of investment projects, risk assessment by stages of the life cycle of IP using expert assessment and fuzzy sets is proposed in the article. Thus, a set of priority IP that need funding is selected, and the implementation of which will allow BIS to obtain certain results from the implementation of innovative activities, and the set of such results of business-industrial structures in the region forms the results of IA regional systems.

For the performance of tasks of Block 4 a model of economic effectiveness evaluation of SESR innovation activity using panel data allowing to consider peculiarities of regional development of innovation infrastructure, innovation potential, sector of production, quality of training, and other factors affecting the final result of innovation activity is designed. Table 1 demonstrates the dependences of the volume of innovation products sold (r_{10}) on production factors, combinations of which are determined by the intersection of line (labour costs) and column (cost of capital), and the coefficients of determination value (R^2), which confirm the high quality of the constructed models.

High quality built dependencies allows to predict the economic efficiency of labor and financial resources used for innovation activities in a region. On the basis of the constructed models the indicators of economic efficiency of innovative activities on regional systems, namely average and marginal productivity of resources and the capital-labor ratio are identified. The lowest level of average productivity of manufacturing innovative products in the calculation ths UAH for one specialist performing scientific and technical work, is observed in Poltava region (179,89), the highest – in Zakarpattia (3870,93) and Volyn (1827,1) regions, the medium - in Sumy (794,86), Mykolaiv (729,33), Kyiv (581,54). High values of marginal productivity of innovative production manufacturing by specialists (ths.UAH per one additional specialist) are in Donetsk (495,87), Khmelnytskyi (453,15) and Volyn (376,35) regions; the lowest is in Ternopil (42,28), Kharkiv (39,99) and Kyiv (35,94) regions.

Table 1. Models of the volume of sold innovative products formation

Volume of sold innovative products (r_{10}) thousand UAH		Factors of financial costs	
		total expenditures on innovation activity (p_{25}), thousand UAH	financing of innovative activity at the expense of own funds, funds of the state budget, local budgets, domestic and foreign investors (p_{33-6}), thousand UAH
Factors of labor costs	number of employees of scientific organizations (p_8), persons	$r_{10t} = A_{0k}^{10} p_8^{0.34} p_{25}^{0.48} e_{kt}$ $R^2 = 0.911$	$r_{10t} = A_{0k}^{10} p_8^{0.47} p_{33-6}^{0.34} e_{kt}$ $R^2 = 0.902$
	the number of specialists who perform scientific and technical work (p_{10}), persons	$r_{10t} = A_{0k}^{10} p_{10}^{0.35} p_{25}^{0.48} e_{kt}$ $R^2 = 0.912$	$r_{10t} = A_{0k}^{10} p_{10}^{0.58} p_{33-6}^{0.28} e_{kt}$ $R^2 = 0.897$
	number of inventors, authors of industrial designs and innovation proposals (p_{29}), persons	$r_{10t} = A_{0k}^{10} p_{29}^{0.43} p_{25}^{0.47} e_{kt}$ $R^2 = 0.924$	$r_{10t} = A_{0k}^{10} p_{29}^{0.58} p_{33-6}^{0.33} e_{kt}$ $R^2 = 0.906$

Note: $A_{0k} = e^{a_0 + a_{0k}}$ – effects that reflect both the general innovation climate in Ukraine (a_0), and the peculiarities of development and individual effects of innovation in regions (a_{0k}).

Zakarpattia region (10.81), Dnipropetrovsk region (4.13), Ternopil region (3.65) and Khmelnytsky region (3.48) are characterized by the largest marginal return on production of innovative products (thousand UAH of products per 1 thousand UAH of additional financing). Regions, with the lowest values are Kharkiv (0.55), Rivne (0.49), Cherkasy (0.28).

Using the method of panel data analysis also allowed to build a model of income generation from innovation (r_{21}) depending on the volume of sales of innovative products (r_{10}):

$$r_{21} = \mu_k^1 + 0.0155r_{10} + \varepsilon_{kt}. \quad (6)$$

Student's criterion for the constructed model was $t = 63.67$ and exceeded the critical value, $t_{kp} = 1.71$, the coefficient of determination $R^2 = 0.96$ confirmed the adequacy of the model, Darbin-Watson's criterion was $dW = 2.05$ and confirmed the absence of autocorrelation between the model residues.

Similarly, using panel data, the dependence of income on innovation (r_{21}) on the volume of scientific and technical work (r_1):

$$r_{21} = \mu_k^2 + 0.0057r_1 + \varepsilon_{kt}. \quad (7)$$

For the model (7) the Student's criterion was $t = 255.98$ and exceeded the critical value, $t_{kp} = 1.71$, the coefficient of determination was $R^2 = 0.91$ and confirmed the adequacy of the

model. The Darbin-Watson criterion is equal to $\epsilon dW = 1.91$, which confirms the absence of autocorrelation between the model residues

Variables μ_k^1, μ_k^2 explain individual effects that reflect the effectiveness of innovation and the overall innovation climate in the regions, ϵ_{kt} - errors in model construction.

The high quality of the built models confirms the possibility of using them to assess the effectiveness of innovation processes in regional systems. Analysis of the results and features of the panel data models allowed to make a conclusion about the low level of efficiency in most regions of Ukraine, which indicates the need to improve the management of IA, namely the importance of stimulating innovation in each SESR.

The study builds a model of innovative activity of regional systems BIS. The simulation model of scenarios realization of regional systems innovative activity stimulation has been developed. Scenarios of innovative activity stimulation have been formed and forecast values of economic result from their realization are received. The best incentive scenarios have been identified.

To forecast the effect of the spread of innovations in the system of the region (block 4, Fig. 1), a model of innovation activity of BIS in a region as a probabilistic process of spreading innovations between enterprises as a result of their interaction is proposed.

The basic system of equations of the constructed model has the form:

$$\begin{cases} \Delta S(t) = \left[-6.67 \cdot 10^{-6} \sigma_t + R(t) \left(\beta(t) + 1 - (1 - p_1)^{r \frac{I(t)}{N(t)-1}} \right) \right] \Delta t + \xi^S, \\ \Delta I(t) = \left[13.34 \cdot 10^{-6} \sigma_t + q \times R(t) - \gamma(t) \cdot I(t) \right] \Delta t + \xi^I, \\ \Delta R(t) = \left[\gamma(t) \cdot I(t) - 6.67 \cdot 10^{-6} \sigma_t - R(t) \left(q - \beta(t) + 1 - (1 - p_1)^{r \frac{I(t)}{N(t)-1}} \right) \right] \Delta t + \xi^R. \end{cases} \quad (8)$$

where $S(t)$ - is the number of enterprises of one region that is receptive to innovation (ERI) in the period t , - units $I(t)$ - is the number of innovation-active enterprises of the region (IAE) that are distributors of innovation units; $R(t)$ - is the number of enterprises that are not receptive to innovation (ENRI) in the region, units σ_t - is the amount of funds aimed at stimulating innovation activity in the region, thousands UAH.; $N(t)$ - is the total number of enterprises in the region under the study, units; $\beta(t)$ - is a share of ENRI that restore susceptibility to innovations; $\gamma(t)$ - is - the share of the IAE, temporarily immune to innovation;; q - is a share of ENRI that go into the IAE due to internal changes; p_1 - the probability of innovation SIFfusion, ξ - possible random obstacles in a closed system (the emergence of a new IAP, IAE, or ENRI to the input interference, the elimination of ENRI for output interference).

The designed models of evaluation of innovative potential and the results of innovative activities of business- industrial structures in Kharkiv region (block 2, Fig. 1) as the result of using the methods of taxonomy and cluster analysis provide an opportunity to determine the groups of BIS: IAE, ENRI. On the basis of such classification the intensity of the transitions of business structures from class to class and the probability of innovation fusion (p_1) was determined as intensity of changes of BIS grade.

Model of effect of innovative activity of business-industrial structures was built using the

method of panel data analysis [28, 29], describing the dependence of income on innovation activities (r_{21}) of the total number of innovative enterprises ($I(t)$):

$$r_{21} = \mu_k^3 + 70.614 \cdot I(t) + \varepsilon_{kt}, \quad (9)$$

where μ_k^3 - is individual effects of innovative activities in the region, ε_{it} - is accuracy of the model.

The student's criterion for the model (9) was $t = 27.24$, that is more than the critical value, $t_{kp} = 1.71$, the coefficient of determination was $R^2 = 0.95$ and confirmed the adequacy of the model, the criterion of Durbin-Watson amounted to $dW = 2.1$, which indicates the absence of autocorrelation between the model residues.

3. Simulation of scenarios to identify possible options for stimulating innovation in regional systems

The proposed models for evaluating and analyzing the effectiveness of IARS (1) - (9) became the basis for developing a simulation model for implementing scenarios to stimulate innovation activity of regional systems for decision-making on IARS management (block 5, Fig. 1), consisting of three blocks: formation of state innovation fund, modeling of innovative activity of BIS and evaluation of results of stimulation of regional systems innovative activity (Fig. 2). Blocks 2 and 3 are repeated in the model, according to the number of Ukraine regions, so the simulation model contains 807 variables.

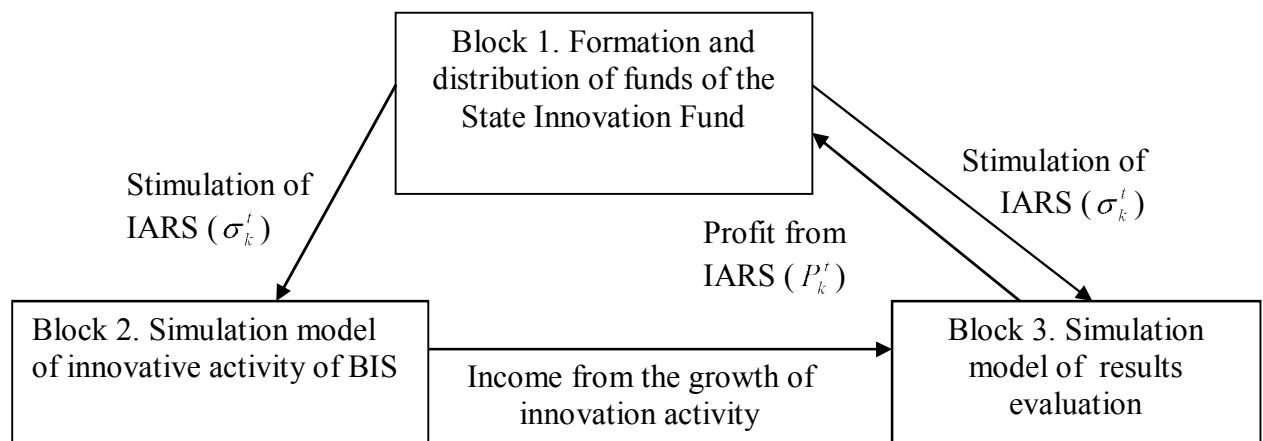


Fig. 2. Scheme of the simulation model of SESR stimulating innovation activity

Along with equations (1)-(9) and functional dependencies, which are given in Table. 1, the main equations of the simulation model are the income functions of k - region, which have the form:

$$H_k^t(\sigma_k^t, \Delta(\tau, t - \tau)) = \frac{\sigma_k^t}{3} [0.0155M_{10,33-6} + 0.0057M_{1,33-6} + 0.00047] + (\mu_k^1 + \mu_k^2 + \mu_k^3 + 2015.606) / 3, \quad (10)$$

where $k = 1, \dots, 25$, $H_k^t(\sigma_k^t, \Delta(\tau, t - \tau))$ – is an income of k – region from the implementation of innovative activities in t – period, thousands UAH; σ_k^t – amounts of SIF funds aimed at stimulating IARS, thousand UAH; $M_{10,33-6} = A_{0t}^{10} \cdot 0.33 \cdot p_{29}^{0.58} (\sigma^t)^{-0.67}$ – marginal productivity of manufacturing innovative products, thousand UAH per 1 thousand UAH; $M_{1,33-6} = A_{0t}^1 \cdot 0.09 \cdot p_{10}^{1.07} (\sigma^t)^{-0.81}$ – marginal productivity of scientific and technical works, thousand UAH per 1 thousand UAH; p_{10} – the number of specialists who perform scientific and technical work, persons; p_{29} – the number of inventors, authors of industrial designs and innovation proposals, persons.

Based on the simulation model, 23 scenarios of IA stimulation for 10 years were modeled depending on the share of deductions from the profit of regional systems got from the implementation of IA to SIF, as well as the method of distribution of SIF funds according to the class of a region and ID development implementation. Combinations of parameters allowed to devise scenarios of IARS stimulation on three groups: according to the available FE and results of IA of regional systems; in accordance with the productivity of scientific and technical work in the regions; in accordance with the productivity of innovative products.

Criteria for selecting the best scenarios depending on the goals of innovation were: maximizing profits from innovation, maximizing the number of IAP regional systems and maximizing the integrated assessment of SESR innovation activity results. The results of the best scenarios of IARS stimulation by SIFferent criteria are presented in Table 2. According to the criterion of profit maximization, the best scenario is to stimulate the acceleration of innovative development of SESR in accordance with the productivity of scientific and technical work (profit amounted to 12.12 bln UAH). According to the criterion of maximizing the growth of innovation results, the most effective scenario of IARS stimulation is proportional to IPR during the whole period (Fig. 3), according to which the increase of integrated assessment of IARS results was 3.56%.

Table 2. The results of the most effective scenarios of IARS stimulation on three criteria

Indicators / scenarios	Scenario of stimulation according to productivity of scientific and technical works performance (acceleration of innovative development)	The incentive scenario proportional to the IPR throughout the period	Scenario of stimulation according to FE (scenario of equalization of innovative development of regions)
Profit from the implementation of the IA, UAH billion	12,120	12,005	11,275
The increase in the number of IAP, pcs.	56	58	65
Increase in integrated assessment of IARS results, %	-3,59	3,56	1,48

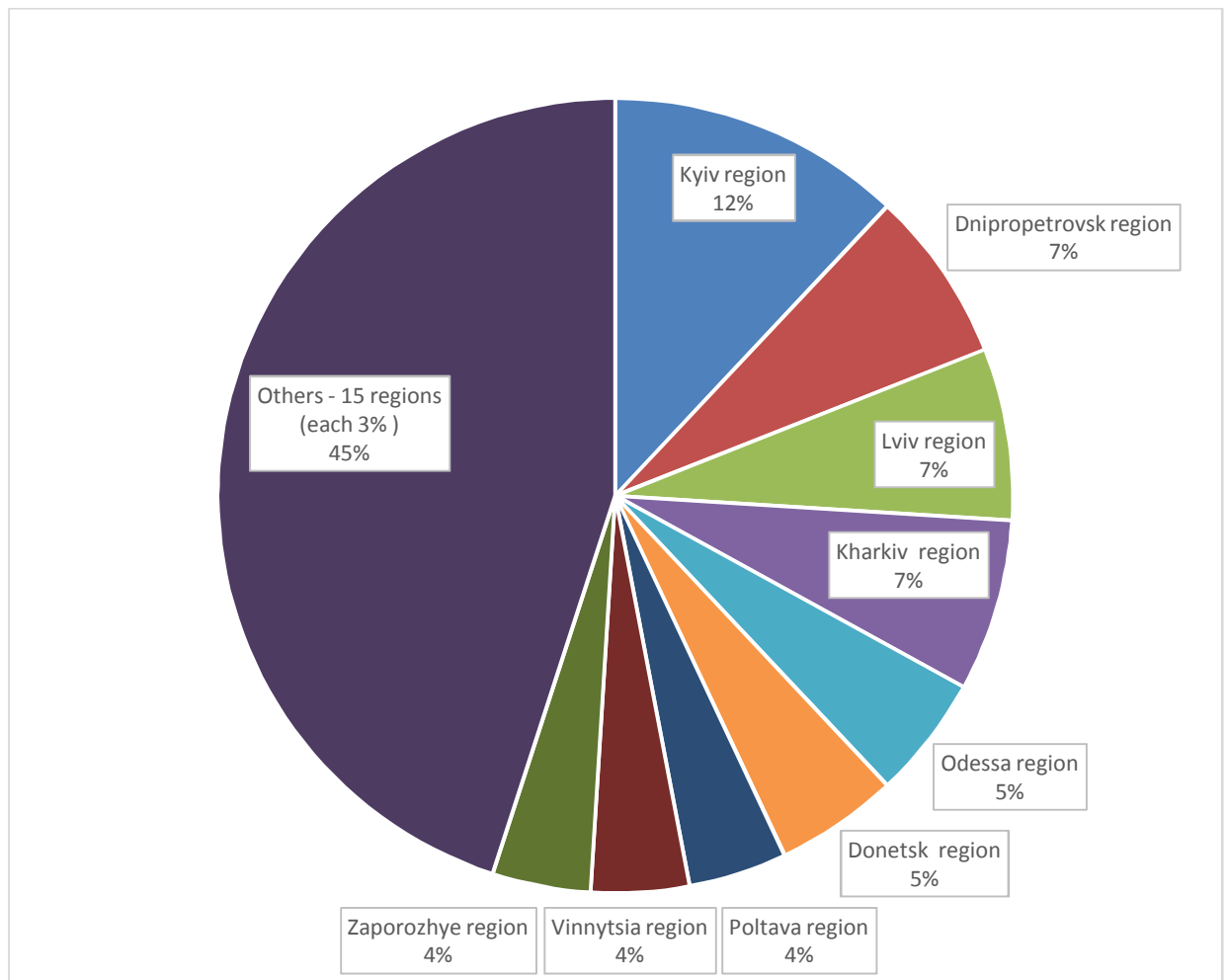


Fig. 3. Chart of distribution of SIF funds according to the best stimulus scenario according to the criterion of growth of innovation activity results

According to the criterion of maximizing the number of IAPs, the best scenario is the stimulus scenario in accordance with the available innovation potential (scenario of equalization of innovative development of SESR) (IAP increase was 65 units). The simulation results also identified the most effective incentive scenarios for selected classes of regional systems. For regions with a low potential and IA results (for example, Sumy region), the most effective scenario is the equalization of innovative development in the allocation of funds in accordance with the innovation potential and with differentiated shares of contributions to SIF. For regions with a medium innovation potential and results of innovation activity (Zaporizhzhya region) the best scenario is the acceleration of innovative development with funds allocated in accordance with the productivity of scientific and technical work in the regions with SIF differentiated shares of SIF contributions. For regions characterized by a high innovation potential and results of IA (Kharkiv region) the most attractive is the scenario of distribution of SIF funds in proportion to the accumulated innovation potential with a constant share of deductions from IA revenues.

Thus, the forecast values of economic results got from the implementation of scenarios for stimulating innovation in the regions have been obtained and the most effective in terms of the main management criteria have been identified.

Conclusions.

1. The analysis of innovative activity in Ukraine indicates the decline in innovation activity of enterprises, which is associated with the inefficiency of the administrative-organizational structure of management of science, technology and innovation activities, as well as priority financing of innovative activity of business-industrial structures at their own cost and expense. The results of the analysis of a condition of innovative processes management in the country confirmed the objective necessity of designing a complex of models of innovative activity management of regional systems.

2. The mechanism of innovative activity management of complex hierarchical systems: an enterprise – a region –the state, based on the application of complex economic-mathematical models, provides a solution to such basic tasks as: the analysis of existing innovative potential of the regional system; the analysis and selection of promising from the standpoint of innovation projects, business and industrial structures, evaluation of their effectiveness, the analysis of innovative activity of entrepreneurial structures in the region, forecasting of results of regional systems innovative activity, adoption of decisions on management of innovation and assessment of their effectiveness for each subsystem and the whole country.

3. A model of stimulation of innovative activity at the state level, which takes into account the regional peculiarities of the development of innovative processes and the level of development of its innovative potential is designed. The model is based on the review of the system of management of SESR innovative activity as an active system of a specific type, which stands on public administration as the top-level element, the regional administrations as the subjects of management of the second level, which interact in the process of implementing innovations.

4. The analysis of the innovative activities of the regional systems of Ukraine has allowed to propose a system of indicators that comprehensively characterizes innovation potential and results of SESR and BIS innovative activity and to design a model of their assessment using the method of taxonomy. For the comparative analysis of the innovation potential and results of its usage, a set of nonlinear econometric models, which allowed to conclude that the low use of capacity in most regions of Ukraine, indicating the need to stimulate innovation in the whole country has been developed.

5. To assess the efficiency of innovative projects the model based on the use of fuzzy set theory and methods of solving multicriteria problems, taking into account the risks inherent in a particular stage of the innovation life cycle is proposed.

6. To build models of economic evaluation of regional systems innovative activity the method of panel data analysis that takes into account the characteristics of regional innovation infrastructure development, innovative potential, the sectoral focus of production, quality of training, and other factors affecting the final result of innovation activities, and evaluate the effectiveness of the use of human and financial resources was used.

7. To assess the impact of state stimulation of innovation activities on the growth of the number of innovative-active business-industrial structures and the assessment of income from IA implementation, the model of innovative activity of enterprises, which takes into account the probabilistic nature of SIFfusion of innovation as a result of interaction of enterprises has been designed.

8. On the basis of the developed complex of models of estimation of IARS efficiency stimulation, the simulation model of implementation of the scenarios that stimulate IA from the funds of the CIF, which allows to evaluate the effectiveness of the ongoing management of IARS for the developed scenarios has been designed. On the results of the scenario analysis the predicted values of the results of their implementation have been obtained and the best scenarios of IARS stimulation according to the main criteria have been identified.

References

1. Gerasimchuk, SV, Kovalevskaya, LL. (2003). Productive Potential of the Region: Methodology of Evaluation and Mechanism of Building up: Monograph. Lutsk, 242.
2. Kobushko I.M., Guseynova E.I. (2003). (2011). Ways to improve financing of innovation development in Ukraine using international experience. *Marketing and Management of Innovations*, 2 (124), 124.
3. Martynenko V.F. (2013). State Management of Investment Process in Ukraine in the Context of Globalization of Economy. *Scientific Journal of the Academy of Municipal Management. Management" Series*, 4, 41-50.
4. Zabrodskaia L. (2015) Innovation priorities of scientific and technological development: international and regional aspects. *Theory and methods of educational management*, 2 (16)
5. Moskovkin V. M., Laktionov AA, Rakovskaya-Samoilova AH (2004). Methodology of Assessment of Integral Indicator of Innovation Activity of Regions of Ukraine with Implementation of EU Approaches. *Problems of Science*, 6, 7-14.
6. Tarasyuk M.V., Malyarchuk A.V. (2017). Current state of implementation of innovation policy of Ukraine and its financial support. *Economic science*, 1, 19-24.
7. Ten types of innovation. (2015). URL: <https://www.doblin.com/ten-types>
8. Yakovlev A. I. (2018). Analysis of innovation activity in Ukraine and ways to improve it. *Science and Science Studies*, 2 (100), 29-44.
9. Onegina V. Onegina V.M., Luneva V.A. (2015). Innovation potential of enterprises and state policy. *KNTUSG Bulletin: Economic sciences*, 161, 50-59.
10. On scientific and technical expertise: Law of Ukraine from February 10, 1995 N 51/95-VR / Verkhovna Rada of Ukraine. URL: <http://zakon.rada.gov.ua>
11. On scientific and scientific-technical activity: Law of Ukraine from November 26, 2015 № 848-VIII / Verkhovna Rada of Ukraine. URL: <http://zakon.rada.gov.ua>
12. On special regime of innovation activity of technological parks: Law of Ukraine dated July 16, 1999 N 991-XIV / Verkhovna Rada of Ukraine. URL: <http://zakon.rada.gov.ua>
13. On priority directions of science and technology development: Law of Ukraine from July 11, 2001 N 2623-III / Verkhovna Rada of Ukraine. URL: <http://zakon.rada.gov.ua>
14. On innovation activity: Law of Ukraine dated July 4, 2002 N 40-IV / Verkhovna Rada of Ukraine. URL: <http://zakon.rada.gov.ua>
15. On priority directions of innovation activity in Ukraine: Law of Ukraine dated September 8, 2011 No. 3715-VI / Verkhovna Rada of Ukraine. URL: <http://zakon.rada.gov.ua> (date of address: 15.01.2020).
16. On the National Complex Program of High Technologies Development: Law of Ukraine dated April 9, 2004 N 1676-IV / Verkhovna Rada of Ukraine. URL: <http://zakon.rada.gov.ua>
17. About creation of the regional centers of innovative development: Decree of the Cabinet of Ministers of Ukraine from May 3, 2007 N 255-r. URL: <http://zakon.rada.gov.ua>
18. Artemenko L. II. (2015). Influence of European Integration on Competitiveness and Innovative Development of Countries. *Economics. Management. Business*, 2 (12), 84-89.
19. Oleinik, L.V. (2017). Management of Innovative Development of Enterprise on the Basis of Formation of Innovative Programs. *Economics and organization of production*, 3, 51-59.

20. Kviatko T.M., Ryzhikova N.I. (2017). Genesis of Competition Theories and Applied Basics of Their Implementation in Innovative and Investment Development of Social and Economic Systems. *Problems of Innovative Economy*, 4, 45-54.
21. Karpets O. S. (2008). Scenario Modeling of Regional Innovation Activity Management. *Business Informational*, 8, 26-29.
22. Translated with www.DeepL.com/Translator (free version)
23. Cooke Ian, Mayers P. (1996). Introduction to innovation and technology transfer. Boston: *Artech House Inc.* 126.
24. Dodgson M. J. W. (2001). Statistical physics of phase transitions (lecture notes). 72.
25. Freeman C. (1995). The national system of innovation in historical perspective. *Cambridge Journal of Economics*, 19(1), 5-24.
26. Freeman C., Clark J., Soete L. (1982). Unemployment and technical innovation. A study of long waves and economic development. L.: *Frances Pinter*, 15-20.
27. Innovation Union Scoreboard (2014). URL: http://ec.europa.eu/enterprise/policies/innovation/policy/innovation-scoreboard/index_en.htm
28. Reamer A., Icerman L., Youtie J. (2003). Technology transfer and commercializations: Their role in economic development U.S. department of commerce report. *U.S. Economic Development Administration*. 84.
29. Baltagi Badi H. (1995). Econometric analysis of panel data. New York: *John Wiley&Sons Inc.*. 253.
30. Wooldridge Jeffrey M. (2001). Econometric analysis of cross section and panel data. M: *MIT Press*. 752.