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OPTIMIZATION OF THE STRUCTURE OF AN INNOVATIVE CLUSTER ON A COMPETITIVE BASIS IN A FREE MARKET

Abstract. In the development of innovative economy it is important to create new cluster forms and models of joint activities that would take full account of the goals and potential of participants and features of territorial localization of economic entities interaction of one or related sectors. In this regard, the relevant areas of research are the development of tools for effective interaction of participants in innovation clusters in order to increase their competitiveness and ensure the stable development of the cluster as a whole. The aim of the article is to model the rational structure of the innovation cluster to increase the competitiveness of its members.The direct use of numerous models and methods of analysis and optimization of real cluster structures is quite difficult due to the complexity and large size of such tasks, but it is possible to build a simulation model to describe the associated activities of innovation cluster members, which should contain all available information about the simulated process, and to use the decomposition approach for its research.In the article it was calculated the simulation model, using economic-mathematical modeling, which is oriented towards choosing the optimal structure of the cluster association, the rational composition of its members, and the goals of their associated activities within the cluster. To determine the directions of the construction of the model, some properties were chosen from the whole spectrum of specific properties of the innovation cluster which define its economic content as a specific modeling structure. The simulation model of the optimal structure of the innovation cluster is calculated in the article with the help of economic-mathematical modeling. The proposed simulation model can be used to quantify the feasibility of creating a territorial production association of the cluster type, taking into account the specifics of the territory (region) of the cluster, the sectoral affiliation of its potential participants, the degree of institutional environment for such associated interaction for specific participants and a specific territorially localized economic system.

***Keywords*:** innovation cluster, competitiveness, economic-mathematical modeling, simulation model, decomposition.

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ОПТИМІЗАЦІЯ СТРУКТУРИ ІННОВАЦІЙНОГО КЛАСТЕРА НА КОНКУРЕНТНИХ ЗАСАДАХ В УМОВАХ ВІЛЬНОГО РИНКУ

Анотація. В умовах розвитку інноваційної економіки важливим є створення нових кластерних форм і моделей спільної діяльності, що максимально повно враховували б цілі та потенціал учасників та особливості територіальної локалізації взаємодії суб'єктів економічної діяльності однієї або суміжних галузей економіки. У зв'язку з цим актуальними напрямами дослідження є розроблення інструментарію ефективної взаємодії учасників інноваційних кластерів з метою підвищення їхньої конкурентоспроможності та забезпечення стабільного розвитку кластера в цілому. Мета статті — моделювання раціональної структури інноваційного кластера для підвищення конкурентоспроможності його учасників. Пряме використання численних моделей і методів аналізу й оптимізації реальних кластерних структур — достатньо важке через складність і велику розмірність такого роду завдань, але можливе, якщо для опису асоційованої діяльності учасників інноваційного кластера будувати імітаційну модель, що повинна містити в агрегованій формі всю наявну інформацію про модельований процес, і для її дослідження використовувати декомпозиційний підхід. За допомогою економіко-математичного моделювання розраховано імітаційну модель, орієнтовану на вибір оптимальної структури кластерного об'єднання, раціонального складу його учасників, а також цілей їхньої асоційованої діяльності у складі кластера. При цьому для визначення напрямків побудови такої моделі з усього спектра специфічних властивостей інноваційного кластера обрано ті, що визначають його економічний зміст як особливої модельованої конструкції. Запропонована імітаційна модель може бути використана для проведення кількісної оцінки доцільності створення територіально-виробничого об'єднання кластерного типу за умов більш повного врахування специфіки території (регіону) розташування кластера, особливостей галузевої належності його потенційних учасників, ступеня сприяння інституційному середовищу такій асоційованій взаємодії для конкретних учасників і конкретної територіально-локалізованої економічної системи.

***Ключові слова*:** інноваційний кластер, конкурентоспроможність, економіко-математичне моделювання, імітаційна модель, декомпозиція.

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Introduction. The directions of development of national economies, due to the trends of globalization and territorial localization, as one of the important conditions for intensifying the use of innovation potential include the creation of groups of enterprises or clusters which are competitive in the global market and united by common goals. World experience shows that in the modern economy a high level of competitiveness of certain areas is provided by the strong position of cooperating enterprises, which are a set of geographically concentrated firms that have numerous competitive advantages as a result of synergies from their interaction [1]. In this regard, potentially more productive and focused on modernization and implementation of innovations, able to function more effectively together than independently, are companies that are ready to interact on the principles of cluster associations.

In the development of innovative economy it is important to create new cluster forms and models of joint activities that would take full account, on the one hand, the goals and potential of participants, and on the other — features of territorial localization of economic entities interaction of one or related sectors. In this regard, research aimed at developing tools for effective interaction of cluster participants in order to increase their competitiveness and increase inclusion in the system of modernization relations, as well as to determine the institutional conditions and factors stimulating clustering of the economy, including the separation of state and market regulators of this process.

Research analysis and assignment. The scientific works of many scientists are devoted to the study of the specifics of functioning and interaction of the innovation clusters participants. Thus, the article by S. Martin and H. Mayer [2] reflects the main aspects of the functioning of innovation clusters and their impact on the stability and competitiveness of the national economy. M. Delgado, M. Porter and S. Stern [3] in their scientific work considered the role of regional clusters in regional entrepreneurship. Using empirical analysis, the authors found that industries located in regions with strong clusters have a higher level of new business formation and employment in established enterprises. J. Hervas-Oliver and J. Albors-Garrigos [4] based on the results of a study of the functioning of 48 small and medium enterprises that are part of one of the leading European clusters, identified a significant role of internal resources of cluster participants as extremely important in accessing external knowledge. The authors [4] identify the competitive advantages that innovative enterprises receive from operating in the cluster. E. Hill and J. Brennan [5] present a theoretically substantiated method that combines cluster analysis with discriminant analysis and aims to identify cluster industries in which the study region has a competitive advantage. J. Montana and P. Nenide [6] studied cluster development trends in the central San Joaquin Valley of California and northeastern Indiana by introducing quantitative methods that detect micro changes in cluster development. The approach proposed by the authors can be used to identify at an early stage the factors of positive and negative impact on the cluster functioning and in the process of assessing the sustainability of its development. T. Wolf, U. Cantnerand H. Graf [7] investigated the main aspects of the cluster management process and the role of development strategies of enterprises participating in the cluster in ensuring its stable operation. J. Albors [8] analyzes the competitiveness of industrial clusters and technological formal and informal cooperation networks in Spain operating in the enameling and decoration sector, outlining their importance for the development of the country's economy. L. Shridharan and H. Manimala [9] made a comparative characterization of European, East Asian and Indian clusters based on the evaluation of the process of supporting small and medium enterprises in these regions. E. Feser, H. Renski and H. Goldstein [10] investigated the relationship between the development of clusters and the growth of the national economy, traced the changes in certain clusters that occurred during the study period.

Paying tribute to the above mentioned scientific achievements, it is worth noting the need for further research aimed at forecasting by modeling the interaction of participants in the

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innovation cluster to ensure a high level of competitiveness of these entities and the national economy as a whole. In this regard, the aim of the article is to model the rational structure of the innovation cluster to increase the competitiveness of its members.

Research results. In modern conditions, a single enterprise is unable to successfully compete in open markets, while the main mechanism of any cluster development is a combination of competition and cooperation, interaction of all major participants, aimed at optimizing the conditions of joint development, leading to synergies [11; 12]. In turn, the synergetic effect causes the participants of the cluster to gain numerous competitive advantages through the joint use of factors of production, technology, information, formation of specialized infrastructure and coordination with other related companies based on common interests [13]. At the same time, the key to the economic success of the cluster member enterprises is the stable development and functioning of the latter, which is realized by building the optimal internal structure of the cluster and ensuring the rational interaction of its members [14]. We believe that to solve this problem it is advisable to use the method of economic and mathematical modeling.

In the context of the modeling of the optimal structure of the territorial production cluster carried out in this study, the latter means a group of geographically and economically interconnected enterprises (suppliers, manufacturers, intermediaries) and related organizations (financial and credit structures, educational institutions and scientific research organizations, government agencies, infrastructure companies) operating in a particular field and complementary. Thus, the cluster is a network of independent manufacturing and (or) service companies, including their suppliers, technology developers and know-how (universities, research institutes, engineering companies), connecting market institutions (brokers, consultants) and consumers interact with each other within a single value chain.

To determine the directions of building an economic-mathematical model focused on the choice of the optimal structure of the cluster association, the rational composition of its members, as well as the goals of their associated activities in the cluster, significant methodological interest is the choice of those that determine its economic content as a special simulated design. These features include the following:

innovation clusters are based on a stable system of dissemination of new technologies, knowledge, products — on a technological network based on a common scientific base;

cluster members have additional competitive advantages due to the ability to carry out internal specialization and standardization, minimize the cost of innovation;

an important feature of innovation clusters is the presence in their structure of flexible business structures — small businesses that allow you to form innovative growth points of the economy of a particular region;

clusters are extremely important for the development of small business: they provide small firms with a high degree of specialization in servicing a particular business niche, as it facilitates access to capital of industrial enterprises, as well as active exchange of ideas and knowledge transfer from professionals to entrepreneurs.

Taking into account the given clarifications of conceptual and terminological constructions of cluster problems, we present the characteristics of coordination of decision criteria for global (for the cluster as a whole) and local model blocks selected from it at decomposition of simulation model of cluster structure.

Suppose that a simulation model is created to study a complex financial-industrial cluster structure. As a criterion for the optimality of this cluster, the scalar objective function can be used (1):

$$P(X) \to \max, X \in \Omega, \quad (1)$$

where x — dimensional vector of parameters of the studied model; Ω — many valid parameter values $\Omega \subset E^n$.

The objective function $P(X)$ allows to find the optimal variant of the parameters X^*, at which $P(X^*) = \max P(X), X \in \Omega$.

Suppose that it is possible to present a complex simulation model of an innovation cluster in the form of some set of m simplest models. Let X_k be the vector of parameters of the k-th selected

model, $k \in M, M = 1, \dots, m$. Then the admissible solution of the global problem can be described by the composition of the vectors of local solutions $X = (x_1, \dots, x_m)$ of the selected models, and the criterion of the global model can be represented as (2):

$$P = (X_1, \dots, X_m) \to \max \quad (2)$$

provided $X_k \in \Omega_k, \Omega_k \in \Omega$.

This representation of the studied cluster model allows us to formulate an approach to the choice of solution for a particular *k*-th model.

Let the selected model k include m_k participants, and each j_k-th participant has its own criterion $P_{jk}, j_k \in M_k M_k = 1, \dots, m_k$.

Then the task of each participant is built taking into account external relations:

$$P_{jk}(X_k) \to \max, X_k \in \Omega_k(q_k), k \in M. \quad (3)$$

Here $\Omega_k(q_k)$ is a set of admissible solutions to the k-th selected model, which depends on the external relations of this model, which are determined by resource-technological and other conditions given by the vector q_k. The optimal solution of the k-thselected model is to choose such a vector X_k^0 cluster parameters of this model, which ensures that each of the cluster members achieves the maximum guaranteed income in the planned interval $[t_0, \mathrm{T}]$ (4).

$$P_{jk}(X_k^0) = \max P_{jk}(X_k), j_k \in M_k, \quad (4)$$

moreover, an additional condition must be satisfied to ensure the stability of the k-th model (5):

$$P_{jk}(X_k^0) \geq P_{Hjk}(X_k^0), \quad (5)$$

where $P_{Hjk}(X_k^0)$ — maximum guaranteed incomej_k-participant of the k-th group with its alternative independent activity.

The vector X_k^0 will be called the optimal solution of the k-th selected model.

Building an optimal global solution based on the composition of locally optimal solutions is accomplished by adjusting the values of q_k.

As a result of the analysis of the global task for the cluster as a whole redistribution of a resource between local models is carried out. The problem of reconciliation in the model system is understood as the reconciliation of local and global solutions. Let's present a global criterion in the form (6):

$$P(X) = \sum P_k(X_k), k = 1, \dots, m, \quad (6)$$

where $P_{jk}(X_k) = \sum P_{jk}(X_k), j = 1, \dots, m_k$. Then for the k-th selected model the task is built (7):

$$P_{jk}(X_k) \to \max \quad (7)$$

provided $g_k(X_k) \leq q_k, X_k \in \Omega_k, j_k \in M_k$, where Ω_k — many valid solutions for the k-th model, which do not depend on the parameters of external relations, and the condition $g_k(X_k) \leq q_k$ reflects explicitly the dependence of the solution on external conditions. Obviously that (8):

$$\Omega_k(g_k) = \{X_k \in \Omega_k \cdot g_k(X_k) \leq q_k\}. \quad (8)$$

Coordination of solutions of local problems is carried out by adjusting the parameters q_k. The purpose of the negotiation process is to determine such values of q_k^*, which would allow to obtain optimal solutions for local models that maximize the objective function (9):

$$P(X) = \sum\sum P_{Jk}(X_k) \to \max, \quad k = 1, \dots, m, j_k = 1, \dots, M_k,$$
$$\sum g_k(X_k) \leq q, q = \sum q_k, k = 1, \dots, m, X_k \in \Omega_k. \quad (9)$$

The use of the proposed decomposition approach for the analysis of large cluster structures can be carried out as follows. Thus, a complex model of cluster structure includes three levels of vertical integration, and for simplicity of description and construction of the model it will be assumed that there is one enterprise at each level (existence of several parallel enterprises, close to each other in terms of technological processes, is possible). The scheme of the cluster structure is shown in *Fig.*

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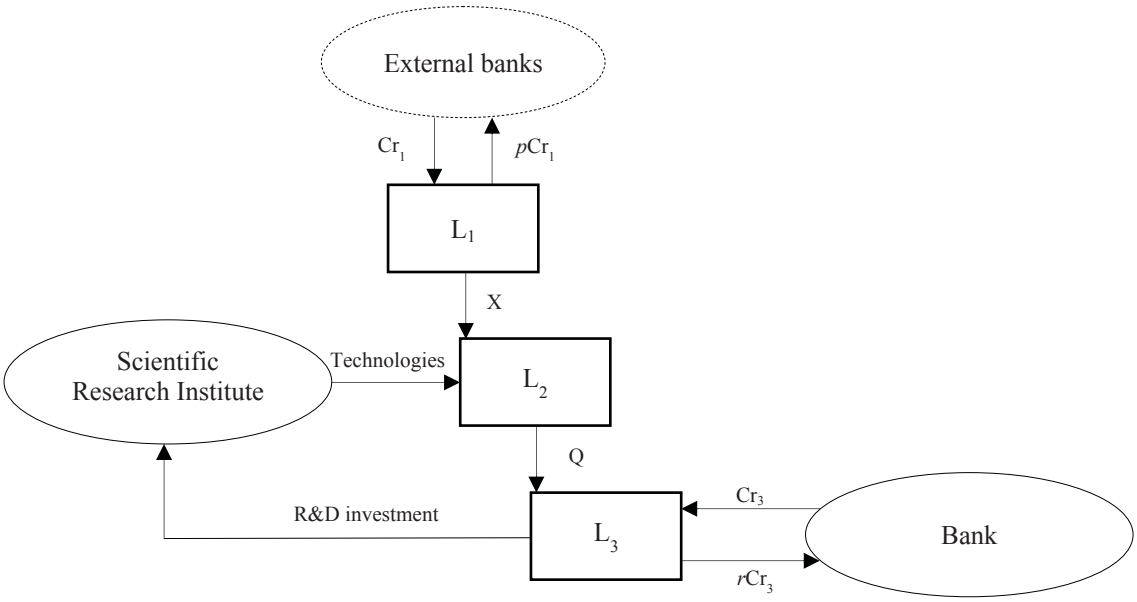

Fig. **Three-level cluster structure of vertical type**

Source: Created by the authors.

Obviously, the optimization of financial flows in such a multilevel and multiparameter cluster model is almost impossible. Therefore, it will be considered its decomposition, which allows to identify simplest models.

The main purpose of the decomposition procedure is to determine the values of the model parameters that provide the maximum total for the entire period of the cluster structure guaranteed income of each cluster member, as well as its stability throughout the interval.

A brief description of the main characteristics of the production activities of enterprises and their interaction with each other as part of an innovation cluster for a conditionally complex model will be given.

The enterprises of the cluster of different levels are connected in vertically integrated cluster structures by a common technological process, and the products produced in the previous technological link are the source material for the enterprises of the next level.

The first level of the cluster structure of the vertical type — L_1 is represented by the enterprise-supplier of raw materials, the second level L_2 — is an enterprise that is directly engaged in production, the third level L_3 — a sales company that supplies products to markets.

Thus, the sales company of the cluster works with the consumer. Its key functions are: marketing, industrial design, R&D. The company orders finished products from the manufacturer in full, and innovative projects — from the research institute as needed to update equipment and technology. In turn, the manufacturer specializes in performing a limited number of production processes and strives to meet the high requirements for product quality, compliance with the terms of the agreed delivery schedule.

The cluster group includes a financial and credit organization — a bank. In addition, enterprises — members of the cluster can use loans from external banks, i. e. those that are not a part of the cluster, taking into account the market value (p) of loans.

Let the bank-member of the cluster structure provide loans to the company L_3 at intra-corporate interest r ($r \leq p$) for the purpose — to reduce unit costs, and the company L_1 uses market loans.

Further the main characteristics of the production interaction of enterprises sequentially for each of the selected levels of the cluster structure of the vertical type will be considered.

Level L_1 consists of the enterprise-supplier of raw materials to the enterprise B in the amount of $X = (x_1, \dots x_n)$ at the price $W = (w_1 \dots w_n)$. In order to reduce unit costs L_1 can use external credit Cr_1.

It will be assumed that the maximum total needs of the enterprise L_2 in raw materials exceed the maximum output of the enterprise L_1 even with infinitely large investments aimed at reducing

its costs. Thus, the supplier of raw materials L_1 at each moment of time t sells all raw materials to the enterprise L_2.

Level L_2. Enterprise L_2 produces the same type of product in the amount of q on the basis of raw materials purchased by it, produced by the enterprise of the first level. Then the manufacturer sells its products to sales companies L_3 at domestic cluster prices p_1.

Level L_3. The sales company promotes products on the markets. The profit of the enterprise of this level is provided at the expense of a difference of market purchase prices for final production Q, and also incomes on actions. The sales company is interested in reducing intra-cluster prices for products. This can be achieved by reducing production costs by upgrading equipment and developing new technologies. Therefore, the sales company cooperates with research institutes, investing some of its own funds in innovative projects. And then the research institute transfers new technologies to the enterprise — the manufacturer.

The bank included in the cluster structure provides L_3 with a loan Cr_3 to reduce unit costs L_3 and owns shares of the sales company.

The given description is a basis for construction in rather aggregated kind of imitation model of joint cluster activity of all levels enterprises of vertical type cluster structure of the organization of industrial-innovative interaction of its participants.

The model will be considered as a controlled dynamic system. The purpose of management is to maximize the global criterion of economic efficiency of enterprises in the studied cluster structure for a long time interval $[t_0, T]$. As such a criterion we will use the sum of the maximum integrated guaranteed income of all members of the cluster structure.

The following chains of conditionally independent subsystems will be distinguished:

1. External credit — L_1 — L_2 — L_3;
2. Bank — L_3 — Research Institute — L_2.

These are selected circuits that local models are investigated for.

To quantitatively substantiate the effectiveness of creating a cluster structure, it is proposed to use the following model of intracluster interaction.

Suppose that three companies interact in this model, financial and credit organization — the bank (and the bank lends to the sales company and at the same time participates in its authorized capital, which allows it to manage and control the intended use of credit resources provided to this company) and external banks, which lend to the enterprise-supplier of resources.

It is assumed that each of the members of the simulated cluster association seeks to maximize the end result of their activities. In this case, this result is the profit that remains at the disposal of both enterprises and the bank after certain transactions.

Let $X = (x_1, \dots x_n)$ — the amount of resource costs required by the enterprise L_2 for production, and $W = (w_1 \dots w_n)$ — respectively, the prices of factors of production.

Further, the enterprise L_2 produces one type of product, and the volume of production is reflected by the production function of the type (10):

$$Q = f\ (x_1, \dots x_n). \tag{10}$$

Participants in the cluster structure interact with each other at their own, transfer prices, which differs favorably from similar prices in operating outside the cluster. Let such an intra-corporate issue price be — p_1. Then the amount of profit received by the enterprise — supplier of resources (A) in the cluster, subject to the allocation of an external bank loan in the amount of Cr_1, can be represented as follows (11):

$$P(Cr_1, x_1, \dots, x_n) = Pr_1(Cr_1, x_1, \dots, x_n) = \lambda_{Cr1}\left(\sum_{t-1}^{n} w_1 x_1 - C\right), \tag{11}$$

where C — supplier's costs for resource extraction,

λ_{Cr1} — coefficient reflecting the effect of the loan provided by the external bank to the enterprise L_1 in the amount of Cr_1.

Then, after partial repayment of the loan and payment of interest on it for the period under study, the profit L_1 will look like (12):

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$$Pr_1(Cr_1 x_1, \dots, x_n) - pCr_1 = \lambda_{Cr1}\left(\sum_{t-1}^{n} w_1 x_1 - C\right) - pCr_1 \longrightarrow \max$$
$$Cr_1 \geq 0 \quad (12)$$

Accordingly, the profit of the enterprise — the manufacturer (L_2) can be displayed as follows (13):

$$P_2(x_1, \dots, x_n) = p_1 Q - \sum_{t-1}^{n} w_1 x_1 \longrightarrow \max. \quad (13)$$

Similarly, the profit of the sales company L_3 taking into account the issuance of a loan by an internal bank in the amount of Cr_3 and after partial repayment of the loan and payment of interest on it for the period under review can be represented as (14):

$$Pr_3(Cr_3, x_1, \dots, x_n) = \lambda_{Cr3}(p_2 - p_1) - rCr_3, \quad (14)$$

where p_2 — market prices, $p_2 > p_1$, $r \leq p$, $Cr_3 \geq 0$.

Then the amount of profit of the sales company, taking into account the investment in innovative design, can be presented (15):

$$P_3(Cr_3, x_1, \dots, x_n) = Pr_3(Cr_3, x_1, \dots, x_n)(1 - \nu) = (\lambda_{K3}(p_2 - p_1) - rK_3)(1 - \nu) \longrightarrow \max, \quad (15)$$

where ν — share of own funds in the form of deductions for innovative design, $0 \leq \nu \leq 1$.

In its turn, the bank also seeks to maximize its income. Part of the bank's income from participation in intra-cluster activities, received from lending to the enterprise L_3 in the amount of Cr_3, will be described by the following system of relations (16):

$$P_b(Cr_3, c) = cP_3 + rCr_3 \longrightarrow \max$$
$$Cr_3 + cY_3 \leq l$$
$$0 \leq c \leq 1, Cr_3 \geq 0, \quad (16)$$

where l — financial resources of the bank, which are directed to its participation in intra-cluster activities:

- whether for lending to the company L_3 in the amount Cr_3;
- or to acquire a share c in the authorized capital of the enterprise

Let r_0 — be the level of return of the bank's financial resources when using them outside the cluster structure (alternative directions of capital investment for the bank). Then for the bank the criterion of that its participation in the volume l in the activities of the studied cluster is justified, is the fulfillment of the ratio (17):

$$\frac{cP_3 + rCr_3}{l} \geq r_0. \quad (17)$$

That is, the return on credit operations within the cluster should not be less than the return on possible bank investments in other alternative projects.

Taking into account all the considerations, the basic relations of the model can be represented as follows (18):

$$P_1(Cr_1, x_1, \dots, x_n) = Pr_1(Cr_1, x_1, \dots, x_n) - pCr_1 = \lambda_{Cr1}\left(\sum_{t-1}^{n} w_1 x_1 - C\right) - pCr_1 \longrightarrow \max$$
$$P_2(x_1, \dots, x_n) = p_1 Q - \sum_{t-1}^{n} w_1 x_1 \longrightarrow \max$$
$$P_3(Cr_3, x_1, \dots, x_n) = Pr_3(Cr_3, x_1, \dots, x_n)(1 - \nu) = (\lambda_{K3}(p_2 - p_1) - rK_3)(1 - \nu) \longrightarrow \max \quad (18)$$
$$Cr_1 \geq 0, Cr_3 \geq 0, r \leq p, 0 \leq \nu \leq 1$$
$$P_b(Cr_3, c) = cP_3 + rCr_3 \longrightarrow \max$$
$$Cr_3 + cY_3 \leq l$$
$$\frac{cP_3 + rCr_3}{l} \geq r_0$$
$$0 \leq c \leq 1.$$

The global criterion and global constraints for the modeled cluster structure of a complex type are presented as follows (19):

$$P(x_1, \dots, x_n) = \sum_{k-1}^{3} P_k(X_k) \longrightarrow max$$
$$P_k(X_k^0) \geq P_{hk}(X_k^0)$$
$$\sum_{k=1}^{3} g_k(X_k) \leq q, q = \sum_{k-1}^{3} q_k\,, x_k \in \Omega_k. \quad (19)$$

$P_{hk}(X_k^0)$ — the maximum guaranteed income of the *k*-th enterprise of the cluster in its alternative independent activity.

The vector X_k^0 is the optimal solution of the *k*-th selected model.

In the following stages of the general model study of a large cluster structure in accordance with certain rules, the values of one or more parameters from among the previously recorded external parameters are changed and all calculations are repeated for each selected local model as part of the global one, i.e. the next iteration is calculated, then the following one, etc.

Ultimately, by making targeted changes to the values of external parameters and repeating of all calculations at each iteration, including the evaluation of the global criterion, the optimal (or close to it) global result can be get.

Conclusions. As a result of the carried study it can be concluded that the proposed simulation model of the optimal structure of the innovation cluster can be used to quantify the feasibility of creating a territorial production association of the cluster type, which may include, as its direct participants, both production and credit and financial structures, as well as R&D organizations, insurance and leasing companies, centers for advanced training of human resources of cluster members, including training of highly qualified top managers of large companies. At the same time, it is obvious that the developed model of complex-functional cluster structure for specific participants and specific territorially-localized economic system needs to be modified and clarified in the direction of fuller consideration of cluster territory (region), sectoral affiliation of its potential participants, degree of institutional environment associated interaction in order to build the optimal structure of the innovation cluster and provide its members with significant competitive advantages.

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