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Economic – mathematical models as basis of the interbudgetary regulation in the formation of the digital economy

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***Abstract*—In ensuring the conditions for the implementation of economic growth, a significant role is played by fiscal policy, among the effective instruments of which stand out the relations of interbudgetary regulation built on the principles of fiscal federalism, which perform stimulating and leveling functions. The article pays attention to the implementation of the stimulating function of interbudget regulation. The implementation of this function requires the use of economic and mathematical tools as an analytical platform for the digital economy. It is shown that the concentration of financial activities on the digital economy platform requires the creation of a cyber-system for managing public finances, as a digital environment for the implementation of interaction between participants in intergovernmental relations. The creation of a digital platform will ensure the transfer of financial management to a fundamentally new level, based on information technologies and ensuring the acceleration of the economic development of the country. The article presents a formal formulation of the task of distributing tax revenues among the budgets of various levels, provided that the interests of the administrative-territorial units are consistent. The theory of growth poles is used as a methodological base. A distinctive feature of the formulation of the problem is the use of a vector criterion with components that are functions of clear and fuzzy arguments. In the role of fuzzy arguments are verbally described scenarios of socio-economic development, formally presented in the form of linguistic variables. To solve this problem, a multi-agent approach is proposed, which includes a description of the intelligent agent in the decision-making process.**

Keywords - inter-budget regulation; digital economy; economic and mathematical models

I. INTRODUCTION

Currently, the object of controversy of domestic scientists with increasing frequency are trends in the evolution of the Russian economy, functioning under the influence of various market factors: the impact of sanctions on the part of Western European countries, the raw material orientation of the Russian economy, the penetration of digital technologies that automate document management, and many others. A raw materials export orientation sets the imperatives that come into conflict with the principles of the development of the real sector of the economy. The result of these contradictions is increasing inequality in the socio-economic development of the territories. At the same time, the territories with large reserves of raw materials and fuel and energy resources received a significant impetus to development. Socio-economic differentiation of territories is one of the main reasons that hamper the economic growth of the whole country and cause a shortage of financial resources in the near future. Spatial inequality, which is a consequence of the concentration of competitive advantages in some territorial units and their deficit in others, makes it necessary to apply the system of inter-budgetary transfers in the form of financial assistance to smooth the level of their budgetary provision, which leads to the formation of a subsidized economy in these territories.

Consequently, one of the most important tasks of the state economic policy is to create conditions for the transition to self-development of administrative-territorial entities. In this regard, the problem of finding ways of territorial self-development through the use of internal resources, hidden potentials that provide territories with competitive advantages in increasing their tax potential becomes particularly urgent. A characteristic feature of the present time is the widespread use of information technologies that will radically change socio-economic relations and lead to the formation of a new information society on the platform of the digital economy. The construction of the digital economy is considered as a lever of economic development, which requires the convergence of the theories of economic growth developed to date and the provisions of economic and mathematical modeling.

A wide range of works of Russian scientists is devoted to the study of ways and tools to ensure the economic growth of the Russian economy not only in quantitative but also qualitative manifestation. The qualitative manifestation of economic growth is aimed at ensuring the competitiveness of producers in the Russian territories through the expansion of innovation, the introduction of post-industrial technologies that contribute to the transfer of the national economy to a new stage of development. In this regard, a significant role is played by the formation in a market-oriented society of the rules of economic entities through the use of various tools of relationships, organized spaces that allow successful development of enterprises, research organizations, educational institutions and many other organizations. Among these tools, the clustering of the national economy with an integrated effective model of inter-budgetary relations between administrative-territorial units, economic entities of which are United in a single organizational structure and included in the technological chain to achieve a certain goal, plays a huge role. The cluster approach complements the concept of advanced economic development of territories, the strategic goal of which is to transform Russia into a leading world power. Among the domestic studies devoted to the development of a strategy for the development of territories of advanced economic development in the cluster approach, It is necessary to highlight the work of S. D. Bodrunov, which studied the practical application of this concept in the Russian economy on the example of the Ural region [1]. The zoning of territories of advanced development in the Ural region in terms of their sectoral orientation is proposed. It is proved that the basis of sustainable economic development of the territories is to ensure a close relationship of science, education and production. The study of actual approaches to the management of socio-economic development of the territories is devoted to the work of A. M. Mukhin, K. F. Kochin [2]. The authors assess the possibility of applying a cluster approach to the management of administrative-territorial entities of the Russian Federation in obtaining a synergetic effect through the use of features of their economic development. The questions of clustering of the regions ' economy are revealed in the article of Melnikov [3]. The author proposes an original approach to socially oriented clustering of regions in order to transform them from industrial centers to multifunctional centers. The problems of economic growth strategy are solved in the research of O. S. Sukharev, aimed at finding the structural characteristics of the economy in the process of formation of macroeconomic policy of economic growth [4]. At the same time, the opposite processes of "creative destruction" and "combinatorial growth"are revealed in the process of economic growth. Analyzed of the investment strategy as a fundamental model of economic development. The effectiveness of clustering of economic processes reflected in the works of A. A. Adamenko, V. A. Blaginina, S. A.-Related, V. V. Prokhorov, V. A. Tupchienko [5]. The research in this regard socio-economic space of regions of Russia in article V. A. Blaginina, E. L. Plisetskaya, S. I., Comerci, N. To. Vasiliev [6].

Key features and influence of socio-economic clusters on the development of regional economy are revealed in the work of L. M. Borsch [7]. The author proves that socially oriented clusters are fundamentally different from the classical industrial clusters by the nature of relations with the authorities. And in these clusters, the core is the financial relationship. Thus, a review of Russian literature has shown that there is now a significantly increased interest in finding tools to ensure the creation of conditions to stimulate economic self-development of Russian territories. In this aspect, the formation of public policy plays a primary role.

An essential component of the state economic policy, which inspires incentives for regional and municipal self-development, is the search for effective instruments of inter-budgetary regulation. At the same time, the tools of both passive and active equalization of the level of budget provision are used. Passive equalization of the economic condition of regions and municipalities is ensured through financial assistance. The most effective method of active alignment of financial condition of administrative-territorial units is the share distribution of receipts from payment of taxes between budgets of administrative-territorial units of various levels of the budgetary system of the Russian Federation. This method, focused on the implementation of the stimulating function of inter-budgetary regulation, motivates the authorities to the economic development of the territories. The solution of this problem causes some difficulties connected with determination of proportions of distribution of receipts from payment of taxes between higher and lower budgets of the budget system of the Russian Federation. The higher level of the budget system is represented by the regional budget, and the lower level – by the budget of the municipality. The decision-making process in the management of the share distribution of tax revenues is in need of development and application of economic and mathematical models that ensure coordination of territorial interests at different levels of administrative and territorial division in accordance with the strategies of their socio-economic development. This task is poorly structured, since the strategic guidelines for the development of territories are determined by the presence of propulsive industries or institutional residents, which enable the development of certain scenarios, usually described verbally. The use of verbal characteristics of scenarios does not allow their quantitative analysis and their further consideration as

arguments for the functions of economic growth rates. In this regard, the methodological basis of the research was the synthesis of formalized methods in the construction of mathematical models with informal provisions of the theory of the poles of economic growth. The synthesis of economic and mathematical knowledge will determine the reflection in mathematical models of objective economic laws in the creation of an economic cybersystem that takes the Russian economy to a new level.

II. PROBLEM STATEMENT

The process of creating an analytical platform for the digital economy requires the development of information technologies along the path of embedding economic-mathematical models in them to optimize their decisions The article proposes the formulation of a multicriterial optimization problem with a vector criterion, whose components are functions of a clear and fuzzy argument. The functions of the fuzzy argument are the rates of economic growth of territories of different levels of the hierarchy of administrative-territorial division, depending on the projected scenarios of socio-economic development. At the same time, the subjects of the Russian Federation are considered at the upper level, and municipalities at the lower level. As functions of a clear argument, described the state of balance of budgets of different levels, we consider the probability of deficit and surplus. The following scenarios are considered as strategic guidelines for the development of territories at different levels: stagnation, inert development and balanced growth. Strategic development under the "stagnation" scenario assumes the preservation of the existing production trends, a weak degree of diversification. The scenario of "inert development" can be predicted in the presence of points of economic growth, allowing to give a certain impetus to the development of the territorial economy. The "balanced growth" scenario assumes a close connection between science and production with the introduction of high technologies and the intensification of economic growth points to transfer the economy to a qualitatively new level.

To assess the level of socio-economic development of the territorial sector of the economy, such functions of a fuzzy argument as indicators of the growth rate of GRP and GDP are used. These functions are considered dependent on the scenario described by a fuzzy argument $Scenar$:

$$\lambda_{GRP}(Scenar_2) = \frac{GRP_P}{GRP_B} \cdot 100\% , \quad (1)$$

$$\lambda_{GMP}(Scenar_1) = \frac{GMP_P}{GMP_B} \cdot 100\% . \quad (2)$$

In expressions for $\lambda_{GMP}(Scenar_1)$ and $\lambda_{GRP}(Scenar_2)$ variables GRP_B , GRP_P , GMP_B , GMP_P describe gross regional and municipal products respectively in the base and planned periods. Currently, the calculation of quantities GRP_B , GRP_P , GMP_B , GMP_P no. As noted in the works of Yuri A. Gadzhiev, V. D. Kolechko, T. A., Kishenko, O. A. Ochkin, A. Tatarinov, in the preparation of the economic portrait of Russian economy sectors there is an internal incompatibility between GDP and GRP [8,9,10]. In addition, there is a problem of methodological vacuum in the logical continuation of GRP indicators to the level of municipalities [8,9,10]. As a result, $\lambda_{GMP}(Scenar_1)$ and $\lambda_{GRP}(Scenar_2)$ are represented by functions fuzzy argument functions. The fuzzy argument is a variable $Scenar_i$, $i \in \{1,2\}$ a scenario of territorial development $Scenar_1 = \{Stagnaz, Inert, SbalRost\}$, the values of which are described in table 1.

TABLE I. THE RANGE OF VARIATION THE COEFFICIENT OF GROWTH OF GROSS DOMESTIC PRODUCT

Scenario	The values of the linguistic variable $Scenar$	The values of the coefficient of growth of gross domestic product $\lambda(Scenar)$
Inertial	$Stagnaz$	$1 < \lambda(Scenar) \le \alpha$
Dynamic	$Inert$	$\alpha < \lambda(Scenar) \le \beta$
Innovative	$SbalRost$	$\alpha < \lambda(Scenar) \le \beta$

The values given in the table α and β representing, respectively, the limit values of change in the growth coefficients corresponding to the scenarios "Inertial" and "Dynamic", "Innovative". These values are determined using the method of expert evaluation. To solve the problem of the share distribution of tax revenues between budgets of different levels, it is proposed to create an agent system, which involves the formalization of the behavior of the person maker decision (PDM). The proposed agent system describes the structure of relations between regional and municipal PDM in solving the problem of inter-budgetary regulation and is conceptually presented in figure 1. According to figure 1, the variables X_{ri} , $i = \overline{1,n}$ of vector $X_r = (X_{r_1}, X_{r_2}, ..., X_{rn})$ identify tax revenues to the sub-Federal budget, collected at the local level, but intended for transfer to the sub-Federation. The variables π_i , $i = \overline{1,n}$ of the vector $\pi = (\pi_1, \pi_2, ..., \pi_n)$ describe the share of deductions from the appropriate type of tax X_{ri} , $i = \overline{1,n}$ in the local budget.

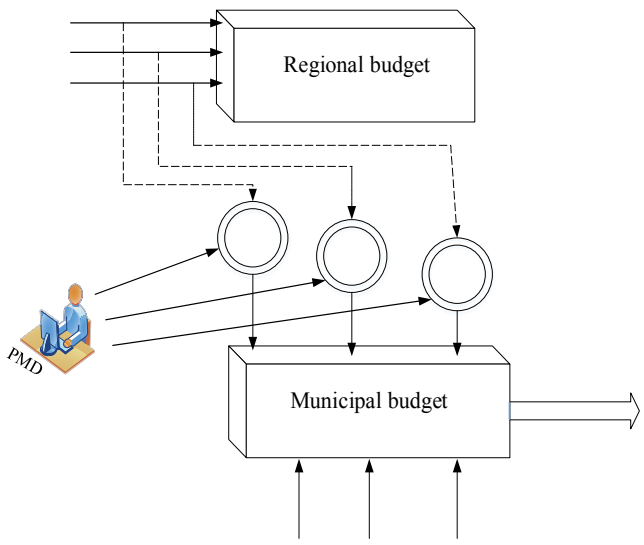

Fig.1. Conceptual scheme of interaction of intelligent agents in a multi-agent system

At the same time, local budget revenues are increased by the amount $\sum_{i=1}^{n} \pi_i X_{r_i}$ and change the value of the stock $Q(t)$ in accordance with the expression:

$$Q(t+1) = Q(t) + \sum_{i=1}^{n} \pi_i X_{r_i}(t) + X_N(t) + \overline{X_N}(t) - R(t) \quad (3)$$

where t - is the current time; $R(t)$ - budget expenditures; $X_N(t)$ – local tax revenues; $\overline{X}_N(t)$ - local non-tax revenues and fees. In accordance with figure 1, decision-making is carried out with respect to the values π_i, $i = \overline{1,n}$, that must meet the condition of coordination of interests of the territories along the vertical line of power. This balance, responding to the principle of balance of budgets of different levels, should be aimed at financing the processes of development of territories in accordance with scenario calculations. The formal formulation of the problem of multi-criteria optimization of decisions on the values π_i, $i = \overline{1,n}$, that ensure the compromise of the interests of the territories of administrative-territorial units in the vertical has the following form:

$$\forall \pi_1, \forall \pi_2, \ldots, \forall \pi_n, \exists \tilde{\pi}_1, \exists \tilde{\pi}_2, \ldots, \exists \tilde{\pi}_n / P(\tilde{\pi}_1, \tilde{\pi}_2, \ldots, \quad (4)$$

The optimality criterion is a vector with components, $p(\pi_1, \pi_2, \ldots, \pi_n)$ and $q(\pi_1, \pi_2, \ldots, \pi_n)$ as clear dependencies, and components $\lambda_{GMP}(Scenar_1)$ and $\lambda_{GRP}(Scenar_2)$ as functions of fuzzy arguments:

$$P(\pi_1, \pi_2, \ldots, \pi_n) = (p(\pi_1, \pi_2, \ldots, \pi_n), q(\pi_1, \pi_2, \ldots, \pi_n)$$

.

Clear functions are, respectively, estimates of the probability of deficit and budget surplus:

$$q(\pi_1, \pi_2, \ldots, \pi_n) = \frac{1}{N} \sum_{t=1}^{N} \rho_2(t),$$

$$\rho_2(t) = \frac{1}{2}\left(1 - \frac{|Q(t)|}{Q(t)}\right), \quad (5)$$

$$p(\pi_1, \pi_2, \ldots, \pi_n) = \frac{1}{N} \sum_{t=1}^{N} \rho_1(t),$$

$$\rho_1(t) = \frac{1}{2}\left(1 + \frac{|Q(t)|}{Q(t)}\right), \quad (6)$$

The functions of fuzzy arguments are the growth factors of gross municipal $\lambda_{GMP}(Scenar_1)$ and gross regional products $\lambda_{GRP}(Scenar_2)$, where N - the period of study. The solution of the problem is based on the concept based on the Pareto-Zadeh equilibrium, in which the components $p(\pi_1, \pi_2, \ldots, \pi_n)$ and $q(\pi_1, \pi_2, \ldots, \pi_n)$ are probabilistic characteristics, $\lambda_{GMP}(Scenar_1)$ and $\lambda_{GRP}(Scenar_2)$ the functions of the scenarios $Scenar_j$, $j = 1,2$, which are linguistic variables. To solve this problem, a game-theoretic model is proposed, the solution of which is sought in fuzzy strategies.

III. ECONOMIC AND MATHEMATICAL MODEL OF THE SHARE DISTRIBUTION OF TAX REVENUES

The solution $\pi = (\pi_1, \pi_2, \ldots, \pi_n)$ of the problem of inter-budget regulation is sought in the class of fuzzy strategy game-theoretic model. Participants in the game are stochastic automatons that describe the behavior of the intelligent agent as the subject of decision-making. The game involves two stochastic automatons , each of which makes a decision that is optimal with respect to the interests of the territory of its level of administrative-territorial division: regional or municipal. Stochastic automaton operate in random environments, which are formed as a result of probabilistic nature of revenues and expenditures of budgetary funds. As the states of the automaton are the values $\varphi(t) = \{\varphi_1(t), \varphi_2(t), \ldots, \varphi_k(t))\}$ representing the coordinates of the ends of the segments into which the interval [0,1] is divided. The economic meaning of these states is the size of the standards of contributions to the budget of municipalities from taxes in the process of inter-budgetary regulation. Its output signals, in the role of which is the value stock $Q(t)$ in the budget, the automaton affects the external environment, which reacts to them, sending the automaton signals of encouragement or punishment. The external environment sends a signal to the input of the automaton "encouragement" if state automaton $\varphi_i(t) \in \varphi(t)$ leads to the formation of a surplus $Q(t) > 0$. When appearing at the exit of automaton value $Q(t) < 0$ automaton punished. The behavior of the automaton under the influence of an external signal is similar to the behavior of natural intelligence: when encouraged, it remains in the same state, and when punished, it goes into any randomly selected state. In [11] a formal proof of theorems on the expediency of

the behavior and asymptotic optimality of the automaton is given. In the course of the proof, the expressions obtained by the authors for the final probabilities are used.

$$P_1^{\phi} = \frac{1}{q_1 \sum_{i=1}^{k} \frac{1}{q_i}}; \quad P_2^{\phi} = \frac{1}{q_2 \sum_{i=1}^{k} \frac{1}{q_i}}; \quad \ldots;$$

$$P_k^{\phi} = \frac{1}{q_k \sum_{i=1}^{k} \frac{1}{q_i}}. \quad (7)$$

In expressions for P_i^{ϕ}, $i = \overline{1,k}$, in values p_i and q_i reflected respectively estimates of the probability of encouragement and punishment of the automaton in the its states $\varphi_i(t) \in \varphi(t)$. The economic meaning of variables p_i and q_i previously defined as estimates of budget deficit and surplus probabilities. These values are determined as a result of computer experiments on the constructed and software-implemented simulation model IMIT. This model, based on the reproduction of budget flows (i.e. revenues $X_r = (X_{r_1}, X_{r_2}, \ldots, X_{rn})$, $X_N(t)$, $\overline{X}_N(t)$, and budget expenditures $R(t)$) when generating their values by the method of statistical tests , allows at each current time to determine the value of the current stock $Q(t)$ and thus to find the values p_i and q_i. The canonical form of the game-theoretic model is represented by a tuple $G = <Players, \Psi, Gain>$, in which the variable $Players = \{A_1, A_2\}$ represents a set of participants in the game, i.e. the previously described stochastic automata A_1 and A_2; $\Psi = \{\Psi_i(1)\}_{i \in J, \alpha \in S} \times \{\Psi_j(2)\}_{j \in J}$, $J = \overline{1,k}$ means a set of pure strategies of players compiled by of states of automata as well $Gain = <gain_1, gain_2>$ - the functions of the winnings of players from the use of these sets of pure strategies. For the participant of the game A_1 the winning function from the choice of clean strategies is determined by the expression:

$$gain_1(\Psi_i(1), \Psi_j(2)) = 0, \text{ if } j \neq k - i + 1; \quad (8)$$

$$gain_1(\Psi_i(1), \Psi_j(2)) = r_i^{\alpha} \cdot p_i^{\alpha}, \text{ if } j = k - i + 1; \quad (9)$$

Let's denote the winning of the participant of the game A_1 from the application of his net strategy $\psi_i(1)$ through u_{ij}: $u_{ij} = gain_1(\psi_i(1), \varphi_j(2))$, and winning player A_2 through $l_{ji} = gain_2(\psi_i(1), \psi_j(2))$. Then bimatrix game can be written in the form of table 2. In a bimatrix game, the many pure strategies of the players are mapped to the linguistic variable $Scenar = \{Stagnaz, Inert, SbalRost\}$.

The values of the linguistic variable $Inert$, $SbalRost$, $Stagnaz$ are the names of fuzzy sets given on the universal $U = [0,10]$: $Inert = <U, \mu_{A_i}^{Inert}>$, $SbalRost = <U, \mu_{A_i}^{SbalRostt}>$, $Stagnaz = <U, \mu_{A_i}^{Stagnas}>$, where $\mu_{A_i}^{Inert}$, $\mu_{A_i}^{SbalRostt}$, $\mu_{A_i}^{Stagnas}$ − trapezoidal membership functions. Analytical expressions for membership functions have the form of expressions (10), (11), (12).

TABLE I. MATRIX $Gain$ OF SLOT MACHINES A_1 AND A_2

	The state of the machine A_2					
The state of the machine A_1		$\psi_1(2)$	$\psi_2(2)$	$\psi_3(2)$	$\cdots$	$\psi_k(2)$
	$\psi_1(1)$					$(u_1, l_{k1}$
	$\psi_2(1)$			$(u_2, l_{32}$		
	$\psi_3(1)$		$(u_3, l_{23}$			
	…	…	…	…	…	…
	$\psi_3(1)$	$(u_k, l$				

$$\mu_{A_i}^{Stagnaz}(\Psi) \begin{cases} 0, & \Psi \leq 0, \\ 1, & 0 < \Psi \leq 3, \\ \frac{10 - \Psi}{10 - 3}, & 3 < \Psi \leq 1 \\ 0, & \Psi \geq 10 \end{cases} \quad (10)$$

$$\mu_{A_i}^{Inert}(\Psi) = \begin{cases} 0, & \Psi \leq 0, \\ \frac{\Psi}{3}, & 0 < \Psi \\ 1, & 3 < \Psi \leq 6 \\ \frac{10 - \Psi}{10 - 6}, & 6 - \\ 0, & \Psi \geq 10. \end{cases} \quad (11)$$

$$\mu_{A_i}^{SbalRost}(\Psi) = \begin{cases} 0, & \Psi \leq 0, \\ \frac{\Psi}{6}, & 0 < \Psi \leq 6, \\ 1, & 6 < \Psi \leq 10. \end{cases} \quad (12)$$

The kind of graphs of membership functions $\mu_{A_i}^{Inert}$, $\mu_{A_i}^{SbalRostt}$, $\mu_{A_i}^{Stagnas}$ and production rules, are compiled by experts. Production rules allow for a given composition of strategic orientations of socio-economic development of the territories of different levels of the hierarchy of administrative-territorial division to find a measure of the possibility of choosing $\tilde{\mu}(\varphi_i)$ participants in the game of

their pure strategies. In this case, the value of the standard of the share distribution of the tax, ensuring the balance of interests of the territories, is determined in the form of a centroid of the fuzzy set, the carrier of which is the net strategy of player A_1 with the membership function $\tilde{\mu}(\varphi_i)$:

$$S_\alpha = (\sum_{i=1}^{k} (\tilde{\mu}(\varphi_i) \cdot u_i) / \sum_{i=1}^{k} \tilde{\mu}(\varphi_i),$$

where - u_i is the win value of player A_1 , defined as $u_i = P_i^{\Phi} \cdot p_i$.

The author has developed a software tool that allows to determine the compromise value of normative deduction from the specific type of tax to the budget of the municipality (Fig.2).

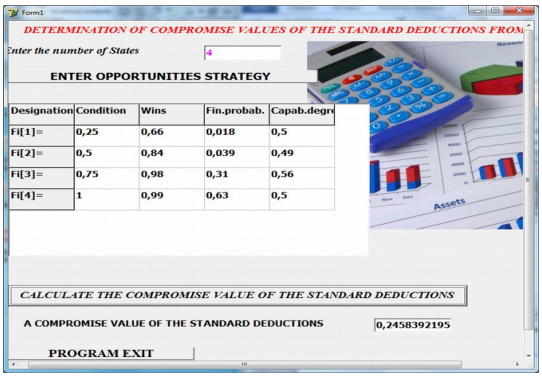

Fig.2. The interface of the software product to determine the value compromise normative deduction in the order of inter-budgetary regulation

IV. PRACTICAL SIGNIFICANCE

The application of the developed software package makes it possible to quantitatively justify alternatives in the share distribution of tax revenues between the levels of the budget system, which contributes to improving the quality of financial management.

V. CONCLUSION

The conducted researches allow to draw the following conclusions. In accelerating the economic growth of sectors of the economy, the state should perform a regulatory function, in which inter-budgetary relations using are an effective tool. In order to obtain significant results of socio-economic development, inter-budgetary relations should be focused on stimulating government structures to enhance innovation and investment activities that ensure the development of the tax base of the territories.

The function of motivation of power structures of administrative-territorial units to creation of conditions of self-development of territories subordinated to them is performed by interbudget regulation at the share distribution of tax receipts between budgets of various levels of the budget system of the Russian Federation. The choice of effective solutions in this regard is largely due caused by of economic and mathematical modeling, which makes it possible to assess the impact of alternatives to establish the proportions of the distribution of tax revenues between the budgets of different levels of the budget system of the Russian Federation. The article proposes a system of economic and mathematical models, as the scientific basis of the digital economy, for solving a weakly structured problem of intergovernmental regulation.

VI. DISCUSSION OF RESULTS

The article notes that in ensuring the economic growth of administrative-territorial units of the Russian Federation the leading role should be played by public authorities using the tools of fiscal policy. Among these instruments, a powerful register is the stimulating function of inter-budgetary regulation, which activates the self-development of territories by increasing its tax potential. The successful implementation of this function is largely determined by the availability of tools to assess the impact of possible alternatives on the distribution of tax revenues between the budgets of different levels of the budget system of the Russian Federation. The developed software-implemented complex of economic and mathematical models, which makes it possible to make quantitatively sound decisions when distributing tax revenues, is considered as an analytical platform for the digital environment when building up the relations of authorities vertically.

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