Запропоновано метод формування опти-мальної структури регіональних державних інвестицій, що сприяє через випереджаль-ний розвиток людського капіталу досягнен-ню стратегічних цілей і завдань соціально-економічного розвитку регіону. Розглянуто динамічну модель, що представляє собою задачу математичного програмування і описує у вигляді рекурентних залежно-стей ланцюжок каналів впливу: «структу-ра та обсяги інвестицій→показники регіо-нального людського капіталу→показники соціально-економічного розвитку регіону». В якості цільової функції використовуєть-ся зважене середнє значення ступенів досяг-нення цільових значень результуючих показ-ників соціально-економічного розвитку на даному горизонті планування. Рекурентні залежності являють собою лагові еконо-метричні моделі панельних даних з викори-станням головних компонент. Для побудови трьох типів моделей (наскрізні, з детер-мінованими і випадковими просторовими ефектами) методом Best Subset використо-вувалося відкрите програмне забезпечення R. Кращі моделі вибиралися за допомогою тестів Вальда, Хаусмана і Бройша-Пагана. Обмеження в моделі являють собою ряд припущень щодо процесів розвитку людсь-кого капіталу та соціально-економічного розвитку з урахуванням невизначеностей. Змінними оптимізації є частки розподілу інвестиційних ресурсів за напрямками інве-стування та роками. За результатами моделювання і чисельними розрахунками на прикладі кількох регіонів Росії в динаміці по роках запропонована оптимальна струк-тура інвестицій. Дана структура дозволяє максимально просунутися до досягнення цільових значень стратегічних показників розвитку регіону за рахунок розвитку люд-ського капіталу

Ключові слова: соціально-економічний розвиток регіону, людський капітал регіо-ну, оптимізація структури інвестицій, бага-топеріодна економіко-математична модель

DEVISING A METHOD TO OPTIMIZE THE INVESTMENT STRUCTURE AIMED TO ACHIEVE STRATEGIC TARGETS IN THE SOCIO-ECONOMIC DEVELOPMENT OF REGIONS

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1. Introduction

Under conditions of the increased competition between entities in different markets, there is a necessity to form new competitive advantages. On the one hand, this is due to the creation of new entities related to the production and implementation of informational and innovative products. On the other hand, that necessitates reducing the costs of production by automating, digitizing, and robotizing most processes, that is, by improving labor productivity. Under these conditions, highly skilled personnel, the main resource for the development and implementation of completely new tools, rank first. At the same time, the main indicator of the effectiveness of the use of human capital is the level of devel-opment of a territory, which is expressed by the main indica-tors of socio-economic development. In turn, in order to take a qualitative leap in the development of human capital, it is necessary to optimize all capital investments that directly or indirectly affect it (including those at the regional level).

Thus, one of the ideas for the country's development implies that investing in life quality and human capital should lead to the development of the social and economic environments of territories. As shown by the experience of the developed countries of the late XX – early XXI centu-ries, the development of human capital and the high-tech industries related to it occurs faster than the growth of a

gross domestic product. This enables national economies not only to compensate for the recessive signs in traditional economic spheres but also to achieve a balance of the territorial-industry development in the long term. Accordingly, it is possible to argue about an organic link between investments in human capital and economic growth, characterized by specific statistical indicators.

Numerous studies within the theory of human capital substantiate the leading role of investment in education, health care, and quality of life, which contribute to the development of the intellectual and innovative potential and economic growth. The very concept of human capital is interpreted by prominent scientists within this theory as a set of investments in human education and professional skills that increase the ability to work. In particular, paper [1] gives a comparison between the human and physical capital and shows that investment expenditures related to human capital are equivalent to the investment in physical capital and are able to bring not less but even more profit in the future.

The issues related to the processes of optimizing the structure of state investments in investment areas are of great practical importance for national and regional management bodies. Governing bodies are seeking to increase the innovative and socio-economic potential of their territories in line with current development priorities.

In this process, the state authorities rely on a series of program documents on the socio-economic development, which outline targets for meeting the needs of basic stakeholders – population, business, and the state.

For regions, the ultimate effect of investment in human capital is expressed in the increasing competitiveness of the regional economy, growth of the gross regional product and the steady improvement in the living standards of people at the territories. Currently, the public administration adheres to the policy of increasing investment as a key factor in GDP growth. However, limited financial resources in regions raise the urgency of the issue of their optimal distribution by funds investment. In this regard, it is relevant to optimize the investment structure, which would make it possible:

– to achieve target values of the regional socio-economic development by increasing the level of development of human capital;

– to use available resources rationally;

– to improve the territorial and industrial components of GDP.

2. Literature review and problem statement

The prominent scholars of human capital theory made a great contribution to the development of views on the role and place of investment in the development of human capital (IHC) and the acceleration of economic growth on this basis. The research was continued by a series of modern scientists who made a lot of conclusions and recommendations on the issues of rationalization of the investment process in countries and regions. In the scientific literature, there are several large groups of research in this field. The studies on the assessment of the role of human capital and the IHC in overall socio-economic development determine the place of human capital in the modern social and reproductive process. They also identify the specifics of the transformation of investment in human capital into specific parameters of economic growth. Some papers are systemic studies of the fundamental properties of investments directed to human capital and their place in the socio-economic development. Other works, on the other hand, view the role of the IHC in a more focused way through the prism of separate industries, markets, and areas of activity. Thus, paper [2] substantiates the role of human capital and the economy of knowledge as the main source of economic growth. Article [3], based on the concept of innovative economy, proposes an increase in the share of productive expenditures in the Russian state budget, that is, investments in human and physical capital with the aim of significantly accelerating the economic growth of the country. However, the work does not specify how much and in what way the budget should be optimized and expenditures for human capital should be increased. Study [4] reveals that throughout 1960–2011, investments in human capital and the dynamics of productive specialization were crucial factors of the economic growth for developed countries. However, the macro-regional aspect will be touched upon here without analyzing the national specifics of human capital development. Study [5] conducted for the OPEC countries shows that the development of human capital became a decisive factor in long-term economic growth, having significantly affected the decreasing poverty in these countries. Article [6], examining the factors of economic growth in Africa, shows clear feedback between the intensity of using natural resources and the level of human capital development. Despite the findings that are of scientific interest, the relationships between human capital and the level of socio-economic development in this article were analyzed through the prism of the economic specifics of African countries and cannot be applied entirely to other countries. The analysis of the data on the USA in the period from 1949 to 2014, presented in [7], reflects the positive impact of an investment made by the country's defense sector on human capital, on the human capital accumulation and the economic growth in the country in general.

At the same time, during the lengthy recession of the world economy, in which many countries were involved, some of the traditional notions of human capital theory and the postulates of the role of the IHC in the socio-economic development are criticized increasingly often. Source [8] considers the very concept of "human capital" to be harmful in terms of the development of an individual and the state. Article [9] actively criticizes many well-established concepts and points of the human capital theory as illogical and contradictory, including the concept of "investment in human capital" itself. Study [10] substantiates that modern theory does not take into consideration a series of important macro-social aspects, the impact of which in some countries leads to social conflict and marginalization of certain layers of the population. Of course, the role of the IHC in the development of countries and regions is significant and positive, but now it is most appropriate to change the focus of research towards the improvement of the methodological apparatus of the theory of human capital. The use of economic-mathematical methods enables solving the problem of the maximal progress of regions to the set goals of socio-economic development. Such advancement is seen as a chain of channels of influence: investment→development of human capital→social and economic growth of a region under conditions of high uncertainty of external and internal environments.

Many studies prove the synergistic effect of the interaction of various kinds of investments, in particular, investments in basic and human capital. It is noted in paper [2]

that investments in basic and human capital are two inter-connected and mutually determined sources of socio-economic growth of a country. The low degree of integration of investments into basic and human capital is the main reason for a series of depressions and stagnations in the Russian economy in the 2010s [2], and this is particularly evident at the regional level [11]. However, neither [2] nor [11] have any specific proposals to improve the situation to overcome these problems. Chinese scientists in paper [12] find that the GDP growth rate in China positively correlates with the dynamics of investment in both basic and human capital, while the effect of direct foreign investment is greatly enhanced by human capital. Study [13] shows that the impact of human capital on the economic growth of China is predominantly indirect and manifests itself through investment in physical capital. Moreover, the stronger this influence, the higher the risk of increasing interregional socio-economic inequality in the country. Despite the important findings, these studies by Chinese scientists do not include measures and recommendations on the optimization of the geographical and economic structure of investments. Article [14] identifies that the reason for a decrease in the U.S. economic growth is a two-fold reduction in the indicator of cumulative factor productivity of the country, reflecting the synergic effect of the interaction of physical and human capitals in manufacturing processes. In turn, the increased role of investment in physical capital results in a sharp increase in income distribution inequality in American society.

Most of the studied sources as an indicator of socio-economic development determine the actual rate of GDP growth per capita or the generalized characteristics of the economic growth, that is, apply positive analysis. From the positions of strategic planning, the drawback of positive analysis is the inability to determine the target effectiveness of national investments, taking into consideration the targets of socio-economic development. In this case, it is difficult to improve the investment structure in such a way as to make maximum advances in the development of human capital, ensuring the achievement of the set parameters of economic growth.

It should be noted that social inequality and differentiation of territories by life quality are the important components, through which the impact of the IHC on the socio-economic development of regions is analyzed and the effectiveness of the structure of investment in human capital is determined. For example, in article [15], enhanced efficiency of accumulation of regional human capital is the key recommendation for mitigating the territorial economic inequality in the Republic of Korea. Having studied the results of research [16, 17], it can be concluded that the weaker the territory is developed, the greater the impact of investment in human capital on the socio-economic development of a region is. Nevertheless, the variety of the used data, methods and conditions of the study, different rates of the innovative process give non-homogeneous and sometimes contradictory conclusions about the impact of investment on the development of territories.

In particular, the analysis of similar empirical data for China and the OECD countries produces opposite results. It is not possible to determine unambiguously the causes of such discrepancies, which requires further improvement in the methodology for the assessment of the impact of investment in human capital on regional development.

The dependences between various components of investment in human capital and indicators of economic growth are also a significant subject in the problem under consideration. In particular, studies [18, 19] link the social-economic development of entities of the Russian Federation (and their differentiation) to the generalized indicators of education. Article [20] analyzes the regional experience of investing in human capital through the dynamics of investments in the spheres of education and health care. Papers [15, 21] examine the impact of human capital on regional economic growth through investment in education and scientific research, article [22] – through health and professional competences. Thus, most studies attach much importance to education and health care in the process of investing in human capital and substantiate the growth of the shares of these areas in overall investment expenditures. However, some authors have grounds to believe it is not enough to invest only in education and health alone. Thus, papers [23, 24] propose to expand the directions of investments in such areas as culture, well-being (infrastructure security), research and development, activities of recreation organizations, entertainment, and sport, as well as in the environment.

A new integrated measure of investment in human capital as an alternative to the traditional system of education-based assessment was developed in paper [25]. At the same time, it should be recognized that in the scientific literature there is still a lack of the experience of research into the impact of a whole range of different areas of investment in human capital, taking into consideration their synergic effect.

Thus, investment in human capital is a complex and integrated category, which means investment not only in education and health care – traditional industries of formation of a human as a carrier of the production factor. Human potential is objectively preserved and developed through such important areas as housing and utilities, environmental protection, culture and sport, urban and rural infrastructure, and social support. At the same time, in the Russian regions, the chronic lag of socio-economic indicators from their targets indicates the low performance of the implemented investment, both in terms of economic growth and in terms of the life quality of the population.

The conducted data analysis suggests that there is a shortage of tools that make it possible to form an optimal structure of investments, directly or indirectly affecting the development of regional human capital, for the maximum possible achievement of the indicators of socio-economic development of a region. At the same time, during the calculation of the optimal investment structure, it is necessary to take into consideration the current parameters and specifics of a region, horizon of planning and the existing resource constraints. This leads to the need to develop new methods and models.

3. The aim and objectives of the study

The aim of this study is to develop an economic-mathematical method for the formation of the optimal structure of state investments, contributing to the achievement of target values of strategic indicators of the socio-economic development of a region.

To achieve the aim, the following tasks were set:

– to develop the optimization model that makes it possible to make maximal progress towards the achievement of an integrated indicator of the development of a region, based on

advanced development of human capital, taking into consideration the importance of strategic priorities;

– to construct functional dependences of the impact of the scope and the structure of investment in the spheres of activity on the change in indicators of the socio-economic development of a region through the development of human capital;

– to explore the computational aspects of using the model in the face of the actual development of regions.

4. Model for the formation of the optimal structure of state investment of a region, taking into consideration the development of human capital

Article [26] presents the conceptual model of development of human capital and the system of indicators describing the categories of "human capital", "social and economic development of a region", "investment in improving the life quality and development of human capital". In continuation of [26], this research proposes formalizing the conceptual model in the form of a problem of mathematical programming based on the representation of channels of influence in the form of constructed functional dependences.

At the heart of the concept model, there is the following chain of impact channels:

– "the structure and volumes of investment for different areas of investment in life quality and human capital of region indicators of regional human capital";

– "indicators of regional human capital→advancement towards the achievement of strategic goals and objectives of socio-economic development of a region".

All investments that have a direct or indirect impact on the development of human capital are considered investments in the human capital of a region. Each direction of investment in the human capital of a region to some extent leads to its growth due to a change in the components describing the given capital. It is also worth noting that certain areas of investment affect regional human capital directly, and some of them contribute to improving the quality of life of the population of a region. At the same time, the improvement of life quality to a varying degree also leads to the development of the human capital of a region.

In turn, the development of the human capital of a region has a qualitative impact on the change in the current situation in a region. For example, the growth of human capital leads to the development of a professional component, and consequently, to an increase in labor productivity in various areas of activity. Thus, the development of regional human capital affects the socio-economic development of a region.

In the context of the set aim of the study, we will consider the problem of choosing the optimal structure of investment in human capital and the life quality by the areas of investment and by years with the horizon of planning T. Optimization of the investment structure will give the maximum possible progress towards achieving the target values of the indicators of socio-economic development. The paper examines a multi-period dynamic process in which time $t=0, 1, ..., T–1$. At any given moment t, there is an investment of financial resources that affect the development of regional human capital directly or indirectly.

Investment in human capital at the regional level refers to state and private investment, directed both to the development of human capital and to the improvement of life quality of the population of a region. Public (variables $x_1,..., x_{12}$) and private (variables x_{13}, x_{14}, x_{15}) investments directly or indirectly influencing the development of human capital are considered as investments in the human capital of a region. We will use thousands of roubles/thousands of people as a unit of measurement of indicators. The list of investment directions was formed based on the current classification of expenditures of the budget of Russia [27] and is supplemented by variables of private investment:

– national issues (x_1);
– national defense (x_2);
– national security and law enforcement (x_3);
– national economy (x_4);
– housing and utilities (x_5);
– environmental protection (x_6);
– education, state-funded (x_7);
– culture, cinematography (x_8);
– health care, state-funded (x_9);
– social policy (x_{10});
– physical culture and sport, state-funded (x_{11});
– mass media (x_{12});
– education, private (x_{13});
– health care, private (x_{14});
– physical culture and sport, private (x_{15}).

Regional human capital as a holistic system is made up of certain components. Six basic groups of components, specifically, levels of professionalism, education, scientific and innovative development, health care and culture were identified, and 24 indicators to assess regional human capital were proposed in paper [26]. Each region will be aligned with the vector-function:

$$Z_n^t = \left(z_{1n}^t, z_{2n}^t, ..., z_{Mn}^t \right), \quad n = 1, ..., N, \qquad (1)$$

where z_{mn}^t is the level of the m-th indicator of the human capital of the n-th region at moment t; M is the number of indicators describing the regional human capital; N is the number of regions.

The model examines the impact of the level of human capital on changing the following key indicators of the development of a region (the list is a modification of the one given in [28]):

– share of the employed population in the labor force (w_1);

– average per capita monetary income, correlated with the magnitude of subsistence minimum (w_2);

– amount of consumer expenditures per capita per month (w_3);

– share of consumer expenditures in the total volume of population income (w_4);

– index of consumer prices (w_5);

– gross regional product per capita (gross value added in current prices) (w_6);

– value of fixed assets at the end of the year by total accounted value per capita (w_7);

– investment in fixed assets per capita in actual current prices (w_8);

– index of industrial production (w_9);

– the volume of shipped goods of own production, executed works and services for the kind of economic activity "Minerals mining" per capita (w_{10});

– the volume of shipped goods of own production, executed works and services for the kind of economic activity "Processing enterprises" per capita (w_{11});

– the volume of shipped goods of own production, executed works and services for the kind of economic activity

"Production and distribution of electric power, gas and water" per capita" (w_{12});

– agricultural products per capita (w_{13});

– putting in operation residential and non-residential buildings (total area of buildings) per capita (w_{14});

– retail turnover per capita (w_{15});

– the specific weight of loss-free (including profitable) organizations (w_{16});

– the income of consolidated budgets of the entities of the Russian Federation per capita (w_{17}).

Thus, for the functional description of the influence of investments on the indicators of socio-economic development, construct the two-level system of econometric dependences:

– influence of investments on the indicators of human capital;

– influence of indicators of human capital on the indicators of socio-economic development.

When constructing the dependences of the first level, to eliminate multi-collinearity and reduce the dimensionality of the problem, we will follow the following scheme:

1) construct the main components for the system of the indicators of human capital;

2) construct the econometric dependences of the main components of human capital on investments.

Similar to [29], by using the Kaiser method, we separated L main components, which explain 76 % of the variance of variables of human capital and carried out their rotation according to the "varimax" method in order to obtain an interpretable load matrix. The explaining features were selected with the help of the factor load matrix for each main component.

Then, the models of panel data of the dependence of the main components of the indicators of the regional human capital on investments were constructed:

$$RCZ_{\ln}^{t} = g_l\begin{pmatrix} RCZ_{\ln}^{t-1}, x_{1n}^{t-1}, ..., x_{In}^{t-1}, \\ x_{1n}^{t-2}, ..., x_{In}^{t-2}, x_{1n}^{t-3}, ..., x_{In}^{t-3} \end{pmatrix}, \qquad (2)$$

where RCZ_{ln}^{t} is the l-th main component of human capital for the n-th region at moment t; x_{in}^{t-1} is the magnitude of investments at the moment $(t-1)$ for the i-th investment direction; l is the number of the main component, $l=1,..., L$.

When constructing these dependences, the existence of the time lag between investing and getting a useful effect was taken into consideration.

Each region will be assigned a vector-function:

$$W_n^t = \left(w_{1n}^t, w_{2n}^t, ..., w_{Kn}^t\right), \qquad (3)$$

where w_{kn}^t is the value of the k-th indicator of the socio-economic development of the n-th region at moment t; K is the number of the indicators describing the socio-economic development.

The impact of human capital on indicators of socio-economic development indicators is assigned by econometric models constructed based on the panel data of the following type:

$$w_{kn}^{t+1} = f_k\left(w_{kn}^t, RCZ_{1n}^t, ..., RCZ_{Ln}^t\right). \qquad (4)$$

The target values of the resulting indicators of socio-economic development on the considered horizon of planning are assigned in the strategies and programs of the socio-economic development of a region in the framework of strategic targets and tasks. Designate these values as $\widehat{w}_{kn}$.

The degree of achievement the k-th goal for the n-th region at moment t:

$$D_{kn}^t = \frac{w_{kn}^t}{\widehat{w}_{kn}}, \quad t = 0, 1, ..., T. \qquad (5)$$

An integral indicator of reaching the targets of the socio-economic development of a region:

$$ISE_n^t = \sum_{k=1}^{K} v_k(t) \cdot D_{kn}^t, \quad \sum_{k=1}^{K} v_k(t) = 1, \qquad (6)$$

where $v_k(t)$ is the weight factor, characterizing the importance of the k-th target of the socio-economic development of a region at moment t.

Coefficients $v_k(t)$ are determined expertly with the use of the verbal estimates considering the levels of competence of experts. Verbal estimates are defuzzified using the average maximum method.

The following vector-function will be implied by the structure of investments:

$$d_n^t = \left(d_{1n}^t, ..., d_{In}^t\right), \quad d_{in}^t = \frac{x_{in}^t}{R_n^t}, \qquad (7)$$

where R_n^t is the total amount of investments, influencing the life quality and human capital of the n-th region at moment t.

To construct a model, we will make a series of assumptions about the process of the development of human capital:

1) annual amounts of investment in each area have constraints from below and from above;

2) if one period in the model is one year, then each indicator of human capital and socio-economic development during the period cannot change very significantly, that is, the relative growth of the indicator is limited from above and from below;

3) the degrees of achieving target values at the end of the horizon of planning, that is, at moment T, should not differ significantly from target values.

Thus, it is proposed to implement the formation of an optimal investment structure that makes it possible to advance as much as possible to the achievement of an integrated indicator of the development of a region based on advanced development of human capital, using the following model:

$$\begin{cases} ISE_n^T = \sum_{k=1}^{K} v_k(T) \cdot D_{kn}^T \to \max, \\[2mm] D_{kn}^t = \frac{w_{kn}^t}{\widehat{w}_{kn}}, w_{kn}^{t+1} = f_k\begin{pmatrix} w_{kn}^t, RCZ_{1n}^t, \\ ..., RCZ_{Ln}^t \end{pmatrix}, t=0,...,T-1, \\[2mm] RCZ_{ln}^t = g_l\begin{pmatrix} RCZ_{ln}^{t-1}, x_{1n}^{t-1}, ..., x_{In}^{t-1}, \\ x_{1n}^{t-2}, ..., x_{In}^{t-2}, x_{1n}^{t-3}, ..., x_{In}^{t-3} \end{pmatrix}, t=1,...,T, \\[2mm] x_{in}^t = d_{in}^t \cdot R_n^t, \sum_{i=1}^{I} d_i^t \le 1, t=0,...,T-1, \\[2mm] \alpha_i \le d_{in}^t \le \beta_i, n=1,...,N, t=0,...,T-1, \\[2mm] -\varphi_k \le \frac{w_{kn}^{t+1} - w_{kn}^t}{w_{kn}^t} \le \psi_k, t=0,...,T-1, \\[2mm] -\delta_l \le \frac{RCZ_{ln}^{t+1} - RCZ_{ln}^t}{RCZ_{ln}^t} \le \gamma_l, n=1,...,N, t=0,...,T-1, \\[2mm] p_k \le D_{kn}^T \le q_k, n=1,...,N, \end{cases} \qquad (8)$$

where $\bar{\alpha}=(\alpha_1,...,\alpha_I)$, $\bar{\beta}=(\beta_1,...,\beta_I)$ are the constraints from below and from above to the volume of investments in each direction; $\bar{\delta}=(\delta_1,...,\delta_L)$, $\bar{\gamma}=(\gamma_1,...,\gamma_L)$ are the constraints from below and from above to the relative change of each main component of human capital for one period of time; $\bar{\varphi}=(\varphi_1,...,\varphi_K)$, $\bar{\psi}=(\psi_1,...,\psi_K)$ are the constraints from below and from above to the relative change of each indicator of socio-economic development for one period of time; $\bar{p}=(p_1,...,p_K)$, $\bar{q}=(q_1,...,q_K)$ are the constraints from below and from above to the degree of the achievement of the target value of each indicator of human capital.

Note that when calculating the main components at moments $t=1, 2, 3$, the values with lag 2 and 3 are taken from retrospective data.

Variable models, by which optimization is carried out, are the annual shares of investments in certain areas of investment $d_1^t,...,d_{12}^t$, $t=0, 1,..., T$.

5. Computational aspects of application of the model under conditions of the actual development of regions

The above model of the formation of the optimal structure of regional investments can be applied under actual conditions. Consider the example of the formation of the optimal structure of regional investments, making it possible to advance as much as possible to reach the target values of indicators of the socio-economic development of a region based on the advanced development of human capital on the example of Primorsky, Zabaikalsky, Altai and Belgorod regions.

The statistical data on the indicators of human capital development, amount of investments in the areas and socio-economic development for the regions of the Russian Federation for 2011–2017 were taken as initial data from the open sources. Paper [26] contains the clustering of regions by the indicators of human capital. Regions are divided into five clusters: "scientific", "environmental", "industrial", "resource" and "small" (according to the types of leading industries and those lagging behind). Primorsky and Zabaikalsky regions were included in the "small" cluster, which includes the regions that do not have a clear industry affiliation, with the dominance of small and medium-sized businesses and indicators of development of regional human capital at the average level. Belgorod and Altai regions are included in the "industrial" cluster that contains industrial and agricultural regions, which are the main "suppliers" of permanent jobs in the country. In the regions of this cluster, there is a certain monopoly created by large agricultural and industrial enterprises.

The main components of the system of indicators of human capital and interpretable load matrices based on the "varimax" method were plotted for these clusters for the database supplemented with the data of 2017, using the Kaiser method. The number of main components will be taken as equal to seven, which makes it possible to explain about 76 % of the variance.

For the dependences of the main components of indicators of regional human capital on the lag indicators of investments, using the Best Subsets method, the models of panel data of three types were constructed: through models, models with deterministic and models with random spatial effects. Using the tests by Wald, Hausman, and Breusch-Pagan, the best ones of the constructed models were selected. They turned out to be the models with deterministic spatial effects. To verify the hypotheses about the significance of equations, an approach based on the concept of a minimum level of significance or p-value was used, which could be considered as the minimum possible error of kind I.

Models of form (1) of the seven main components for the "small" cluster are shown in Table 1. The table shows that the sets of significant exogenous variables for the main components, obtained by using the Best Subsets method, vary in both variables, and time layers they are taken from.

Table 1

Results from modeling the main components of human capital

Main component	Model	p-value	R^2
RCZ_{1n}^t	$RCZ_{1n}^t = 0.17 + 1.08 \cdot RCZ_{1n}^{t-1} - 1.85 \cdot 10^{-5} \cdot x_{7n}^t - 1.77 \cdot 10^{-4} \cdot x_{12n}^t + 3.40 \cdot 10^{-5} \cdot x_{13n}^{t-1} + 2.70 \cdot 10^{-5} \cdot x_{7n}^{t-2}$	$< 2.2 \cdot 10^{-16}$	0.95
RCZ_{2n}^t	$RCZ_{2n}^t = 9.30 \cdot 10^{-2} + 9.08 \cdot 10^{-1} \cdot RCZ_{2n}^{t-1} + 3.45 \cdot 10^{-5} \cdot x_{7n}^t - 3.80 \cdot 10^{-5} \cdot x_{7n}^{t-2}$	$< 2.2 \cdot 10^{-16}$	0.95
RCZ_{3n}^t	$RCZ_{3n}^t = 1.35 \cdot 10^{-1} + 9.70 \cdot 10^{-1} \cdot RCZ_{3n}^{t-1} + 2.60 \cdot 10^{-5} \cdot x_{7n}^t + 4.40 \cdot 10^{-4} \cdot x_{15n}^t - 5.07 \cdot 10^{-5} \cdot x_{7n}^{t-1} + 5.06 \cdot 10^{-5} \cdot x_{14n}^{t-1} - 6.80 \cdot 10^{-4} \cdot x_{15n}^{t-1} - 9.40 \cdot 10^{-5} \cdot x_{3n}^{t-2} + 3.48 \cdot 10^{-5} \cdot x_{7n}^{t-2}$	$< 2.2 \cdot 10^{-16}$	0.91
RCZ_{4n}^t	$RCZ_{4n}^t = -1.50 \cdot 10^{-1} + 9.80 \cdot 10^{-1} \cdot RCZ_{4n}^{t-1} - 5.07 \cdot 10^{-5} \cdot x_{9n}^t - 3.30 \cdot 10^{-5} \cdot x_{10n}^t + 1.60 \cdot 10^{-4} \cdot x_{14n}^t + 1.08 \cdot 10^{-4} \cdot x_{3n}^{t-2} + 5.90 \cdot 10^{-5} \cdot x_{9n}^{t-2} - 2.20 \cdot 10^{-4} \cdot x_{14n}^{t-2}$	$< 2.2 \cdot 10^{-16}$	0.86
RCZ_{5n}^t	$RCZ_{5n}^t = 1.76 \cdot 10^{-1} + 9.84 \cdot 10^{-1} \cdot RCZ_{5n}^{t-1} - 7.80 \cdot 10^{-5} \cdot x_{7n}^t - 8.80 \cdot 10^{-5} \cdot x_{8n}^t - 3.20 \cdot 10^{-4} \cdot x_{14n}^{t-1} + 7.60 \cdot 10^{-5} \cdot x_{7n}^{t-2} + 3.30 \cdot 10^{-4} \cdot x_{13n}^{t-2}$	$< 2.2 \cdot 10^{-16}$	0.90
RCZ_{6n}^t	$RCZ_{6n}^t = 2.10 \cdot 10^{-1} + 9.99 \cdot 10^{-1} \cdot RCZ_{6n}^{t-1} - 1.50 \cdot 10^{-5} \cdot x_{4n}^t + 1.40 \cdot 10^{-4} \cdot x_{13n}^t - 5.09 \cdot 10^{-4} \cdot x_{15n}^{t-1} + 4.40 \cdot 10^{-5} \cdot x_{7n}^{t-1} - 6.80 \cdot 10^{-5} \cdot x_{9n}^{t-1} - 1.10 \cdot 10^{-4} \cdot x_{3n}^{t-2}$	$< 2.2 \cdot 10^{-16}$	0.81
RCZ_{7n}^t	$RCZ_{7n}^t = -0.30 \cdot 10^{-1} + 9.80 \cdot 10^{-1} \cdot RCZ_{7n}^{t-1} - 3.30 \cdot 10^{-4} \cdot x_{1n}^t - 2.80 \cdot 10^{-4} \cdot x_{8n}^t + 7.02 \cdot 10^{-4} \cdot x_{12n}^t + 4.20 \cdot 10^{-4} \cdot x_{14n}^t - 1.70 \cdot 10^{-3} \cdot x_{15n}^t + 2.90 \cdot 10^{-4} \cdot x_{1n}^{t-1} - 4.60 \cdot 10^{-4} \cdot x_{14n}^{t-1} + 1.80 \cdot 10^{-3} \cdot x_{15n}^{t-1} + 1.96 \cdot 10^{-4} \cdot x_{8n}^{t-2}$	$< 2.2 \cdot 10^{-16}$	0.86

Econometric dependences in form (4) were plotted to describe the impact of the level of human capital on the socio-economic development of a region. Open software R was used for the construction.

The most high-quality models from the considered types of the model for some indicators for the cluster "small" are shown in Table 2.

Table 2

Fragment of results from modeling the indicators of socio-economic development indicators of the region (SED)

Indicator of SED	Model	p-value	R^2
w_{1n}^t	$w_{1n}^t = 0.78 + 0.09 \cdot RCZ_{2n}^t + 0.04 \cdot RCZ_{4n}^t - 0.01 \cdot RCZ_{5n}^t + 0.01 \cdot RCZ_{1n}^{t-1} - 0.03 \cdot RCZ_{6n}^{t-1} - 0.02 \cdot RCZ_{7n}^{t-1}$	$< 2.2 \cdot 10^{-16}$	0.75
w_{2n}^t	$w_{2n}^t = 0.58 - 0.14 \cdot RCZ_{1n}^t + 0.13 \cdot RCZ_{2n}^t - 0.12 \cdot RCZ_{3n}^t + 0.08 \cdot RCZ_{4n}^t + 0.22 \cdot RCZ_{1n}^{t-1} - 0.08 \cdot RCZ_{2n}^{t-1} + 0,.9 \cdot RCZ_{3n}^{t-1} + 0.03 \cdot RCZ_{5n}^{t-1}$	$< 2.2 \cdot 10^{-16}$	0.72
w_{3n}^t	$w_{3n}^t = \alpha_i + 2.20 \cdot 10^{-16} \cdot RCZ_{3n}^t - 0.04 \cdot RCZ_{5n}^t - 0.02 \cdot RCZ_{6n}^t + 0.04 \cdot RCZ_{1n}^{t-1} + 0.04 \cdot RCZ_{2n}^{t-1}$	$< 2.2 \cdot 10^{-16}$	0.84
w_{4n}^t	$w_{4n}^t = 0.52 + 0.03 \cdot RCZ_{2n}^t + 0.01 \cdot RCZ_{5n}^t - 0.05 \cdot RCZ_{3n}^{t-1} - 0.02 \cdot RCZ_{7n}^{t-1}$	$5.5 \cdot 10^{-8}$	0.65
w_{5n}^t	$w_{5n}^t = \alpha_i - 0.43 \cdot RCZ_{1n}^t + 0.56 \cdot RCZ_{2n}^t - 0.15 \cdot RCZ_{5n}^t + 0.12 \cdot RCZ_{6n}^t + 0.27 \cdot RCZ_{7n}^t + 0.29 \cdot RCZ_{3n}^{t-1} - 0.41 \cdot RCZ_{6n}^{t-1} - 0.23 \cdot RCZ_{7n}^{t-1}$	$< 2.2 \cdot 10^{-16}$	0.48
w_{6n}^t	$w_{6n}^t = \alpha_i + 0.02 \cdot RCZ_{3n}^t + 0.01 \cdot RCZ_{4n}^t - 0.01 \cdot RCZ_{5n}^t + 0.02 \cdot RCZ_{2n}^{t-1} + 0.02 \cdot RCZ_{3n}^{t-1} - 0.01 \cdot RCZ_{7n}^{t-1}$	$< 2.2 \cdot 10^{-16}$	0.81
w_{7n}^t	$w_{7n}^t = \alpha_i + 0.01 \cdot RCZ_{1n}^t - 0.01 \cdot RCZ_{2n}^t + 0.24 \cdot RCZ_{3n}^t + 0.01 \cdot RCZ_{4n}^t + 0.01 \cdot RCZ_{3n}^{t-1} - 0.01 \cdot RCZ_{5n}^{t-1}$	$< 2.2 \cdot 10^{-16}$	0.74

The models with deterministic individual effects turned out to be preferable for the "small" cluster, and the through panel data models were mostly preferable for the "industrial" cluster. In terms of the p-value, the determining factor and approximation error that is average for all regions, the best are linear models.

As an example, we will analyze the models presented in Tables 1, 2. When considering the models of the main components, note that:

1) state investments in national defense, housing, and utilities, physical culture and sport do not have a significant impact on the main components in the "small" cluster;

2) state investments in education and private investments in education, health care, physical culture, and sport have the maximum impact on the main components in the "small" cluster.

Both patterns can be explained by the peculiarity of regions. As noted earlier, they are dominated by small and

medium-sized businesses, there is no industry specificity and human capital indicators are at the medium level. This leads to the need to rationalize the use of private resources of companies at limited volumes of state investment.

In turn, all the main components influence the change in the indicators of socio-economic development of the regions in the "small" cluster.

It is worth noting that for three indicators of socio-economic development (w_5, w_{10}, w_{14}) it was not possible to construct significant enough regressions. It is most likely that the used main components of human capital are not significantly affected by these variables. That is why in order not to distort the results of modeling, it was decided not to use these variables in the integrated indicator of socio-economic development.

In addition, note the existence of differentiation of the list of model predictors (and their coefficients), depending on the specifics of the cluster.

For the selected regions, consider the optimization of the investment structure with the horizon of planning of three years ($T=3$). The target values for the indicators of the development of human capital will be set as follows:

$$\widehat{w}_{kn} = 1.15 \cdot w_{kn}^0, \tag{9}$$

where w_{kn}^0 is the value of the k-th indicator in 2017.

The constraint vectors, used in the optimization model, have the following form:

1) vectors $\overline{\alpha} = (\alpha_1, ..., \alpha_I)$ and $\overline{\beta} = (\beta_1, ..., \beta_I)$, representing the constraints from below and from above to the investment volumes by directions for Primorsky region are shown in Table 3.

Table 3

Lower and upper limits of the volume of annual state investment by directions (thousand rubles / thousand people) for the Primorsky region

Variables of investment volume	Lower limit	Upper limit
x_1	950	2,774
x_2	10	18
x_3	549	4,063
x_4	3,807	16,428
x_5	2,619	10,379
x_6	21	94
x_7	1,456	18,061
x_8	31	2,223
x_9	3,246	15,020
x_{10}	4,470	16,651
x_{11}	407	2,589
x_{12}	72	295

The limits listed in Table 3 are calculated based on selective mean x_{icp} and selective root mean square deviations σ_i, found according to the statistical data for Primorsky region for 2011–2017:

$$\alpha_i = x_{icp} - 3 \cdot \sigma_i, \quad \beta_i = x_{icp} + 3 \cdot \sigma_i; \tag{10}$$

2) the lower and upper limits of relative changes of the main components of regional human capital at one moment for this example take the form of $\overline{\delta} = (0, ..., 0)$, $\overline{\gamma} = (1, ..., 1)$;

3) based on what the degrees of reaching the indicators of human capital at moment $t=0$ are equal to, the limits from below on the degree of reaching the target value of each indicator for all groups will be set at 0.75; the limits from above – at 1.5.

Below, there is a fragment of results on optimization of the structure of financial investment resources on the proposed model of reaching strategic targets for the socio-economic development of a region with the above restrictions on the horizon of planning $T=3$ (Table 4).

Table 4

Fragment of the results of the distribution of state investments for investment areas and years

Name of a region	Period	x_1	x_2	x_3	x_4	...
Primorsky region	$t=1$	3.6 %	0.0 %	3.9 %	20.6 %	...
	$t=2$	3.3 %	0.0 %	0.5 %	38.2 %	...
	$t=3$	3.0 %	0.0 %	0.5 %	14.6 %	...
Zabaikalsky region	$t=1$	2.9 %	0.1 %	2.0 %	21.9 %	...
	$t=2$	5.0 %	0.1 %	1.0 %	13.8 %	...
	$t=3$	3.5 %	0.1 %	1.0 %	13.5 %	...
Belgorod region	$t=1$	1.7 %	0.0 %	4.3 %	42.0 %	...
	$t=2$	1.7 %	0.0 %	0.3 %	40.5 %	...
	$t=3$	1.7 %	0.0 %	0.3 %	28.7 %	...
Altai region	$t=1$	1.1 %	0.0 %	5.6 %	26.4 %	...
	$t=2$	1.6 %	0.1 %	0.5 %	37.7 %	...
	$t=3$	1.4 %	0.0 %	0.5 %	14.7 %	...

Two scenarios are considered below:

a) inertial, the data for which are taken from regional budget draft laws;

b) optimization, which uses the optimal investment structure calculated by the model (the amount of the cost part of the budget is similar to the amount in the inertia scenario).

Fig. 1 shows the diagram of maximum deviations on the time interval of investment volumes for directions in the optimization scenario from investment volume in the inertial scenario.
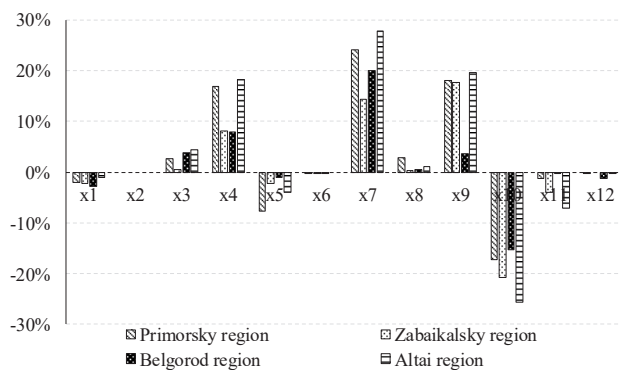

Fig. 1. Diagram of deviations of investment volume under the optimization scenario from the inertial scenario

Analyzing the results (Fig. 1), it is worth noting the following:

– for Primorsky region, the maximum deviation of investment volumes in the positive direction is observed for 3 areas – education (x_7), health care (x_9) and national economy (x_4) (the change by 24.1 % ($T=2$), 18.1 % ($T=3$)

and 16.9 % ($T=2$), respectively). The maximum decrease in investment volumes is observed for 2 areas – social policy (x_{10}) and housing and utilities (x_5) (the change by – 17.2 % ($T=3$) and –7.6 % ($T=1$), respectively);

– for Zabaikalsky region, the maximum increase in investment volume in the positive direction is observed for 3 areas – health (x_9), education (x_7) and the national economy (x_4) (the change by 17.7 % ($T=3$), 14.3 % ($T=3$) and 8.1 % ($T=3$), respectively). The maximum decrease in investment volumes is observed for the area of social policy ($T=3$) (the change by –20.8 % ($T=3$));

– for Belgorod region, the maximum increase in investment volume in the positive direction is observed for two areas – education (x_7) and the national economy (x_4) (the change by 20.1 % ($T=3$) and 8.0 % ($T=1$), respectively). The maximum decrease in investment volumes is observed for the area of social policy (x_{10}) (the change by –15.2 % ($T=3$));

– for Altai region, the maximum increase in investment volume in the positive direction is observed for 3 areas – education (x_7), health care (x_7) and the national economy (x_7) (the change by 27.9 % ($T=3$), 19.6 % ($T=3$) and 18.3 % ($T=3$), respectively). The maximum reduction in investment volumes is observed for the area of social policy (x_{10}) (the change by –25.6 % ($T=3$)).

Thus, it is possible to make a conclusion about the high effectiveness of such areas as education, health care, and the national economy. These areas have a comprehensive impact on the development of human capital and through its increasing on most indicators of the socio-economic development of regions. The maximum decrease in investment volumes for all regions is observed in one investment area – social policy. This indicates investing a significant amount of financial resources, which are ineffective in terms of advancement towards achieving the target values of indicators of socio-economic development of regions.

Fig. 2 shows the diagram of deviations of degrees of reaching the target values of indicators of socio-economic development of regions under the optimization scenario from the inertial one at moment $T=3$.
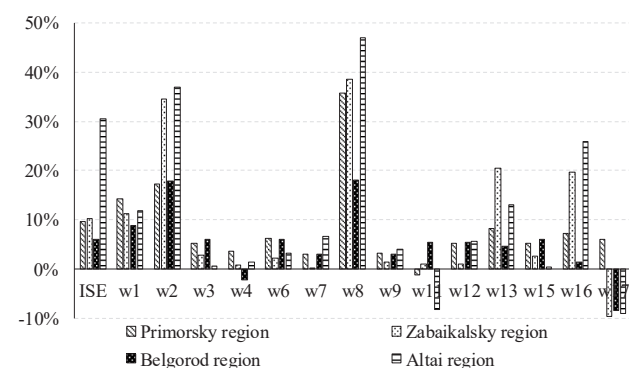

Fig. 2. Deviations in the degrees of reaching target values of indicators of socio-economic development

Analyzing the data, graphically presented in Fig. 2, note the following:

– For Primorsky region, the value of the integrated indicator $\left(ISE_n^3\right)$ under the optimization scenario is by 9.7 % higher than under the inertial scenario and will be equal to 1.08. The improvement by more than 10 % under the optimization scenario (in comparison with the inertial one) is observed for such indicators as:

1) "share of the employed population in work" (w_1) by 14.2 % (equal to 0.80);

2) "average per capita monetary income related to the magnitude of the subsistence minimum" (w_2) by 17.2 % (equal to 1.16);

3) "investments in fixed capital per capita" (w_8) by 35.8 % (equal to 1.04).

It is also worth noting that there is a slight deterioration in the indicator "the volume of shipped goods of own production, performed works and services in-house by the type of economic activity "Processing enterprises" per capita" (w_{11}) by 1.3 % (equal to 1.47).

– For Zabaikalsky region, the value of the integral indicator (ISE_n^3) under the optimization scenario is by 10.3 % higher than under the inertial one and will be equal to 1.06. The improvement of more than 10 % under the optimization scenario (compared to the inertial one) is observed for such indicators as:

1) "share of the employed population in the workforce" (w_1) by 11.2 % (equal to 1.05);

2) "per capita monetary income related to the magnitude of subsistence minimum" (w_2) by 34.6 % (equal to 1.51);

3) "investments in fixed capital per capita" (w_8) by 38.6 % (equal to 0.47);

4) "agricultural products per capita" (w_{13}) by 20.5 % (equal to 1.25);

5) "specific weight of loss-free (including profitable) organizations" (w_{16}) by 19.7 % (equal to 1.62).

It is also worth noting that there is some deterioration in the indicator "revenues of consolidated budgets of entities of the Russian Federation per capita" (w_{17}) (the change by 9.6 % (equal to 0.81)).

– For Belgorod region, the value of the integrated indicator (ISE_n^3) under the optimization scenario is by 5.9 % higher than under the inertial scenario and will be 0.95. The improvement by more than 10 % under the optimization scenario (compared to the inertial one) is observed for indicators such as:

1) "per capita monetary income related to the magnitude of subsistence minimum" (w_2) by 17.8 % (equal to 0.88);

2) "investments in fixed capital per capita" (w_8) by 18.1 % (equal to 0.67).

It is worth noting that there is a deterioration in the indicators:

1) "the share of consumer expenditures in the total amount of income of population" (w_4) by 2.3 % (equal to 0.84);

2) "revenues of consolidated budgets of the entities of the Russian Federation per capita" (w_{17}) by 8.5 % (equal to 1.16);

– For Altai region, the value of the integrated indicator (ISE_n^3) under the optimization scenario is by 30.6 % higher than under the inertial one and will be equal to 0.93. The improvement by more than 10 % at the optimization scenario (in comparison with the inertial scenario) is observed for such indicators as:

1) "the share of the employed population in the workforce" (w_1) by 11.8 % (equal to 0.94);

2) "per capita monetary income related to the magnitude of subsistence minimum" (w_2) by 37.0 % (equal to 0.99);

3) "investments in fixed capital per capita" (w_8) by 47.1 % (equal to 0.19);

4) "agricultural products per capita" (w_{13}) by 13.1 % (equal to 0.78);

5) "specific weight of loss-free (including profitable) organizations" (w_{16}) by 26.0 % (equal 0.68).

It is also worth noting that there is some deterioration for the indicators:

1) "the volume of shipped goods of own production, performed works and services in-house by the type of economic activity "Processing enterprises" per capita (w_{11}) by 8.2 % (equal to 1.12);

2) "revenues of consolidated budgets of the entities of the Russian Federation per capita" (w_{17}) by 9.0 % (equal to 1.06).

It is also worth noting that for some indicators there is a negative tendency compared to the inertia scenario. However, on the one hand, these deviations are not significant, on the other hand, they do not lead to negative consequences (that is, target values for most indicators are reached).

It is not possible to reach the target values for the socio-economic development indicators for a whole range of indicators at the assigned amount of investment. This may indicate the need either to adjust the target values of the development of a region or to increase the amount of the state financial resources.

The dynamics of the change of indicators for two scenarios for Primorsky krai is shown as an example below in Fig. 3.
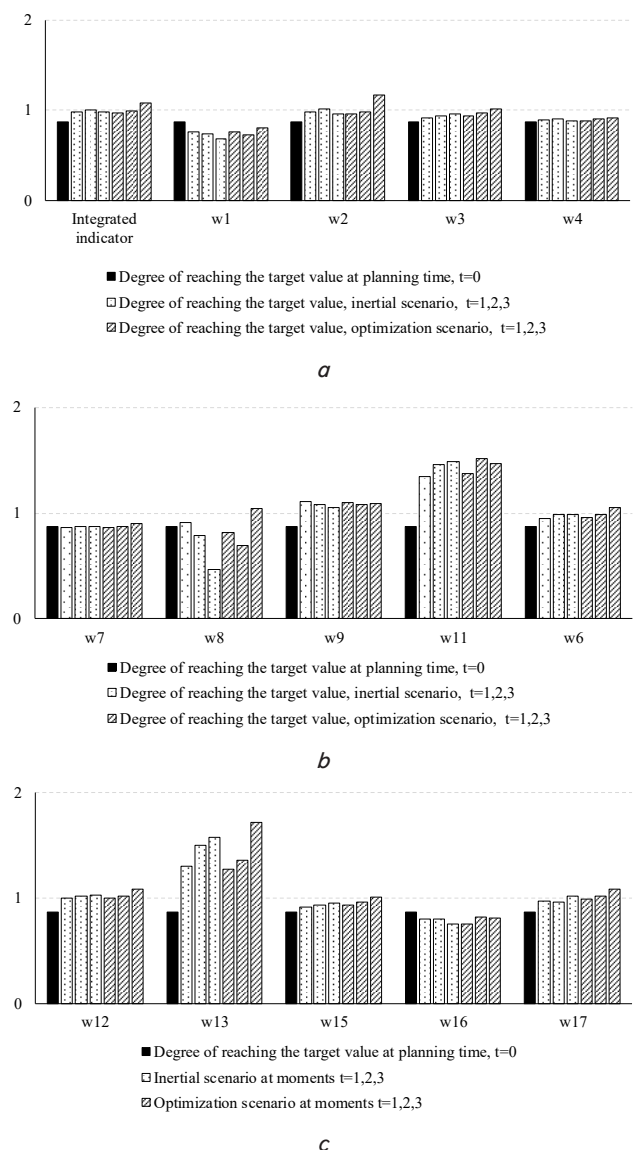

a

b

c

Fig. 3. Dynamics of changes in the indicators of socio-economic development of regions under different scenarios: *a* — for the integrated indicator and indicators 1—4; *b* — for indicators 6—9, 11; *c* — for indicators 12, 13, 15—17

Analyzing the data in Fig. 3 for Primorsky region, it is possible to draw conclusions about the existence of positive dynamics with a higher growth rate under the optimization scenario compared to the inertial scenario. Thus, we can talk about the improvement of efficiency in planning the structure of state investment using the author's optimization model.

6. Discussion of results of studying the optimization of the investment structure for reaching the target values of indicators of the development of a region

The problem of the development of a region due to the advanced development of its human capital, which means the growth of the professional and innovative components of the labor force and, consequently, productivity, was explored. The method for the formation of the optimal structure of state investments, which contribute to reaching the target values of strategic indicators of socio-economic development of a region, was designed. The method is based on model (8) of determining the optimal structure of state investments, directly or indirectly affecting the development of regional human capital, the objective function (6) of which is chosen in accordance with the target values of socio-economic development of a region.

A distinctive feature of the model is two-stage modeling of the channels of influence:

1) structures and amounts of investment that directly or indirectly affect the development of human capital, the indicators of human capital;

2) achieved level of regional human capital on the advance to reaching the strategic goals and objectives of the socio-economic development of a region. This makes it possible to consider the process of regional development from a different angle – through the prism of the development of regional human capital.

In addition, one of the advantages of the model is the quantitative description of the modeled channels of influence. To do this, relevant econometric dependences (2) and (4) were constructed based on open sources of the panel database (the resulting functional dependences for the "small" cluster are shown in Tables 1, 2). At the first stage of modeling, we used the method of main components enabling the elimination of the shift of selected estimates of regression coefficients, which occur due to the existence of multi-collinearity. In the second stage, it is impossible to use the main components of the system of indicators of socio-economic development, as they do not have a monotony in the following sense "the greater the value, the better". That is, they cannot be used as criteria in the problem of mathematical programming. On the other hand, it is unnecessary to use them, as multi-collinearity of the main components of human capital is insignificant.

It should be noted that all constraints in model (8) are assigned rigidly using crisp numbers as boundaries, although it is more natural to assign them in the form of fuzzy numbers to model the existing uncertainty. It also makes sense to assign weight factors in the objective function, which model the importance of indicators of socio-economic development, on the basis of verbal statements of experts and represent them in the form of fuzzy numbers. In this regard, it seems appropriate in the future to develop a fuzzy multi-period model and an appropriate method for finding a solution.

The performed comparative analysis of the inertial scenario (which used an investment structure consistent with the draft law of the regional budget) and the optimization scenario (within which the investment structure was obtained using the proposed optimization model) revealed that:

1) the main vector of redistribution of state resources is the reduction of investments in "social policy" and their increase in the three main areas of "education", "health" and "national economy", as can be seen from Fig. 1. It is worth noting that the impact of these directions on the indicators of socio-economic development is the most significant;

2) under the optimization scenario, there is more effective progress towards reaching the target values of indicators of socio-economic development. This is evidenced by the higher value of both integral indicator, and degrees of achievement of the vast majority of the set goals, as it is shown in Fig. 2, 3.

It is also possible to speak about the practical significance of this study, expressed in the formation of an application tool, the use of which makes it possible to increase the efficiency of distribution of financial resources in the formation of the regional budget taking into account their limitations and set objectives.

7. Conclusions

1. A multi-period model has been constructed, which makes it possible to find the optimal structure of state investment resources at the regional level. The model is a mathematical programming problem, in which the objective function is the integral indicator that characterizes the levels of achievement on a given horizon of planning of the target values of 17 indicators of socio-economic development in a region. The solution of the model is the structure of investment by the investment areas, which affects directly or indirectly the development of regional human capital, and by years. From the practical point of view, the model is a tool that enables the state governing bodies to reach the maximum possible advancement in the development of a region. Under conditions of limited regional financial resources, such advancement becomes possible by increasing the level of human capital, taking into consideration the importance of strategic priorities.

2. The functional dependences of the chain of influence channels, proposed in the conceptual model, were constructed:

– "the structure and amount of investments by different areas of investment in life quality and human capital of a region"→"indicators of regional human capital";

– "indicators of regional human capital"→"advancement to reaching strategic targets and tasks of socio-economic development of a region".

The dependences are the econometric models for panel data. The database consists of values for 56 indicators of development of human capital, socio-economic development and investment amount by areas for the regions of the Russian Federation within 2011–2017, taken from the open sources. To eliminate multi-collinearity and to reduce the dimensionality of the model, the method of the main components was used at the first level of the chain. For each cluster, into which [29] in terms of human capital the regions of Russia are divided, the lag models with deterministic or random spatial effects were constructed. The best models were chosen using the tests by Wald, Hausman, and Breusch-Pagan.

3. The computational aspects of the proposed method were considered during the formation of the optimal structure of state investment resources for several regions of Russia. Based on the performed calculations, the investment structures by investment directions and years, which are optimal by the criterion of the maximum degree of reaching the target values of the indicators of socio-economic development of a region, were formed. The examined examples show that the optimization of the investment structure enables making better progress in the development of a region in comparison with the inertia scenario. Under the inertial scenario, the investment structure on the horizon of planning corresponds to the structure proposed in the regional budget law drafts.

References

1. Becker, G. S. (1962). Investment in Human Capital: A Theoretical Analysis. Journal of Political Economy, 70 (5, Part 2), 9–49. doi: https://doi.org/10.1086/258724
2. Aganbegyan, A. G. (2017). Human Capital and Its Main Component – the "Knowledge Economy" Sphere as the Main Source of Socio-Economic Growth. Ekonomicheskie strategii, 3, 66–79.
3. Kudrin, A., Sokolov, I. (2017). Fiscal maneuver and restructuring the Russian economy. Voprosy Ekonomiki, 9, 5–27.
4. Teixeira, A. A. C., Queirós, A. S. S. (2016). Economic growth, human capital and structural change: A dynamic panel data analysis. Research Policy, 45 (8), 1636–1648. doi: https://doi.org/10.1016/j.respol.2016.04.006
5. Olopade, B. C., Okodua, H., Oladosun, M., Asaleye, A. J. (2019). Human capital and poverty reduction in OPEC member-countries. Heliyon, 5 (8), e02279. doi: https://doi.org/10.1016/j.heliyon.2019.e02279
6. Zallé, O. (2019). Natural resources and economic growth in Africa: The role of institutional quality and human capital. Resources Policy, 62, 616–624. doi: https://doi.org/10.1016/j.resourpol.2018.11.009
7. McDonald, B. D. (2019). A human capital model of the defense-growth relationship. The Social Science Journal. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0362331919300618
8. Liberal'niy udar po rossiyskomu obrazovaniyu: Kak lobbisty pytayutsya upravlyat' budushchim strany. Available at: http://electek.ru/articles/31059-liberalnyy-udar-po-rossiyskomu-obrazovaniyu-kak-lobbisty-pytayutsya-upravlyat-buduschim-strany.html
9. Belkin, V. N., Artemova, O. V., Garina, V. U. (2012). The conceptual device of the theory of the human capital. Zhurnal ekonomicheskoy teorii, 2, 7–13.
10. Campbell, C. (2019). Social capital, social movements and global public health: Fighting for health-enabling contexts in marginalised settings. Social Science & Medicine, 112153. doi: https://doi.org/10.1016/j.socscimed.2019.02.004
11. Osipov, V. A., Krasova, E. V. (2015). Features of forming of a manpower in strategically important cities of the Far East of Russia (on the example of Vladivostok). Mediterranean Journal of Social Sciences, 6 (5), 108–117. doi: https://doi.org/10.5901/mjss.2015.v6n5s3p108
12. Su, Y., Liu, Z. (2016). The impact of foreign direct investment and human capital on economic growth: Evidence from Chinese cities. China Economic Review, 37, 97–109. doi: https://doi.org/10.1016/j.chieco.2015.12.007
13. Chi, W. (2008). The role of human capital in China's economic development: review and new evidence. China Economic Review, 19 (3), 421–436. doi: https://doi.org/10.1016/j.chieco.2007.12.001
14. Vasiliev, V. S. (2018). The Deterioration of Reproduction Conditions in the U.S. Economy. Outlines of global transformations: politics, economics, law, 11 (2), 133–150. doi: https://doi.org/10.23932/2542-0240-2018-11-2-133-150
15. Woo, Y., Kim, E., Lim, J. (2017). The Impact of Education and R&D Investment on Regional Economic Growth. Sustainability, 9 (5), 676. doi: https://doi.org/10.3390/su9050676
16. Fleisher, B., Li, H., Zhao, M. Q. (2010). Human capital, economic growth, and regional inequality in China. Journal of Development Economics, 92 (2), 215–231. doi: https://doi.org/10.1016/j.jdeveco.2009.01.010
17. Zhou, G., Gong, K., Luo, S., Xu, G. (2018). Inclusive Finance, Human Capital and Regional Economic Growth in China. Sustainability, 10 (4), 1194. doi: https://doi.org/10.3390/su10041194
18. Koritskiy, A. V. (2018). Are the returns to human capital assets in Russia really great? EKO, 2 (524), 35–47.
19. Korshunov, I. A., Gaponova, O. S., Gaponova, N. S. (2019). Adult training and education in the context of economic development of regions. Economy of Region, 15 (1), 107–120. doi: https://doi.org/10.17059/2019-1-9
20. P'yanova, M. V. (2018). Regional experience in investing in the developing human capital. Nalogi i finansy, 2 (38), 26–36.
21. Kottaridi, C., Louloudi, K., Karkalakos, S. (2019). Human capital, skills and competencies: Varying effects on inward FDI in the EU context. International Business Review, 28 (2), 375–390. doi: https://doi.org/10.1016/j.ibusrev.2018.10.008
22. Salike, N. (2016). Role of human capital on regional distribution of FDI in China: New evidences. China Economic Review, 37, 66–84. doi: https://doi.org/10.1016/j.chieco.2015.11.013
23. Rudenko, D. Yu., Tilimbaeva, A. B. (2013). Otsenka vzaimosvyazi investitsiy v chelovecheskiy kapital i urovnya sotsial'no-ekonomicheskogo razvitiya stran mira. Vestnik Tyumenskogo gosudarstvennogo universiteta, 11, 20–30.
24. Ermoshina, T. V. (2018). Investment in human capital as a priority of the neo-industrial economy. Economics and Environmental Management, 4, 3–10. doi: https://doi.org/10.17586/2310-1172-2018-11-4-3-10
25. Fraumeni, B. M., He, J., Li, H., Liu, Q. (2019). Regional distribution and dynamics of human capital in China 1985–2014. Journal of Comparative Economics, 47 (4), 853–866. doi: https://doi.org/10.1016/j.jce.2019.06.003

26. Mazelis, L. S., Lavrenyuk, K. I., Krasko, A. A., Zagudaeva, O. N. (2018). A conceptual model of the regional human capital development. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 9 (4), 477–494. doi: http://doi.org/10.14456/ITJEMAST.2018.44

27. Byudzhetniy Kodeks RF. Stat'ya 21, p. 3. Ofitsial'niy sayt kompanii «Konsul'tantPlyus». Available at: http://www.consultant.ru/document/cons_doc_LAW_19702/8d384913e40ef9a5709117de01aa1f44f7cab76f/

28. Metodicheskie rekomendatsii po razrabotke i korrektirovke strategii sotsial'no-ekonomicheskogo razvitiya subekta RF i plana meropriyatiy po ee realizatsii. Utverzhdeny prikazom Minekonomrazvitiya ot 23.09.2017 g. No. 131. Sayt Ministerstva ekonomicheskogo razvitiya RF. Available at: http://economy.gov.ru/minec/activity/sections/StrategTerPlanning/komplstplanning

29. Mazelis, L. S., Emtseva, E. D., Lavrenyuk, K. I., Krasko, A. A. (2018). Analysis of regional human capital's development because of investment process. Azimuth of Scientific Research: Economics and Administration, 7 (3 (24)), 180–184.

Розглядається задача визначення безвідмовності водія в транспортній системі міста з урахуванням заторів. Перебування водія в заторах призводить до зростання його психоемоційної напруженості, підвищенню рівня втоми і, як наслідок, до зниження безвідмовності. Рівень безвідмовності водія безпосередньо впливає на безпеку дорожнього руху. Безвідмовність водія на елементах транспортної системи визначена ймовірністю скоєння дорожньо-транспортної пригоди, яка залежить не тільки від параметрів мережі і транспортних потоків, а насамперед й від часу реакції водія.

Розроблено моделі оцінки безвідмовності водія на ділянках транспортної мережі і в транспортних вузлах з урахуванням заторів руху, які дозволяють оцінити ймовірність скоєння дорожньо-транспортної пригоди для середньостатистичного водія. У цих моделях вплив затору враховується зміною часу реакції водія, яка є функцією зміни рівня його стомлення.

Для визначення у скільки разів ймовірність скоєння дорожньо-транспортної пригоди середньостатистичного водія на ділянках транспортної мережі і в транспортних вузлах з затором вище, ніж ця ж ймовірність на тих же елементах транспортної системи без затору, було розглянуто співвідношення цих ймовірностей.

Визначено адекватність моделей шляхом співставлення відношення ймовірностей скоєння дорожньо-транспортної пригоди з затором на ділянках транспортної мережі і без нього до відповідного відношення кількості дорожньо-транспортних пригод на цих же ділянках транспортної мережі та на перехрестях.

Розроблені моделі оцінки безвідмовності водія на елементах транспортної мережі з урахуванням транспортних заторів дозволяють порівняти і оцінити різні варіанти проектних рішень з підвищення безпеки дорожнього руху

Ключові слова: безвідмовність водія, дорожньо-транспортна пригода, транспортна система, дорожній затор, час реакції

DEVELOPMENT OF MODELS FOR ASSESSING A DRIVER'S FAILURE-FREE OPERATION IN A TRANSPORTATION SYSTEM UNDER CONDITIONS OF TRAFFIC CONGESTION

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1. Introduction

The efficiency and failure-free operation of a driver in a transport system depend greatly on specific working conditions under which a driver operates. The parameters of a transportation process, which exist in specific situations, determine these conditions. One such situation is a traffic jam, which arises due to the excess of traffic intensity over the capacity of streets and roads. A traffic jam has a negative impact on the psychophysiology of a driver. It leads to an