Research article

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Model of Global Optimisation and Planning of Research and Development Costs of an Industrial Region

Dmitrii Rodionov[1], Egor Koshelev[2*], John Gayomey[3], Olga Ferraro[4]

[1] Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia, drodionov@spbstu.ru
[2] Lobachevsky State University of Nizhny Novgorod, Nizhny Novgorod, Russia, ekoshelev@yandex.ru
[3] Tamale Technical University, Tamale, Ghana, gayomey@hotmail.com
[4] University of Calabria, Italy, olga.ferraro@unical.it
[*] Corresponding author: ekoshelev@yandex.ru

Abstract

The subject of the work is a study of the patterns and prerequisites for the formation of regional innovation systems along with the analysis and synthesis of a significant array of information on elements of interaction at the regional level on the basis of economic and mathematical modelling. The purpose of this work is to develop a science-based flexible management model that, on the one hand, takes into consideration the specificity of the development cycle for the innovative system of an industrial region, as well as the level of its socio-economic development, and on the other hand, contributes to overcoming the economic determinism of territories and stimulating the economic growth of an industrial region. A regional model for planning innovative development programmes has been created, which consists of the global optimisation of current domestic research and development (R&D) costs of the industrial region, depending on its investment planning according to the fixed capital investment data, production planning according to the gross regional product (GRP) data, and financial planning for the accounts payable data of organisations. In the Nizhny Novgorod region, to minimise all R&D costs, investments in fixed assets and GRP should be increased, and the quantity of accounts payable by organisations should be reduced. However, for basic research, there is a limit on the debt of organisations, the excess of which is impractical because it leads to an outflow of the necessary funds for basic research. The increase in this debt also leads to an increase in the costs of applied research. For developments, there is a lower limit on the amount of GRP, below which it is not advisable to drop, as it leads to an outflow of the funds necessary for development.

Keywords: innovative development of the region, investment planning, production planning, financial planning, research and development costs

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Модель Глобальной Оптимизации и Планирования Затрат на Научно-Исследовательские Работы Промышленного Региона

Дмитрий Родионов[1], Егор Кошелев[2*], Джон Гайомей[3], Ольга Ферраро[4]

[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия, drodionov@spbstu.ru
[2] Нижегородский государственный университет им. Н.И. Лобачевского, Нижний Новгород, Россия, ekoshelev@yandex.ru
[3] Технический университет Тамале, Тамале, Гана, gayomey@hotmail.com
[4] Университет Калабрии, Италия, olga.ferraro@unical.it
[*] Автор, ответственный за переписку: ekoshelev@yandex.ru

Аннотация

Предметом работы является исследование закономерностей и предпосылок формирования региональных инновационных систем с учетом анализа и обобщения значительного массива информации по элементам взаимодействия на региональном уровне на основе экономико-математического моделирования. Цель работы заключается в разработке научно-обоснованной гибкой управленческой модели, с одной стороны, учитывающей специфику цикличности развития инновационной системы промышленного региона, а также уровень его социально-экономического развития, с другой стороны, способствующей преодолению экономического детерминизма территорий и стимулирующей экономический рост промышленного региона. Создана региональная модель планирования программ инновационного развития, которая заключается в глобальной оптимизации внутренних текущих затрат на научно-исследовательские работы (НИР) промышленного региона в зависимости от его инвестиционного планирования по данным об инвестициях в основной капитал, производственного планирования согласно данным о валовом региональном продукте (ВРП) и финансового планирования по данным о кредиторской задолженности организаций. В Нижегородской области с целью минимизации всех затрат на НИР следует увеличивать инвестиции в основной капитал и объем ВРП, а также снижать размер кредиторской задолженности организаций. При этом для фундаментальных исследований существует предел задолженности организаций, превышение которого нецелесообразно, т. к. это приводит к оттоку необходимых средств на фундаментальные исследования. Увеличение данной задолженности приводит также к повышению затрат на прикладные исследования. Для разработок существует нижний предел объема ВРП, ниже которого опускаться нецелесообразно, т. к. это приводит к оттоку необходимых средств на разработки.

Ключевые слова: инновационное развитие региона, инвестиционное планирование, производственное планирование, финансовое планирование, затраты на научно-исследовательские работы

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1. Introduction

Currently, the conditions of the external environment in the Russian Federation suggest considering the issues of nationally effective and balanced socio-economic and innovative development of the nation's industrial regions by modelling their innovative development processes. In this regard, works on the problems of functioning of regional innovation systems, developed by Russian and foreign scientists, summarise that most systems have a stable set of structural elements, which are well studied and described, and the institutional relationships of innovation chains have been identified. However, the role of regional innovation systems is still underestimated, most of the works are devoted to national innovation systems, and most studies are socially oriented without proper economic and mathematical description. The present study is distinguished by the analysis and generalisation of a significant array of information on the elements of interaction at the regional level based on economic and mathematical modelling. In the framework of this study, we propose analysing regularities and considering prerequisites for the formation of regional innovation systems. The goal of this study is to develop a science-based flexible management model that, on the one hand, considers the specifics of cyclic development of the innovation system in an industrial region and its socio-economic development level, and on the other hand, contributes to overcoming the economic determinism of territories and stimulating the economic growth of the industrial region. To achieve this goal, it is necessary to create a regional model of simultaneous investment, production, and financial planning of innovative development programmes.

The problems of planning for investment, production, and financial programmes and their interrelation were studied by scientists such as Brigham and Gapenski (1993), Kruschwitz and Lorenz (2019), and Limitovskiy (2019). Brigham and Gapenski (1993) investigated the planning processes of investment programmes for commercial companies' projects. Kruschwitz and Lorenz (2019) studied the processes of simultaneous investment and financial planning, as well as simultaneous investment and production planning. Limitovskiy (2019) supplemented their results by considering the systemic financial effects of investment programmes. However, the processes of simultaneous investment, production, and financial planning have not been sufficiently investigated. In addition, these technologies have yet to be adapted into state structures to plan the innovative development programmes of regions.

2. Literature review

Overall, various scientists have studied the processes of simultaneous and financial planning. The available extant findings allow for individual perspectives on this issue by supplementing the already established technologies with production planning. Thus, Naumenkova and Glazun (2002) used simulation and analytical methods of quantitative analysis and forecasting to study the management processes of the investment and financial activity of an enterprise. By including the time parameter, the authors mutually linked the key variables and functional areas of the model created in time. Hahn and Kuhn (2012) found that since the aggregate planning of capital (one-time) investments is done in the long term, the detailed timing of their adjustment remains at the medium-term level. In combination with capacity control measures to optimise the use of assets, the time of capacity adjustment can also be used. The study presents a relevant technology for cost- and risk-based performance optimisation in supply chains, simultaneously covering investment, operations, and financial planning.

Nedosekin and Abdulaeva (2013), in their monograph, reviewed the models and methods of various planning options—strategic, investment, operational, and financial in a narrow sense—providing simplified types of plans while considering the issue of normalising plan parameters. Rytikov et al. (2014) presented a model of simultaneous planning and a corresponding tool that takes into consideration the conditions of financial feasibility, liquidity, and the impact of the tax burden. The model enables optimisation of the project financing scheme (its full financial plan) according to one of two criteria (maximum final property value or maximum net discounted income). The study showed that the proposed model makes it possible to find balanced financing schemes for investment projects, to determine the optimal sequence of commissioning their capacities, and to effectively use free funds generated by the project. In their monograph, Dinges and Pozdeyeva (2018) proposed methods for optimising the investment and financial programmes of road organisations, providing: (1) dynamic formulation of the problem for enterprise development in the short and medium term; (2) interrelated consideration of possible options for investment and financial activities of enterprises; and (3) an indicator that maximises the value of enterprise capital at the end of its implementation as a criterion for the optimality of programme formation.

The useful findings of these studies of simultaneous and financial planning, they should be used to create innovative development programmes for manufacturing companies and industrial regions. In this regard, the works of the following researchers are of separate interest. Fabiana et al. (2016) investigated how the technological innovation process occurs in small- and medium-sized technology companies located in the metropolitan region of Paraiba Valley and the Northern Coast of Brazil. The theoretical methodology they used consisted of the authors' six models of innovation: the technology push, the market pull, the coupling innovation process, the functional integration innovation process, the systems integration and networking innovation process, and open innovation. By observing models of innovative development adopted by companies, it appeared to the researchers that the models were closer to what was proposed as the chain interaction model. They concluded that the development of innovation depends on the type of economic activity that the company develops, and the interactions that it has with the internal and external environment.

Vasconcellos et al. (2016) argued that the resources invested in research do not guarantee immediate practical application. Companies and governments are increasingly looking for mechanisms to prioritise R&D projects when resources are scarce. Thus, the researchers aimed to develop and present a methodology that could be used to evaluate a research portfolio and to help select the best investment in research. The findings show that risk and return criteria should be used to manage an R&D portfolio when selecting projects. Thus, the problem of planning the costs of scientific research work (SRW) becomes relevant, and Feoktistova (2014) identified the following key principles in this process:

1) Understanding that scientific research work is a unique process, different in its characteristics from any other work, and requires a special methodological and legislative approach;

2) Using the project approach in planning R&D and its financing as the most effective and proven strategy in Russian and international practice;

3) Applying competitive principles of funding research projects and independent expert scientific evaluation, which allows for selecting truly best performers and ensuring high-quality results;

4) Selecting the expected results of a research project as one of the key criteria in planning the costs of the project;

5) Selecting the results already achieved by a potential contractor is the key criterion in determining the funding of a research project.

Gaponenko (2018) considered situations in which it is potentially possible to reduce the actual costs of conducting SRW, highlighting the following:

1) Carrying out SRW similar to the works carried out earlier by the same contractor, that is, a scientific organisation or a researcher.

2) Carrying out SRW close to what was previously done by other contractors—that is, scientific organisations.

3) Carrying out (possibly simultaneously) similar SRW for different customers.

4) Using previously obtained research results, previously collected findings in a new study in case the subjects of old and new research are not related.

5) Including in the terms of reference tasks that do not correspond to the goal of the SRW, the results of which can be used, for example, in another SRW or a publication, a patent.

Thus, there is a need to solve the problem of reducing the cost of SRW in such a way that it would increase the efficiency of the industrial regions' economies. For example, by predicting the evolution of the innovation system of a federal district using a multipurpose genetic algorithm, Yashin et al. (2020) showed that to increase its synergy effect, the federal district should redirect investment resources and SRW costs to regions where economic and financial resources are insufficient. This will eventually increase the average per-capita income in the regions of the federal district, which will, in turn, lead to population growth. In this regard, the issue of managing SRW costs in innovation-industrial clusters, which contribute to the socioeconomic development of the regions where these clusters are located, is relevant. For this purpose, it is necessary to solve the relevant problems of cluster management. Thus, Polyanin et al. (2020) developed scientific and methodological guidelines that can contribute to the timely identification of real and potential economic threats in a cluster. The authors created a methodology for assessing the economic security of a cluster that is characterised by a comprehensive approach that allows for all possible risks and threats in the functioning of individual components of the cluster structure.

Tashenova et al. (2020) developed a method for assessing the digital potential of backbone innovative active industrial clusters. The method was developed based on existing methods and approaches to assessing the innovation potential of industrial clusters and the digital potential of industrial enterprises, and enables calculation of the final integral assessment. The proposed method has been successfully tested on the example of the cluster "Development of information technology, radio electronics, instrumentation, communication, and information and telecommunication devices of St. Petersburg".

However, in a broader sense, the issue of managing SRW costs in an industrial region, rather than in its individual cluster, is important. To this end, regional SRW costs should be optimised. Thus, Xu (2018) found that innovation factor theory considers that regional investment in research and development (R&D) directly affects the new product development (NPD) indicators of the enterprise, and innovation efficiency theory considers that regional investment in R&D affects the NPD indicators of the enterprise, which, in turn, affect the internal efficiency of the enterprise's R&D. The researcher compared data from a Chinese provincial region with enterprise data from China's industrial enterprise database. The empirical results showed that the innovation factor theory and the innovation efficiency theory exist simultaneously. Regional investment in R&D can affect the NPD indicators of enterprises. However, investment in the R&D of other enterprises in the same region has a beneficial effect on the internal R&D efficiency of enterprises. Regional R&D investment in human resources positively affects the internal R&D performance of enterprises. According to the findings, the researcher formulated three policy recommendations: increasing regional investment in R&D, expanding and consolidating the enterprise as the basis for R&D status, and increasing regional investment in R&D in the area of human resources.

Chen et al. (2019), using a stochastic fixed-effects frontier model based on transregistration of the production function, estimated the elasticity of production and substitution of R&D in universities at the provincial level of China during 2009–2016. The authors found that the technical R&D efficiency of Chinese universities tended to become relatively stable after rapid growth. Increasing the degree of internationalisation and externalisation of R&D capabilities contributes to the technical efficiency of R&D, whereas spending on government subsidies hinders the technical efficiency of R&D; the effects of deepening R&D and internet connectivity are not evident. The production elasticity of R&D capital is much higher than that of R&D personnel, suggesting that R&D capital is the main driver of the research results. The elasticity of substitution between R&D capital and personnel has changed from replacement to addition since 2014. To ensure sustainable growth in research results, it is necessary to increase the contribution of R&D with positive output elasticity or to decrease the contribution of R&D with negative output elasticity by making the necessary compromises according to the ratio of substitution between the two R&D inputs.

Dobrzanski and Bobowski (2020) determined whether funds spent on R&D are used in the countries of the Association of Southeast Asian Nations (ASEAN). Fifteen countries were examined over the period of 2000–2016. R&D expenditure efficiency was measured using a non-parametric methodology of data envelopment analysis (DEA), which measures input–output efficiency. The study included the following cost and output variables: annual public and private spending on innovations, high-tech exports as a percentage of manufacturing exports, patent applications to the World Intellectual Property Organisation (WIPO) according to priority years for millions of residents, applications for trademarks (TK) for millions of residents, and information and communication technology (ICT) exports as a percentage of manufacturing exports. Hong Kong and the Philippines are found to be the top-performing countries in R&D when analysed using the constant return to scale (CRS) approach. However, according to the variable return to scale (VRS) approach, Hong Kong, Indonesia, Singapore, and the Philippines are the most efficient ASEAN countries. The study also confirmed that an increase in spending on innovation leads to disproportionate effects.

The solution to the above problems inspires the central question of the present research: How can SRW costs be optimised in an industrial region? Despite the unconditional importance of identifying the necessary parameters of the optimised target function, it is also necessary to determine the methods of global optimisation, that is, to choose those that will allow for obtaining the most reliable final solution to the problem. To solve this problem, we apply the following approaches, which are subsequently described in detail:

1) Genetic algorithm (GA)

2) Simulated annealing (SA)

3) Pattern search (PS)

Let us describe their advantages in more detail.

1. Evolutionary algorithms (genetic algorithms) are relatively new but very powerful methods used to find solutions to many real search and optimisation problems. Most of these problems have multiple objectives, which leads to the need to obtain a set of optimal solutions known as efficient solutions. The use of GAs has been found to be a highly effective way of finding multiple efficient solutions in a single simulation run (Kalyanmoy, 2001).

2. The annealing method makes it possible to avoid a "trap" in the local extrema of the function being optimised and to continue the search for a global extremum. Moreover, even in conditions of insufficient computing power for finding a global extremum, the annealing method usually provides a good solution—that is, one of the local extrema (Lopatin, 2005). A comparison of adaptive simulated annealing (ASA) and GAs revealed that the SA method does not lose to GAs in most problems, and even wins in a number of them (Ingber, and Rosen, 1992).

3. Direct search (pattern search) is a method for solving optimisation problems; it does not require any information about the gradient of the target function. Unlike more traditional optimisation methods that use information about the gradient or higher derivatives to find the optimal point, the PS algorithm looks for a set of points around the current point to identify the point where the value of the target function is lower than the value at the current point. A direct search can be used to solve problems for which the target function is not differentiable or even continuous (Conn et al., 1991; Conn et al., 1997; Kolda et al., 2006).

Thus, using three different algorithms to optimise SRW costs, we can test the resulting solution.

3. Materials and methods

The optimisation of the SRW costs for the industrial region is carried out considering the following factors:

1. Investment planning. For this, we used information on the dynamics of investment in fixed capital in the region.

2. Production planning. Here, we relied on data on the dynamics of the gross regional product (GRP).

3. Financial planning. Given that in this task, we considered the possibility of external financing, which provides an additional opportunity for industrial companies in the region to develop their innovations, we use information about the dynamics of organisations' accounts payable.

Thus, the optimisation of the SRW costs is dependent on the simultaneous processes of investment, production, and financial planning, which allows for obtaining the most effective combination of the values of these three factors. It is also necessary to define what is meant by the optimisation of the SRW costs: their maximisation or minimisation. Obviously, in the ideal case, it is necessary to investigate the problem of finding opportunities to increase SRW costs, because in this case, the industrial region will develop more intensively due to receiving and implementing new technologies, which, in turn, will have a positive effect on the innovative development of the whole country. However, we look for possibilities to decrease the costs of SRW to that optimal value, which will be achievable by simultaneous investment and industrial and financial planning of the region, allowing us to determine the most expedient proportions of the three listed planning factors in monetary terms.

Lastly, the regional model of simultaneous investment, production, and financial planning of innovative development programmes should be sufficiently detailed; thus, several target functions of the internal current costs of SRW for an industrial region are investigated: the total costs of SRW and their three components—basic research, applied research, and developments. This eventually allows us to draw more reasonable conclusions about how an industrial region should develop its internal current costs of SRW, depending on the planning of investment in fixed capital, GRP, and accounts payable of organisations.

Taking these assumptions into consideration, we present the stages of implementing the model under consideration in Fig. 1, followed by a detailed description of the stages.

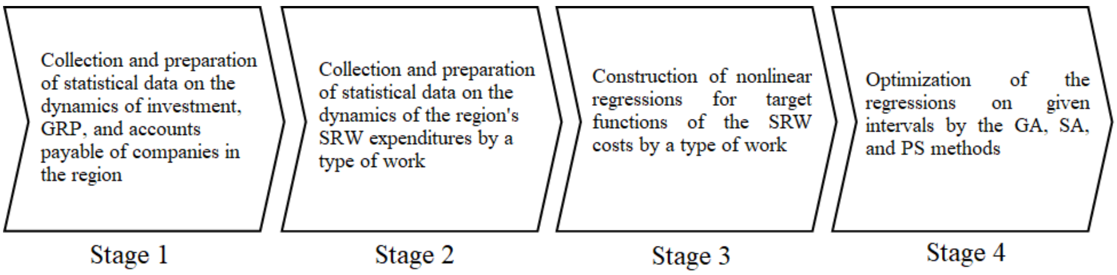

Figure 1. Stages of implementing the regional model of simultaneous investment, production, and financial planning of innovative development programmes

Stage 1 – Collection and preparation of statistical data on the dynamics of investment, GRP, and accounts payable of companies in the region. To construct high-quality future nonlinear regressions of the target functions of SRW expenditure, we needed data on the dynamics of investment in fixed capital (x1), GRP (x2), and accounts payable of organisations (x3) over a long period covering 10 years. Since the website of the Federal State Statistics Service1 contains data on the internal current costs of SRW, investment in fixed capital, and accounts payable of organisations for the period up to and including 2020, but there are no such data on GRP for 2019 and 2020, we forecast them ourselves using WolframAlpha2. Further, to make the collected data comparable, they were adjusted by all the annual inflation rates for the period under consideration.

[1] the Federal State Statistics Service. Available at: https://www.gks.ru
[2] WolframAlpha. Available at: www.wolframalpha.com

Stage 2 – Collection and preparation of statistical data on the dynamics of the region's SRW expenditures by type of work. At this stage, statistical information was collected about the internal current costs of SRW in total (*y*), as well as by type of work: basic research (*y*1), applied research (*y*2), and developments (*y*3). These data were also for the same period covering 10 years as the period of the previous stage, and were also adjusted by all the annual inflation rates for the period in question.

Stage 3 – Construction of nonlinear regressions for target functions of SRW costs by type of work. Nonlinear regressions reflect economic processes more realistically than linear ones. Moreover, in our case, regressions of the form $y = f(x_1, x_2, x_3)$ were multiple. To obtain them, we used the *Statistica* package. We judged the quality of the target function regressions by the determination coefficient (*R*2) and the adjusted *R*2, that is, by the closeness of their values to 1.

Stage 4 – Optimisation of the regressions on given intervals by the GA, SA, and PS methods. This global optimisation was performed with *Matlab* using GA, SA, and PS. To refine the results of the GA and SA methods, we supplemented the optimisation results of the target functions with the hybrid functions of PS and the inner point method (Babynin and Zhadan, 2008). That is, the GA or SA algorithms were run first, and then their results were used as a starting point for the subsequent optimisation of the target function using the hybrid function. This provided a better solution in each case of optimisation of all costs of SRW, basic research, applied research, and developments.

In addition, if we do not set the lower and upper values of each parameter of the target function of the corresponding SRW costs, its minimum value can turn out to be minus infinity. Therefore, for each parameter *x*1, *x*2, *x*3 of the corresponding target function, we set their actual lower and upper values for the period under study. This approach also allowed us to compare the optimal (minimum) value of the corresponding SRW costs with their actual minimum value for the period under study.

4. Results and discussion

In what follows, we illustrate the implementation of the presented model using the example of the Nizhny Novgorod region, which is a large industrial region.

Stage 1 – Collection and preparation of statistical data on the dynamics of investment, GRP, and accounts payable of companies in the region. At this stage, the necessary raw data were collected from the website of the Federal State Statistics Service1. These are presented in columns x1, x2, and x3 in Table 1. Since the above website contains data on internal current expenditures on SRW only for the period from 2015 to 2020, as well as for 2010, we selected the data on investment in fixed capital and accounts payable of organisations for the same years. To make the collected data comparable, we corrected them for all the annual inflation rates for the period in question, according to the data in Table 2. Thus, all the data in Table 3 are presented in the 2020 prices.

Table 1. Initial data on the Nizhny Novgorod region (million rubles)

Years	Investments in fixed capital, x_1	Gross regional product, x_2	Accounts payable of organisations, x_3	Internal current expenses on SRW by type of work			
				Total, y	Basic research, y_1	Applied research, y_2	Developments, y_3
2010	192072.4	652805.9	313700	26992.8	1224.7	4211.6	21556.4
2015	235066.7	1104643.2	623100	56870.6	1912.0	5222.2	49736.4
2016	232010.4	1160782.3	836700	66317.1	1901.6	6592.4	57823.2
2017	245268	1261939.4	869200	64278.4	2026.0	6620.8	55631.5
2018	259392.9	1367544	999200	66202.2	2219.5	9123.8	54858.9
2019	295252.2		1249100	76896.2	4738.0	9506.0	62652.2
2020	383102.1		1425600	68750.3	5220.1	8560.3	54969.9

Table 2. Annual rates of inflation (%)

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
8.78	6.1	6.58	6.45	11.36	12.91	5.38	2.52	4.27	3.05	4.91

Table 3. Initial data on the Nizhny Novgorod region in 2020 prices (million rubles)

Years	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Internal current expenses on SRW by type of work			
				Total	Basic research	Applied research	Developments
	x_1	x_2	x_3	y	y_1	y_2	y_3
2010	354041.7	1203298.9	578234.4	49755.1	2257.5	7763.1	39734.3
2015	286274.2	1345281.2	758837.5	69259.4	2328.5	6359.8	60571.1
2016	268126.9	1341478.2	966946.9	76640.5	2197.6	7618.6	66824.4
2017	276480.9	1422534.3	979814.8	72458.5	2283.8	7463.4	62711.2
2018	280429	1478448.5	1080232.7	71571	2399.5	9863.7	59307.8
2019	309749.1	1462385.4	1310430.8	80671.8	4970.6	9972.7	65728.4
2020	383102.1	1474349.6	1425600	68750.3	5220.1	8560.3	54969.9

We also solved the problem of the lack of data on GRP for 2019 and 2020 on the website of the Federal State Statistics Service. We forecast them independently in the 2020 prices using, for this purpose, the period from 2009 to 2018 and *WolframAlpha*[2] (Fig. 2):

Cubic polynomial (formula 1):

$$2733.04x^3 - 50181.7x^2 + 293422x + 831795 \quad (1)$$

$R^2 = 0.962$, adjusted $\boldsymbol{R}^2 = 0.943$

Quartic polynomial (formula 2):

$$239.151x^4 - 2528.28x^3 - 11678.4x^2 + 188195x + 913872 \quad (2)$$

$R^2 = 0.97$, adjusted $\boldsymbol{R}^2 = 0.946$

Logarithm (formula 3):

$$137502 \ln x + 1.13267 \cdot 10^6 \quad (3)$$

$R^2 = 0.811$, adjusted $\boldsymbol{R}^2 = 0.787$

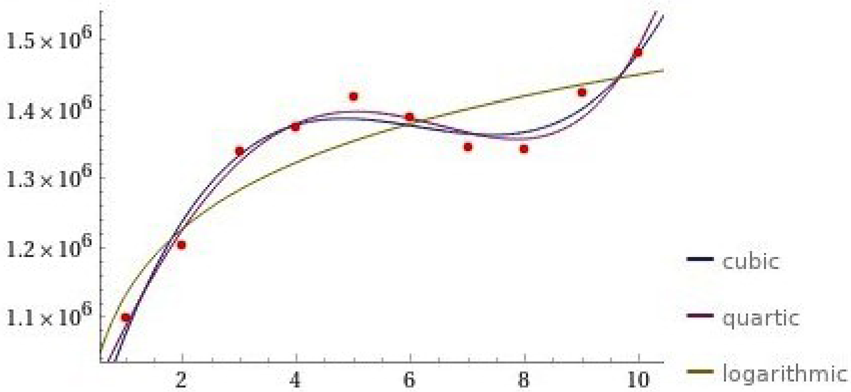

Figure 2. Graphs of the three best forecast functions of the GRP of the Nizhny Novgorod region in 2020 prices (million rubles)

Despite the lowest $R2$ and adjusted $R2$ values, the forecast, according to the natural logarithm, seems the most plausible from an economic point of view, since in 2020, we expect the GRP values to decrease due to the pandemic.

Stage 2 – Collection and preparation of statistical data on the dynamics of the region's SRW expenditures by type of work. At this stage, statistical information was collected on the internal current costs of SRW in total and the type of work: basic research, applied research, and developments. They are presented in columns y, $y1$, $y2$, and $y3$, respectively, in Table 1. The data are for the same period of time as in the previous stage. They were also adjusted by all the annual inflation rates for the period under consideration (Table 2). The results are presented in Table 3.

Stage 3 – Construction of nonlinear regressions for target functions of the SRW costs by type of work. Based on the values in Table 3, the following most accurate nonlinear regressions were obtained in the *Statistica* package:

Regression for all SRW costs (formula 4):

$$y = 1741889 - 0.8089667x_1 - 0.4449632x_2 - \frac{75140630000}{x_1} - \frac{715718200000}{x_2} - \frac{36550920000}{x_3} \quad (4)$$

$$\boldsymbol{R}^2 = 0.999\text{, adjusted } \boldsymbol{R}^2 = 0.995$$

Regression for basic research (formula 5):

$$\mathrm{y}_1 = 25140.5 - 0.04\mathrm{x}_3 \quad (5)$$

$$\boldsymbol{R}^2 = 0.992\text{, adjusted } \boldsymbol{R}^2 = 0.985$$

Regression for applied research (formula 6):

$$\mathrm{y}_2 = 5310.287 + 0.003\mathrm{x}_3 \quad (6)$$

$$\boldsymbol{R}^2 = 0.41\text{, adjusted } \boldsymbol{R}^2 = 0.292$$

Regression for developments (formula 7):

$$\mathrm{y}_3 = -814037 + \mathrm{x}_2 \quad (7)$$

$$\boldsymbol{R}^2 = 0.9999\text{, adjusted } \boldsymbol{R}^2 = 0.9996$$

Stage 4 – Optimisation of the regressions on given intervals by the GA, SA, and PS methods. This global optimisation was performed in the *Matlab* package. GA, SA, and PS were used for this purpose. To refine the results of the GA and SA methods, the optimisation results of the target functions were supplemented with hybrid functions of the PS and interior point methods (fmincon). To this end, all target functions were investigated on the segments of actual values of parameters $x1$, $x2$, and $x3$ for the period under study, according to Table 3, that is, $x_1 \in [268126.9; 383102.1]$, $x_2 \in [1203298.9; 1478448.5]$, and $x_3 \in [578234.4; 1425600]$. The results of optimisation for all costs of SRW, basic research, applied research, and developments are presented in Tables 4-7.

Table 4. Global optimisation results for regression for all SRW costs (million rubles)

Algorithm	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Total SRW costs
	x_1	x_2	x_3	y
GA	383 039.2	1 473 402.4	582 875.9	31 776.3
GA + fmincon	383 102.1	1 478 448.5	578 234.4	30 666.8
GA + PS	383 102.1	1 478 448.5	578 234.4	30 666.8
SA	363 744.5	1 203 308.3	578 253.4	47 626.6

SA + fmincon	383 102.1	1 203 298.9	578 234.4	42 402.3
SA + PS	383 101.9	1 478 448.1	578 235.1	30 667
PS	383 102.1	1 478 448.5	578 234.4	30 666.8

Table 5. Optimisation results for regression for basic research (million rubles)

Algorithm	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Basic research
	x_1	x_2	x_3	y_1
Analytically	-	-	25,140.5	0

Table 6. Optimisation results for regression for applied research (million rubles)

Algorithm	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Applied research
	x_1	x_2	x_3	y_2
Analytically	-	-	0	5,310.3

Table 7. Optimisation results for regression for developments (million rubles)

Algorithm	Investments in fixed capital	Gross regional product	Accounts payable of organisations	Developments
	x_1	x_2	x_3	y_3
Analytically	-	814 037	-	0

As shown in Table 4, the PS algorithm is the most ideal method for solving the problem in question. In addition, adding this algorithm as a hybrid function for the GA or SA allows for achieving a rather high-quality solution to the optimisation problem. On the contrary, adding the interior point method (fmincon) as a hybrid function did not always significantly improve the quality of global optimisation.

Comparing the optimal (minimum) value of the relevant costs of SRW with their actual minimum value for the period under study, we draw the following conclusions:

For all internal current costs of SWR, based on the results in Table 4:

1. The global optimisation algorithms allow planning the minimum of all SRW costs (30,666.8 million rubles), which is less than the minimum value observed in the period under study (49,755.1 million rubles).

2. It is possible to achieve the minimum of all SRW costs at the maximum observed investments in fixed capital (383,102.1 million rubles), the maximum GRP (1,478,448.5 million rubles), and the minimum accounts payable of organisations (578,234.4 million rubles). This means that investment and GRP volume should be increased, and the debt of organisations should be reduced.

For basic research, based on the type of regression and the results of Table 5:

1. The amount of spending on basic research depends only on the accounts payable of organisations.

2. Reducing this debt below 25,140.5 million rubles requires spending on basic research.

3. An increase in debt above 25,140.5 million rubles is inexpedient, because it leads to an outflow of necessary funds for basic research.

For applied research, based on the type of regression and the results of Table 6:

1. The amount of spending on applied research depends only on the accounts payable of organisations.

2. The minimum value of these costs (5,310.3 million rubles) is achieved in the absence of the debt under consideration.

3. The increase in this debt requires an increase in the cost of applied research.

For developments, based on the type of regression and the results of Table 7:

1. The amount of spending on developments depends only on the GRP.

2. The increase in the amount of GRP above 814 037 million rubles requires development costs.

3. Reducing the amount of GRP below 814 037 million rubles is inexpedient because it leads to an outflow of necessary funds for developments.

Comparing the obtained results with the findings of other researchers, we observed that for planning R&D and financing, Feoktistova (2014) highlighted the use of the project approach, indicating the choice of the expected results of the research project as one of the key criteria, and the choice of the results already achieved by the research project by its potential contractor as the key criterion.

Gaponenko (2018) also considered situations in which it is potentially possible to reduce the actual cost of performing SRW: (1) performing SRW similar to work previously performed by the same contractor—that is, a scientific organisation or researcher; (2) performing SRW similar to work previously performed by other contractors—that is, scientific organisations; performing (possibly simultaneously) similar SRW for different customers; (3) using previously obtained research results, previously collected findings in a new study in case the unrelated old and new research topics; and (4) including in the terms of reference tasks that do not correspond to the purpose of research, the results of which can be used, for example, in another study, publication, or patent.

We propose reasonable quantitative guidelines for planning the costs of SRW in an industrial region, obtained as a result of conventional and global optimisation of the indicated costs. The presented model will allow state agencies and their experts to make better decisions regarding the planning of innovative development of industrial regions in the country.

5. Conclusion

The following are the most important conclusions from the results of the study:

1. The regional model for planning of innovative development programmes implies optimisation of internal current costs of SRW for an industrial region, depending on its investment planning according to the data on the dynamics of investment in fixed capital in the region, production planning according to the data on the dynamics of GRP, and financial planning according to the data on the dynamics of accounts payable of organisations.

2. Under optimisation of the SRW costs, we understand the possibilities to reduce them to that optimal value, which will be achievable with simultaneous investment, production, and financial planning of the region, allowing determining the most appropriate proportions of the above three planning factors in monetary terms.

3. The presented regional model should be sufficiently detailed, for which purpose several target functions of the internal current costs of SRW for an industrial region are investigated: the total costs of SRW and their three components—basic research, applied research, and developments. This will eventually allow for drawing more reasonable conclusions on how an industrial region should develop its internal current costs of SRW, depending on the planning of investments in fixed capital, GRP, and

accounts payable of organisations.

4. The most ideal for solving the problem under consideration is the PS algorithm. In addition, adding this algorithm as a hybrid function for the GA or SA allows for achieving a sufficiently high-quality solution to the optimisation problem. On the contrary, adding the inner point method as a hybrid function does not always significantly improve the quality of global optimisation.

5. In the Nizhny Novgorod region, to minimise all the internal current SRW costs, it is necessary to increase investment in fixed capital and GRP volume, as well as to reduce the amount of accounts payable by organisations.

6. However, for basic research, there is a limit of indebtedness of organisations, the exceeding of which is inexpedient, because it leads to an outflow of necessary funds for basic research.

7. The increase in this debt also leads to an increase in the cost of applied research.

8. For developments, there is a lower limit of the GRP amount, below which it is inadvisable to go, as it leads to the outflow of the necessary funds for developments. Since developments constitute the main part of all SRW costs and the management of GRP, production constitutes the main part of the successful financing of all SRW costs in the industrial region under consideration.

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About the authors:

1. Dmitrii Rodionov, Doctor of Economics, professor, Head of Graduate School of Industrial Economics, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia.
drodionov@spbstu.ru, https://orcid.org/0000-0002-1254-0464

2. Egor Koshelev, candidate of economic science, Associate Professor of the Department of Management and Public Administration, Lobachevsky State University of Nizhny Novgorod, Nizhny Novgorod, Russian Federation. ekoshelev@yandex.ru, https://orcid.org/0000-0001-5290-7913

3. John Gayomey, Lecturer, Department of Accountancy, Tamale Technical University, Tamale, Ghana. gayomey@hotmail.com

4. Olga Ferraro, Ph.D. in Business Administration, Resercher of the Department in Business Administration and Law, University of Calabria, Italy. olga.ferraro@unical.it, https://orcid.org/0000-0001-7070-2815

Информация об авторах:

1. Дмитрий Григорьевич Родионов, доктор экономических наук, профессор, директор Высшей инженерно-экономической школы, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Российская Федерация. drodionov@spbstu.ru, https://orcid.org/0000-0002-1254-0464

2. Егор Викторович Кошелев, кандидат экономических наук, доцент кафедры менеджмента и государственного управления, Нижегородский государственный университет им. Н.И. Лобачевского, Нижний Новгород, Российская Федерация. ekoshelev@yandex.ru, https://orcid.org/0000-0001-5290-7913

3. Джон Гайомей, преподаватель кафедры бухгалтерского учета Технического университета Тамале, Тамале, Гана. gayomey@hotmail.com

4. Ольга Ферраро, PhD в области делового администрирования, преподаватель кафедры делового администрирования и права, Университет Калабрии, Италия. olga.ferraro@unical.it, https://orcid.org/0000-0001-7070-2815