

Assessment of Innovative Development of the Russian Economy and Mathematical Modelling

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ABSTRACT

In the article, the authors have developed the method for assessing the innovative development of the Russian economy. For this, an index analysis of the following factors has been carried out: the number of organisations and workers performing research and development; financing innovative activities; advanced manufacturing (nano)technologies in the process brought to the consumer; application of innovative technologies and objects of intellectual property. The integral indicators characterising their changes have been calculated, and the levels of innovative development of the Russian economy have been determined. Then, using the tools of mathematical modelling, a multi-factor mathematical model has been built and tested in real-time that enabled to obtain a high-quality predicted result. Based on the obtained forecasts, it is possible to state the need to adjust specific indicators that actively affect innovative development, which is a mathematical justification for making managerial decisions when developing strategies and programs related to the technological and digital modernisation of the Russian economy.

Keywords: *Innovative development, Evaluation methodology, Integral indicator, Mathematical modelling.*

1. INTRODUCTION

The relevance of the research topic is because there is a lack of scientific knowledge in the development of methods for assessing the innovative development of the economy. Since the first publication in 1911, related to the theory of innovation (Schumpeter J.), the terminology is being enriched; there are many similar categories (innovation: economy, process, activity, activity, etc.) and a significant number of regulatory documents describing the innovation [1-5]. All this complicates the assessment of the innovative development of the economy.

Given the shortcomings of publications on this issue, for example, in the works of Asadova S.S. [6], Belski V., Trigubovich L. [7], Luchko M., Szmitka S., Dmuchowski R. [8], the approach to accounting indicators with different units of measurement is not considered. In the works of Delgado M., Porter M., Stern S. [9], Hilty L., Aebischer B. [10], Lee S.J., Lee E.H., Oh D.S. [11] - there are no mathematical models for the study of economic processes. Along with that, in the articles of

Njos R., Jakobsen S.E. [12], Yoon D. [13], while the statistical information is enclosed, there is no mathematical apparatus given for research and the possibility of obtaining forecasts. Whereas the capabilities of the current state of mathematics and computer technology enable to obtain high-quality, reliable forecasts based on mathematical models, as evidenced by publications in the field of economics [14-15], medicine [16-17], and technology [18-20].

The authors proposed a variant of a mathematical model for research and justification of the measures to improve the quality of indicators of innovation development of the economy. Thus, the purpose of the article is to develop a methodology for assessing the innovative development of the Russian economy using building mathematical models to obtain a high-quality predictable result.

2. RESEARCH METHODOLOGY

At the initial stage, a sample of the most important criteria for assessing the innovative development of the

economy, which are the objects of this study, is formed [21] table 1.

In an enlarged form, it includes a variety of indicators, but for simplification and efficiency of calculations, based on PEST-analysis, twelve factors with a significant impact on the innovative development of the economy have been identified (table 1). The selected factors are provided with accessible information from the website of the Federal state statistics service and are to be added to the index value (in % of the previous year) in tables 2-5

to allow their consideration in calculating the integral indicator.

3. THE RESULTS OF THE STUDY

The information presented in table 1 is heterogeneous in terms of units of measurement and requires preliminary processing to be included in the study. The paper proposes the use of the technology of the index analysis method [14-15], which allows authors to aggregate a wide range of quantitative indicators of

Table 1. Current indicators characterising the innovative development of the Russian economy in 2010-2019.

Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
<i>OESRD - indicators characterising the number of organisations and employees performing scientific research and development</i>										
The number of organisations performed research and development, units	3492	3682	3566	3605	3604	4175	4032	3944	3950	4051
The number of personnel engaged in scientific research and development, thousand people	736.5	735.3	726.3	727.0	732.3	738.9	722.3	707.9	682.6	682.5
<i>FIA - indicators characterising the financing of innovation activity</i>										
Costs of innovation activity, billion rubles	400.8	733.8	904.6	1112.4	1211.9	1200.4	1284.6	1405.0	1472.8	1954.1
Funding of science from the Federal budget, billion rubles	237.6	313.9	355.9	425.3	437.3	439.4	402.7	377.9	420.5	489.2
Internal research and development costs, billion rubles	523.4	610.4	699.9	749.8	847.5	914.7	943.8	1019.2	1028.2	1134.8
<i>MTPBC - indicators characterising advanced manufacturing (nano)technologies, being delivered to the consumer</i>										
Developed advanced production technologies, units	864	1138	1323	1429	1409	1398	1534	1402	1565	1620
The number of developed nanotechnologies, units	222	258	327	411	443	505	494	446	402	555
Patent applications filed, units	58759	58852	62920	64266	59444	62352	58163	53584	53612	52567
<i>ITOIP - indicators characterising the innovative technologies and intellectual property objects used</i>										
Domestically-made goods shipped, including innovative goods, works and services, billion rubles	1243.7	2106.7	2872.9	3507.9	3579.9	3843.4	4364.3	4167.0	4516.3	4863.4
Information about the use of intellectual property objects, thousand units	19.6	22.3	23.6	24.9	26.7	29.1	32.8	33.0	3.8	47.2
Used advanced production technologies, thousand units	203.3	191.7	191.4	193.8	204.5	218.0	232.4	240.1	254.9	262.6
Number of active patents, thousand units	304.3	281.3	302.8	320.4	342.8	354.2	361.5	375.0	393.6	39.3

innovative economic development, which have different units of measurement and are not comparable with each other without standardisation of values. Based on certain factors taken from the table 1, table 2 is compiled, reflecting the index values of indicators that characterise the number of organisations and employees performing research and development in the Russian Federation in 2010-2019.

Based on the following factors in table 2, an integral indicator is calculated using the formula (1), which characterises the number of organisations and employees performing scientific research and development (I_{OESRD}) (in points):

$$I_{OESRD} = \sqrt[2]{I_{OESRD} * I_{NPSRD}} \tag{1}$$

where I_{OESRD} - index changes in the number of organisations engaged in scientific research and development, %;

I_{NPSRD} - index of changes in the number of personnel engaged in scientific research and development, %.

Then, based on the data taken from table 1, table 3 is compiled, reflecting changes in indicators that characterise the financing of innovation activities in the Russian Federation in 2010-2019.

The figures from table 3 are used to calculate the integral indicator that characterises the financing of innovation activities (I_{FIA}), according to the formula (2) (in points):

$$I_{FIA} = \sqrt[3]{I_{CIA} * I_{SFFB} * I_{IESRD}} \tag{2}$$

where I_{CIA} - index of changes costs in innovation activity, %;

I_{SFFB} - index of changes in science funding from the Federal budget, %;

I_{IESRD} - index of changes in internal expenditures on science research and development, %.

Then, consider the following group of factors taken from table 1, table 4 is formed, reflecting the index values of indicators that characterise advanced manufacturing (nano)technologies that are to be delivered to the consumer of the Russian Federation in 2010-2019.

The values of table 4 are necessary for calculating an integral indicator that characterises advanced manufacturing (nano)technologies delivered to the consumer (I_{ATPBC}) using the formula (3) (in points):

$$I_{ATPBC} = \sqrt[3]{I_{DAT} * I_{NDN} * I_{FPA}} \tag{3}$$

where I_{DAT} - index of changes in developed advanced production technologies, %;

I_{NDN} - index of changes in the number of developed nanotechnologies, %;

I_{FPA} - index of changes in filed patent applications, %.

Finally, on the remaining group of factors in table 1, table 4 is formed, reflecting the index values of indicators that characterise advanced manufacturing (nano)technologies delivered to the consumer in the future of the Russian Federation in 2010-2019.

Based on the data of table 5, an integral indicator describing the use of innovative technologies and intellectual property objects (I_{UITOIP}) is calculated under the formula (4) (in points):

$$I_{UITOIP} = \sqrt[4]{I_{SGOP} * I_{UIPO} * I_{UAT} * I_{NAP}} \tag{4}$$

where I_{SGOP} - index of changes in shipped goods of domestic production, including innovative goods, works, services, %;

I_{UIPO} - index of changes in the information on the use of intellectual property objects, %;

Table 2. Dynamics of changes in indicators describing the number of organisations and employees performing research and development in the Russian Federation in 2010-2019, in % compared to the previous year

Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Index of changes in the number of organisations that performed research and development	97.4	105.4	96.8	101.1	99.9	115.8	96.6	97.8	100.2	102.6
Index of changes in the number of employees engaged in scientific research and development	100.1	99.8	98.8	100.1	100.7	100.9	97.8	98.0	96.4	99.9
An integral indicator that describes the number of organisations and employees performing research and development, points	98.7	102.6	97.8	100.6	100.3	108.1	97.2	97.9	98.3	101.2

Table 3. Dynamics of changes in indicators characterising the financing of innovation activities in the Russian Federation in 2010-2019, %, in comparison with the previous year

Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Index of changes in innovation activity costs	70.6	183.1	123.3	123.0	108.9	99.0	107.0	109.4	104.8	132.7
Index of changes in science funding from the Federal budget	86.2	132.1	113.4	119.5	102.8	100.5	91.7	93.8	111.3	85.6
Index of changes in domestic research and development expenditures	92.3	116.7	114.7	107.1	113.0	107.9	103.2	108.0	100.9	110.4
Integral indicator characterising financing of innovation activity, points	82.5	141.3	117.1	116.3	108.2	102.4	100.4	103.5	105.6	107.8

I_{UAT} - index of changes and used advanced production technologies, %.

I_{NAP} - index of changes in the number of patents in force, %.

Thus, we come to the formula (5) for calculating the integral indicator of innovative development of the economy ($II_{I.D.E.}$), (in points):

$$II_{I.D.E.} = \frac{II_{OESRD} + II_{FIA} + II_{ATPBC} + II_{UITOIP}}{4} \quad (5)$$

where II_{OESRD} an integral indicator that characterises the number of organisations and employees performing scientific research and development, points;

II_{FIA} - an integral indicator that characterises the financing of innovation activities, points;

II_{ATPBC} - an integral indicator characterising advanced manufacturing (nano)technologies that are in the process of being brought to the consumer, points;

II_{UITOIP} - an integral indicator describing the use of innovative technologies and intellectual property objects, points.

The values of the integrated indicator of innovative development of the economy ($II_{I.D.E.}$) are presented in table 6.

Based on our calculations, we determine the following levels of innovative development of the

Russian economy:

$II_{I.D.E.} > 110,0$ points - high level;

$100,0 < II_{I.D.E.} < 110,0$ points - medium level;

$II_{I.D.E.} < 100,0$ points - low level.

The results of calculations indicate that in the analysed period, the level of innovative development of the Russian economy was mainly average, and only in 2010 and 2017 it fell below 100.0 points and amounted to 92.7 and 98.4 points, respectively. In 2011, this level rose to a record 118.3 points (for 2010-2019) and in 2012 – to 110.8 points.

Based on the correlation analysis and elimination of correlation of factors presented in Table 6, the structure of the multi-factor model was optimised, gradually eliminating the 4th and then the 3rd factors from

Table 4. Dynamics of changes in indicators that characterise advanced manufacturing (nano)technologies delivered to the consumer in Russian Federation in 2010-2019, in % of the previous year

Indicators	for 2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Index of changes in raw advanced production technologies	86.3	131.7	116.3	108.0	98.6	99.2	109.8	91.4	111.6	103.5
Index of changes in the number of developed nanotechnologies	92.5	116.2	126.8	125.7	107.8	114.0	97.8	90.3	90.1	138.1
Index of changes in filed patent applications	99.9	100.2	106.9	102.1	92.5	104.9	93.3	92.1	100.1	98.1
An integral indicator that characterises advanced manufacturing (nano)technologies delivered to the consumer, points	92.7	115.3	116.4	111.5	99.4	105.9	100.1	91.3	100.2	111.9

Table 5. Dynamics of changes in indicators characterising the use of innovative technologies and intellectual property objects in Russian Federation in 2010-2019, in % compared to the previous year

Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Index of changes in shipped domestically-made goods, including innovative goods, works, and services	74.2	169.3	136.4	122.1	102.1	107.4	113.6	95.5	108.4	107.7
Index of changes in information about the use of intellectual property objects	93.6	113.6	106.1	105.6	107.2	109.0	112.4	100.7	120.7	118.6
Index of changes and applied advanced manufacturing technologies	103.0	94.3	99.9	101.3	105.6	106.6	106.6	103.3	106.2	103.0
Index of changes in the number of active patents	103.9	92.4	107.6	105.8	107.0	103.3	102.1	103.7	104.9	101.4
Integral indicator describing the use of innovative technologies and intellectual property objects, points	92.9	113.8	111.7	108.4	105.5	106.6	108.6	100.7	109.9	107.5

consideration. As a result, we get the structure of a multivariate model of the form:

$$Y = a_0 + a_1x_1 + a_2x_2 \tag{6}$$

where

$$a_0=19.95928615, a_1=0.372341289, a_2=0.439462288$$

The resulting multivariate regression equation has a multiple determination coefficient $R_2=0.9239$. The significance of the regression equation was confirmed

using the Fisher test at the significance level $\alpha=0.05$ and $F_{cr}=4.45; F_{obz}=42.5098216$. The competing hypothesis

$H_1 : R^1 = 0$, which confirms the significance of the constructed multi-factor model (6). A geometric interpretation of the model is shown in figure 1.

The constructed multi-factor regression model (6) was tested on data from 2010 to 2018. Coefficients have values: $a_0=21,99993465; a_1=0,347532675; a_2=0,441420119$. The coefficient of multiple

Table 6. Integrated indicator of innovative economic development of the Russian Federation in 2010-2019, in points

Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Integrated indicator of innovative economic development, points ($II_{I.D.E.}$)	91.7	118.3	110.8	109.2	103.4	105.8	101.6	98.4	103.5	107.1
An integral indicator that describes the number of organisations and employees performing research and development, points (II_{OESRD})	98.7	102.6	97.8	100.6	100.3	108.1	97.2	97.9	98.3	101.2
Integral indicator that characterises financing of innovation activity, points (II_{FLA})	82.5	141.3	117.1	116.3	108.2	102.4	100.4	103.5	105.6	107.8
An integral indicator that characterises advanced manufacturing (nano)technologies that are in the process of being brought to the consumer, points (II_{ATPBC})	92.7	115.3	116.4	111.5	99.4	105.9	100.1	91.3	100.2	111.9
Integral indicator that characterises the use of innovative technologies and intellectual property objects, points (II_{UITOIP})	92.9	113.8	111.7	108.4	105.5	106.6	108.6	100.7	109.9	107.5

determination $R_2=0,933628391$. The significance of the model is confirmed by the Fisher criterion at the significance level $\alpha=0,05$ and $F_{cr}=4,54$; $F_{obz}=42,20004923$. The competing hypothesis $H_1: R^1 \neq 0$. The significance of the constructed multi-factor model is confirmed.

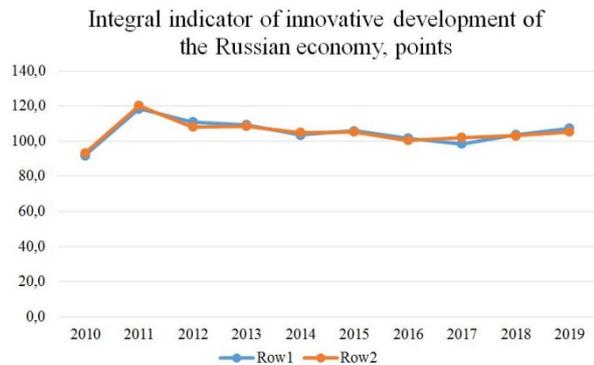


Figure 1 Geometric interpretation of a multi-factor model, where row 1 is the source information, row 2 is the multi-factor model.

The confidence interval of the predicted value of the index of innovative development of the economy of $II_{I,D,E.} = Y_{2019}$

$$95.9549 \leq Y_{2019} \leq 109.5978.$$

Considering that in 2019 the actual value of $II_{I,D,E.}$

is within the obtained confidence interval and is 107.8 points, which indicates the accuracy of the predicted values for the innovative development rates describing the state of the Russian economy.

4. DISCUSSION OF RESULTS

Similarly, the confidence interval of the predicted value of $II_{I,D,E.}$ for 2020 was obtained:

$$97,0257 \leq Y_{2020} \leq 113,0028.$$

Its range is higher than the indicators of 2019, which proves the effectiveness of measures implemented within the framework of the "Strategy for Scientific and Technological Development of the Russian Federation", "Strategy for Innovative Development of the Russian Federation for the Period until 2020" and the state program "Economic Development and Innovative Economy" related to technological and digital modernisation.

The analysis of II_{OESRD} revealed that for 2010-2019. The total change in the index of the number of organisations performing research and development was 9.2%, and the index of changes in the number of personnel engaged in research and development – 0.05%. Accordingly, the first parameter has a more significant impact on the integral indicator, which characterises the

number of organisations and employees performing research and development.

Analysis of II_{FIA} shows that over the analysed period, the total change in the indices had the following values: 188.9% of innovation expenditures, 108.5% of science funding from the Federal budget, and 122.6% of internal research and development expenditures. Consequently, the change in the innovation expenditure index had the most significant impact on the integral indicator that characterises innovation financing.

5. CONCLUSIONS

Thus, the developed algorithm is a unique tool for assessing the innovative development of the Russian economy. It is a universal and accurate means of forecasting for the next period and has excellent potential for further research since it can be used to assess the impact of not only innovative factors but also economic, social, political, legal, environmental and other indicators on the development of the country, Federal districts and regions. The methodology could serve as one of the bases for legislative and executive authorities in the development of socio-economic projects and programs.

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