Efficiency of innovation sector development: the linear and non-linear models of innovative economy building development

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Abstract. The author discusses the problems of the efficiency of innovation sector development: the linear and non-linear models of innovative economy building development. Currently, an active economy transition to a new technological mode and mainstreaming of innovation as a key factor in economic development are taking place all over the world. The Russian Federation is no exception. The undergoing investment policy should be aimed at ensuring the conditions that promote increasing in the rate and efficiency of innovation sector development. Today, the influence of factors determining the conditions for innovative development of the Russian economy, in general, and its regions in particular, is ambiguous. The purpose of this paper is to give a correlation and regression analysis for assessment of factors that impact the innovative activity of the state. Based on the analysis of trends in implementation of the Russian innovation activities over a period of 2000–2018, the paper specifies their strong and weak aspects. In virtue of the correlation and regression analysis, the internal structure of innovative activity was studied and the components were identified, the improvement of which will significantly increase the overall innovation index and transfer the country to the higher positions in the world ranking. It is noted that, in addition to a developed national structure of innovation activity, the fundamental research is required in combination with an effective education system. The dynamics of investments and staff number involved in the field of innovation is traced, the linear and non-linear models are constructed and practical recommendations are formulated. The revealed relations indicate the efficiency of using government expenditures for innovative and scientific development. The directions of increasing the efficiency of innovative economy development are specified.

1. Introduction
The new (“fourth”) industrial revolution defines the modern age and its distinctive features: digital transformation, intellectualization, asset solutions and fintech [1–7]. In these conditions, the problem of dynamic development of the national economy is the cornerstone of sustainability of the state, its security and the growth in the living standard of population; therefore, the success in innovative policies implementation determines the country’s competitiveness and place in the world economy. Country’s economy transition to an innovative development path that is what determines the goal of the strategy of innovative development of the Russian Federation.

The definition and study of the dynamics of factors affecting the innovative activity of the state are of particular interest to scientists.
As you know, these factors are divided into two groups: external and internal. Among the first, market, technological and state factors are noted; the latter include scientific and technological potential, production and management. Innovative activity generally increases against the background of an increase in research and development costs [8-9]. Currently, national, regional, departmental, corporate innovative programs and projects developed and adopted for implementation (The concept of long-term socio-economic development of the Russian Federation until 2020, Strategy of innovative development of the Russian Federation over a period until 2020, On the strategy of scientific and technological development of the Russian Federation, etc.) facilitate the innovative development in the Russian Federation.

To assess the role of factors that have a positive impact on the innovative activity of the country, various approaches are used, among which the innovative theory of demand, theory of technology change, mathematical methods can be distinguished. An important role is assigned to the statistical methods. There is no doubt in the importance of mathematical methods in assessing the factors role.

The experience of advanced foreign countries shows that effective government support measures allow increasing the innovative activity and ensuring a high level of innovative development of the country [5-6, 10–12]. In the modern context, the innovation activity is associated with the transformation of ideas into technologically new or improved products (and/or services), development of new technological processes used in practical activities [7, 11, 13-14]. Advances in science and technology promote the growth of labour productivity, improvement of products and services quality, perfection of production management and increase in its efficiency, labour and material costs saving [8]. The paper [15] relates to the numerical aspects of innovation. Problems with investing in innovative products in the Russian Federation were considered in the papers [1, 14]. Staff problems in the implementation of the innovation process are raised in the papers [16]. However, not much attention was paid to the mathematical analysis of factors influencing on the country's innovation system. Therefore, there are good reasons to consider that the correlation-regression analysis of these factors is necessary.

2. Materials and Methods
This paper covers the correlation and regression analysis of factors influencing the innovative activity of the state. The important point is the establishment and assessment of the relationship between the factors and the theoretical justification of the model. The modelling is one of the methods to identify and analyze the relationships that can be established through the created trends. The empirical base was statistical data for 2000–2018 from the following sources: statistical collections of the Higher School of Economics, Rosstat, and the Federal State Statistics Service. To analyze the trends in the implementation of Russian innovation activity for the specified period, to identify its strengths and weaknesses, the methods of logical design, system and situational analysis, generalization, analogies and non-parametric methods for comparing the included observations were used.

3. Results
In 2018, the Russian innovation activity was first noted in the EIS ranking report along with other BRIC countries, as well as Australia, Canada, the USA, South Korea and Japan (25th place and classification as a country with a relatively low level of innovative development). Based on the results of this study and assessments of modern economists [1], let’s specify the advantages and disadvantages of the Russian innovation process (Table 1). Having analyzed the information of table 1, we mark contradictory tendencies: with the accumulated huge potential represented by the fundamental and departmental research, a low level of bringing the scientific findings to practically used innovations is noted.
Table 1. Strengths and weaknesses of the Russian innovation system.

| Strengths                          | Weaknesses                                                                 |
|------------------------------------|----------------------------------------------------------------------------|
| high level of employment in knowledge-based activities; | insufficient co-financing of research and development costs; |
| high size of college-educated population; | a small proportion of the innovation activity of small and medium-sized business that participated in joint projects; |
| population participation in continuing education; | a small number of publications issued jointly by state and private organizations; |
| patent activity; | low level of joint publication activity of Russian authors with foreign ones; |
| positive developments in the share of business costs associated with GDP innovation. | high cost of innovation and risks associated with them; |

We think that one of the most important indicators characterizing the innovative activity in the Russian Federation is the volume of innovative goods, work, services (million rubles) \( \text{mln. rub.} \). Based on the previous studies and practical experience, a list of independent factors that influence on the effective indicator formation was made (Table 2).

It is known that the quantity of investment is a catalyst for scientific research in the field of innovation [1, 8], therefore, the Russian economy creates favourable conditions for functioning of investment assets in terms of taxation, property rights protection and interests of business partners, political and economic stability [9, 15-16]. The dynamics of investment rates and production of innovative products is shown in Figure 1.

Table 2. Strengths and weaknesses of the Russian innovation system.

| \( X_1 \) | a number of organizations performing research and development, units |
| \( X_2 \) | a number of staff engaged in research and development, pers. |
| \( X_3 \) | a number of researchers having advanced degrees, pers., total |
| \( X_4 \) | domestic research and development costs, mln. rub. |
| \( X_5 \) | a number of developed advanced production technologies, units |
| \( X_6 \) | costs of technology innovations, mln. rub. |
| \( X_7 \) | a number of patent applications received, units |
| \( X_8 \) | a number of patent applications issued, units |

Figure 1. Dynamics of investments in innovations and production of innovative products in the Russian Federation.
The dynamics analysis in figure 1 shows a significant increase in the volume of innovative goods in recent years. Thus, in 2018, there was an increase by 26.16% as compared with 2014, 2016 – by 3.48%, 2017 – by 8.38%. Domestic research and development costs increased in 2018 as compared with 2010 by 21.32%, 2016 – by 8.94%, 2017 – by 0.89%. In the item of costs for technological innovations, the indicator increased in 2018 as compared to 2010 by 21.53%, 2016 – by 14.65%, 2017 – by 4.83%. The equations of the trend models of these indicators, which confirm the identified trend, are shown in Figure 2; their reliability is proved based on the Fisher F-test and the determination factor at the 95% significance level.

![Figure 2. Modelling of investments in innovation in the Russian Federation.](image)

The global experience suggests that the fundamental research sector in combination with the effective education system forms the basis of socio-economic development of the country, its competitiveness in the external market along with the developed national innovation structure and regulatory support of innovative activity [9]. One of the decisive conditions for assessing the human resources of science is the level of qualification and education of staff engaged in this field. As determining conditions and factors, we mark the existing system of society values, institutional organization of scientific activity, applied methods of labour activity motivation, infrastructure support, the economy susceptibility degree to the scientific results, etc. [15]. Based on the histogram shown in Figure 3, it is necessary to certify a reduction in the total number of staff engaged in scientific research, and the number of researchers having advanced degrees. Thus, the total number of staff engaged in scientific research decreased in 2018 compared to 2014 by 6.79%, from 2016 – by 5.5%, from 2017 – by 3.58%; in 2018, the number of researchers having advanced degrees decreased by 8.46% compared to 2014, 2016 – by 7.43%, and 2017 – by 2.9%. However, we mark the benefit: there has been a slight increase in the number of researchers having advanced degrees in the total number of staff engaged in scientific research (in 2000 – 11.93%, in 2008 – 13.27%, in 2018 – 14.7%).

While analyzing the graphic representations in Figure 4, we mark that the number of researchers was approximately six times more than the number of technicians throughout the study period (in 2000 – 5.57, in 2008 – 6.24, in 2014 – 5.92, 2018 – 6.03 times). In addition, in recent years, there has been a noticeable decrease both in the number of technicians and researchers, which accordingly leads to a decrease in the specialists having received a degree which are engaged in innovative activities.
(Fig. 5). Statistically identified trends are reliable according to the Fisher F-test and the determination factor at the 95% level and confirm the conclusions made.

**Figure 3.** Comparative analysis of the total number of staff engaged in research and researchers having advanced degrees.

**Figure 4.** Analysis of the total number of staff engaged in research in a categorical context: (a) technicians, (b) researchers.
The reasons for this reduction can be specified:

1) Increase in the conditions for students training organizations in the areas of graduate education and, as a result, their annual reduction by virtue of the entry into force of the Federal Law of No. 273-FZ “On Education in the Russian Federation” dated December 29, 2012, according to which graduate education is the third stage of higher education. Thus, in 2008, there were 1529 operating organizations that trained post-graduate students and 593 ones – doctoral candidates; in 2018, the numbers decreased down to 1223 (including research (50.5%) and higher education organizations (47.8%)) and 213 ones, respectively (Fig. 6). This number is clearly insufficient versus the total number of research organizations.

2) Postgraduate programs are partially implemented by professional postgraduate education institution (since 2009) and other organizations (a small proportion is 1.6%). Thus, the total number of post-graduate students at the end of 2018 was 90.8 thousand persons, of which 32% – ones on a commercial basis.
3) Problems of demography in the 1990s of the 20th century (reduction in the number of post-graduate students – by 42.3% over a period of 2010–2018; indicators of admission and commencement reduced by almost half – to 27 and 17.7 thousand persons, respectively).

4) The above reasons could not but affect the number of specialists who have passed the Candidate's degree (in research organizations, the share of those graduated with the Candidate's dissertation reduced from 22.9 to 10.3% in 2000–2018; in higher education institutions – from 31.5 to 12.7%).

5) Hard-to-replenished losses of intellectual capital in the 1990s of the last century, which formed over a long time and was directly involved in training of young specialists.

![Figure 6. A number of organizations performing research and staff training by category.](image)

The current state policy in the field of education and science is aimed at actuation of research activities in higher education institutions [15]. An important indicator in the analysis of innovative activity can be considered the number of applications filed and patents issued (Fig. 7). The formed reliable trends in patent activity in the Russian Federation (95% significance level according to the Fisher-test and determination factor) show increasing in the number of applications and patents issued (in 2018 by 4.35% and 10.2%, respectively, as compared with 2017).

4. Discussion

The formation and evaluation of regression models was carried out in the systems STATISTICA and Microsoft Excel. In this case, step-by-step algorithms for including significant variables were used. At the first stage of modeling, \( R \)-matrix of pair correlation coefficients was built and their significance was assessed (Table 3). The calculated values of the pair correlation coefficients show that a strong linear dependence appears between the result of \( Y \) and all factors except \( X_1 \), i.e. the number of organizations performing research and development does not significantly affect the total volume of innovative goods, works and services; whilst the costs of technological innovation have the greatest influence on the effective attribute. The result obtained is consistent with the previously said. Note that although factor \( X_1 \) is insignificant, but together with factors such as the number of personnel engaged in research and development and the number of patent applications issued (Table 4) it is able to influence \( Y \), and, based on common sense, the factor was not excluded from consideration. The matrix also contains intercorrelation coefficients that characterize a linear relationship between factors (\( \) ), and in this regard, when building a model, one of them must be excluded from the model. Therefore, ridge
regression models were built which are more stable in the case of strong correlation of the dependent variables with each other (Table 4).

**Table 3. Matrix of paired correlation coefficients R.**

|   | Y   | X1   | X2   | X3   | X4   | X5   | X6   | X7   | X8   |
|---|-----|------|------|------|------|------|------|------|------|
| Y | 1   |      |      |      |      |      |      |      |      |
| X1| 0.181| 1    |      |      |      |      |      |      |      |
| X2| -0.850| 0.227| 1    |      |      |      |      |      |      |
| X3| 0.527| 0.208| -0.356| 1    |      |      |      |      |      |
| X4| 0.978| 0.088| 0.924| 0.486| 1    |      |      |      |      |
| X5| 0.983| 0.162| 0.821| 0.592| 0.950| 1    |      |      |      |
| X6| 0.995| 0.159| 0.853| 0.521| 0.980| 0.981| 1    |      |      |
| X7| -    | 0.570| 0.343| 0.783| 0.457| 0.640| 0.578| 0.545| 1    |
| X8| -    | 0.564| 0.523| 0.834| 0.183| 0.672| 0.561| 0.579| 0.777| 1    |

**Table 4. Regression models characterizing innovative activity in the Russian Federation.**

| N  | Model                                                                                                                                 |
|----|---------------------------------------------------------------------------------------------------------------------------------------|
| 1  | \[
|    | \frac{1}{Y} = 7.94 \times 10^{-3} + 0.277 \frac{1}{X_4} + 1.5 \times 10^{-16} X_2^2 - 2.158 \cdot X_2 \]
| 2  | \sqrt{Y} = -3552.774 + 5848848127.493 \frac{1}{X_4} - 10525775.382 \frac{1}{X_4} \]
| 3  | \sqrt{Y} = -2542.879 + 0.001X_4 + 0.749X_4 + 206.595\ln X_4 \]
| 4  | \frac{1}{Y} = -1.4 \times 10^{-3} + 0.365 \frac{1}{X_4} - 6.331 \times 10^{-15} X_4^2 + 4.41 \times 10^{-14} X_4^2 \]
| 5  | \sqrt{Y} = -163730 + 187\sqrt{X_5} + 1.182 \times 10^{-4} X_5^2 + 1611015 \frac{1}{X_5} + 12132\ln X_5 \]
| 6  | \frac{1}{Y} = 4.64 \times 10^{-5} + 0.225 \frac{1}{X_6} + 1.2 \times 10^{-15} X_6^2 + 4.09 \times 10^{-15} X_6^2 \]
| 7  | Y = -1941785.865 + 2620.697X_4 + 2.219X_4 \]
| 8  | \ln Y = -74.85 - 0.479\ln X_4 + 0.203\ln^2 X_4 \]
| 9  | \sqrt{Y} = 691.311 + 9.599 \cdot 10^{-11} X_6^3 + 5.618 \cdot 10^{-11} X_6^3 - 1.979X_4^2 \]
| 10 | Y = 121365.484 + 1.012 \cdot 10^{-10} X_6 \]
| 11 | \sqrt{\ln Y} = 5.531 - 22.964 \frac{1}{\ln X_6} \]
| 12 | \ln Y = 27.261 - 169.882 \frac{1}{\ln X_6} \]

The factor features selected for modeling are different in nature and have different units of measurement, for comparability of the regression coefficients of the constructed models we supplement each of the models with comparable indicators of the factor’s relationship with the result, which allow ranking the factors by the strength of their influence on the result (Table 5).
Table 5. Standardized regression models.

| N | Model | N | Model |
|---|-------|---|-------|
| 1 | \( t_1 = \frac{0.44}{X_4} + 7.202X^2_2 - 6.695X_2 \) | 7 | \( t_7 = 0.448X_4 + 0.557X_5 \) |
| 2 | \( t_2 = \frac{0.971}{X_2} - 0.249 \frac{1}{X_1} \) | 8 | \( t_{mY} = -0.905\ln^2X_1 + 0.149\ln^2X_1 \) |
| 3 | \( t_3 = 0.343X_4 + 0.411X_5 + 0.268\ln X_4 \) | 9 | \( t_5 = 0.982X_6^3 + 3.949X_6^3 - 3.887X_6^2 \) |
| 4 | \( t_4 = 1.37 \frac{1}{X_6} - 0.228X_5 + 0.578X_8^2 \) | 10 | \( t_6 = 0.992X_6^2 \) |
| 5 | \( t_5 = 1.581\sqrt{X_5} - 1.928X_5^2 + 0.875 \frac{1}{X_5} + 1.581\ln X_2 \) | 11 | \( t_{mY} = -0.991 \frac{1}{\ln X_6} \) |
| 6 | \( t_6 = 0.842 \frac{1}{X_6} + 5.718X_7^2 + 0.536X_8^2 - 5.068X_8 \) | 12 | \( t_{mY} = 0.991\ln X_6 \) |

The authors managed to establish the availability of both linear and non-linear relationships between factors affecting the development of innovative activity. The validity of the results achieved in the paper was confirmed by statistical tests at the 95% significance level. All formed ridge regression models are accurate and reliable (Table 6).

Table 6. Estimation of parameters of ridge regression models.

| Models No. | F-test | R | R' | \( R^2_{term} \) | Average model error | Standard estimation error \( Y, \% \) |
|---|-------|---|---|-----------|------------------|-----------------|
| 1 | F(3.15)=134.88 | 0.982 | 0.964 | 0.957 | 0 | 0 |
| 2 | F(2.16)=78.988 | 0.953 | 0.908 | 0.897 | 203.42 | 0.011 |
| 3 | F(3.15)=521.58 | 0.995 | 0.991 | 0.989 | 67.506 | 0.004 |
| 4 | F(3.15)=77.161 | 0.969 | 0.939 | 0.927 | 0 | 0 |
| 5 | F(4.14)=363.06 | 0.995 | 0.99 | 0.988 | 70.070 | 0.004 |
| 6 | F(4.14)=233.19 | 0.993 | 0.985 | 0.98 | 0 | 0 |
| 7 | F(2.16)=117.32 | 0.968 | 0.936 | 0.928 | 0.317 | 2.277 |
| 8 | F(3.1)=795.57 | 0.999998 | 0.999996 | 0.99998 | 0.483 | 0.000026 |
| 9 | F(1.3)=179.79 | 0.992 | 0.984 | 0.978 | 18222 | 0.968 |
| 10 | F(1.17)=902.21 | 0.991 | 0.982 | 0.98 | 0.2242 | 1.61 |
| 11 | F(1.17)=958.23 | 0.991 | 0.983 | 0.982 | 0.161 | 1.149 |

5. Conclusions
The formed dependencies explain the variation of the dependent variable \( Y \) by more than 80%, i.e. \( R^2 > 0.8 \) and \( R^2_{rate} > 0.8 \). The regression coefficients and the free term of each model are significant at the level of 0.05. The standard estimation error \( Y \) does not exceed 5%. Regression remaining balance does not have a noticeable autocorrelation, is normally distributed and has no systematic component. Please note that the concept of “the best regression model” is subjective, since currently there is no single statistical procedure to select the appropriate subset of independent variables. Thus, from the obtained dependencies it follows that the factor \( X_6 \) is the cost of technological innovation, million rubles (models 10–12). It has an impact on \( Y \) by more than 99% – the volume of innovative goods, work, services. At the same time, the factor \( X_7 \) – a number of patent applications received was not selected as significant. This can be explained as follows: the quality of innovative developments is important, but not their quantity; in addition, the development process is quite labour-intensive and expensive. Please note that the factors \( X_2 \) – a number of staff engaged in research and development, and \( X_5 \) – a number of
developed advanced production technologies were most often selected by the system during models building (Table 4-5) (are involved in 4 models). This suggests that the human factor and the final innovative product determine the success of the country's innovation system as a whole. The shortage of highly qualified specialists in science is a key problem that Russian product companies focusing on innovative development deal with today. Therefore, issues related to the shortage of human resources are currently being actively discussed and programs are being developed to improve the current situation, so one of the goals of the Federal Program “Research and Development in Priority Trends of the Russian Science and Technology Sector for 2014–2020” is the decrease in the middle age of researchers to 43 years in 2020. Young scientists are capable of implementing complex, creatively rich projects that require a non-standard approach, which finally determines the success of innovative activities. We are fully of the same view that a significant reduction in the scale of migration of scientific manpower from Russia and the youth involvement in science can be primarily achieved by increasing wages in the field of science and scientific service. The built models can be used in various studies on the development of the innovative structure of the regions. They can also act as a component of the integrated model for assessing and managing innovative activities of the Russian Federation, which is one of the topical problems of modern economic science.

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