Econometric Models for Forecasting Innovative Development of the Country

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Abstract: The purpose of this study is to develop models to predict the level of innovative development of countries, as well as to identify the most significant factors influencing innovative development.

The scientific novelty consists in applying a systematic, integrated approach to the selection of statistically significant factors that are drivers of innovative development, with the subsequent construction of econometric models and their testing. When developing models, both resources ("input parameters") and results ("output parameters") were taken into account, which also allows evaluating the effectiveness of innovative development and developing scenario forecasts taking into account the existing possibilities and limitations, optimizing innovative development strategies.

The main methods of research and approaches were used: statistical summary and grouping of information, trend analysis, regression and correlation analysis, testing of statistical hypotheses, factor analysis. The procedure for detecting multicollinearity was performed using the VIF test (Variance Inflation Factor, incremental regression method). In determining the set of explanatory variables (the choice of "short" or "long" regression), the following criteria were used: Akaike criterion and Bayesian Schwarz information criterion. To estimate the parameters of econometric models, the Least Squares Method was used with a preliminary check of the fulfillment of all conditions of the Gauss-Markov theorem. In addition, various tests for checking the constructed models and their parameters for significance, adequacy were applied: Durbin-Watson test, Sved-Eisenhart series method and Breush-Godfrey test, Helvig agreement test, Shapiro-Wilk test, Goldfeld-Quandt test and Spearman's rank correlation test. To determine the influence of explanatory factors on the explained factor, the average elasticity coefficients were calculated on the basis of linear regression as the best model based on the results of all tests.

Data and Empirical Analysis: The main components included in the calculation of the Global Innovation Index (GII) were selected for the study. Statistical data on them are published annually, which allows us to estimate the country's place in international innovation development. The study identified four multiple econometric models: one linear and three non-linear. The value of the Global Innovation Index was chosen as an explained factor, and the indicators for the main groups in accordance with the GII structure were chosen as explanatory factors.

To achieve this goal, the following work was carried out, as reflected in this article: 1) an econometric analysis was performed based on a sample of 30 countries based on the 2018 Global Innovation Index report; 2) multiple regression models were built - linear, polynomial, hyperbolic and power; 3) with the use of special tests, a check for heteroscedasticity and autocorrelation of random residues was implemented; 4) the parameters and the obtained regressions were estimated for statistical significance and adequacy.

According to the results of the study, the model that best approximates the initial data was chosen. Using this regression, one can form scenario forecasts of the country's innovative development, for example, by predicting the values of individual factors using various modern methods of macroeconomic planning and forecasting. The principle is the expediency of the most optimal combination of resources for innovative development in order to ensure the maximum effect on the "output".

Keywords: Econometric model, explanatory factors, explained factor, Global Innovation Index, innovative development, regression, forecasting.

1. INTRODUCTION

In most countries of the modern world, attention is paid to the study and development of innovative economies, and this area is becoming increasingly relevant every year. This is due to a number of factors. Firstly, the close relationship between technological innovation and economic growth, because investment in innovation yields significant profits (Drucker, 1993). Secondly, the rate of turnover of capital and the life cycle of innovation are directly dependent, and thus, countries with a high level of innovative development

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have relatively stable economic growth, and it has a significant impact on the social welfare of the population.

Based on these prerequisites, it can be argued that innovative development should and indeed is a priority of economic policy (Rejmer, 2013). The importance of innovation in resource-intensive countries is also increasing. The irreplaceable nature of fuel and energy reserves and raw materials in these countries, fluctuations in world prices for raw materials make the economies of these countries extremely unstable and vulnerable from the point of view. This problem is especially acute for many countries of the world, including Russia. Therefore, for the further socio-economic development of the country, it is necessary to develop theoretical approaches to the formation of innovative development concepts, based on theories and practical results in this area of other countries where this task is being successfully solved. The role of the innovation factor in the development of the country and its relationship with other growth factors of its economy is considered by many scientists and specialists as a determinant of the transition to a new social formation. A number of them consider the formation of a post-industrial society in which knowledge and innovation will play a major role (Barnett *et al.,* 2016). They argue that it is production innovation that forms the basis of the post-industrial knowledge society. For strategic planning of innovative development of the country, increasing its competitiveness, ensuring a higher position in the international rating of innovative development, it is necessary to identify the key driving forces of this development and identify the main factors that directly affect the formation of final innovation indicators. In this regard, we can use the methodological approaches used in econometric studies. Using the latter, one can specify econometric models with the most important factors for subsequent econometric analysis. These models, if they are statistically significant and adequate, can be used to predict indicators of the country's innovative development, as well as be used by state authorities to determine the directions of budget investments and priority directions of state budget expenditures (Novikov, 2017).

In studies on modeling and forecasting innovative development, for example, such as “Long-term forecasting of S&T and innovation indicators” (Kotsemir, 2011), “Forecasting model and assessment of the innovative and scientific-technical policy of Ukraine in the sphere of innovative economy formation” (Yurynets, 2016), "Strategic planning and forecasting of innovative development of the enterprises" (Mukhina *et al.,* 2014) an analysis of various factors influencing or hypothetically capable of influencing the level of innovative development and its changes is carried out. Attempts have been made to formulate a system of indicators that would most fully reflect various aspects of innovative development (qualitative and quantitative indicators, in statics and dynamics), as well as highlight subsystems of indicators, for example, Macroeconomic indicators, Indicators of S&T sector, Indicators of innovation sector and others. At the same time, in these and a number of other works, the relationship between the subgroups of indicators, their mutual influence and the contribution to the overall result as a whole is not clearly shown. In many works, the explained variable has not been selected, and it is also not clear which form of dependence exists between specific variables, which of the explanatory variables are the most significant. Even with a sufficiently complete set of indicators, the work is inherently fragmented in considering the complex process of innovative development. Unlike a number of works by other researchers, the authors of this article attempted to form models with a clear reflection of the dependencies between variables, in addition, to determine the most significant factors. In this work, we also use aggregated variables that combine a fairly wide range of individual detailed factors, in particular, within the framework of such units as Infrastructure and Human Capital.

The main aggregate indicator, giving a comprehensive assessment of the level of innovative development of the country, is the Global Innovation Index (GII), calculated by the International Business School INSEAD in points for each country separately. When calculating the GII, 2 subindexes are taken into account. The first is the subindex of innovative resources, which includes information about institutions, human capital and science, infrastructure, development of the internal market, and business development. The second is the subindex of innovative results, taking into account the development of technologies and the economy of knowledge, the development of creative activity of the population (INSEAD, 2018).

The paper considered the study of 4 multiple econometric models of the dependence of the explained factor on the explanatory ones. The following 4 econometric multiple models were considered: linear, polynomial, hyperbolic and power. As an explained factor (Y) for them, the Global Innovation Index was chosen, the values of which are indicated in points, the maximum is 100 points. The following seven factors were chosen as explanatory factors: X1 - institutions (includes institutional environment, regulation), X2 - human capital and research, X3 - infrastructure, X4 - domestic market development, X5 - business development (innovative entrepreneurship), X6 - results in science and technology, X7 - results in the field of intangible assets and the development of creative activity. In order to achieve uniformity and comparability of the initial data, a sample of values was taken, which includes 30 countries according to the results of the GII-2018 rating with the highest Global Innovation Index (GII) values. The leader of this rating is Switzerland, the GII index of which is 68,40 out of 100, and Slovenia closes a selected group from 30 countries (GII is 46,87 out of 100 points). The regressions obtained on the basis of the values were compared and the one that best approximates the selected source data was determined.

2. CONTENTS AND RESULTS OF THE STUDY

To identify the factors affecting the innovative development of countries, the main modern research methodologies were preliminary considered: The Boston Consulting Group Index, European Innovative Scoreboard – EIS Index, Knowledge Economy Index (Knowledge for Development – K4D program), The Global Innovation Index and The Bloomberg Innovation Index. The Boston Consulting Group (BCG) Index is built on a model consisting of two main blocks: “Innovation Inputs” and “Innovation Performance”. EIS Index is a tool of the European Commission, developed in the framework of the Lisbon strategy to provide a comparative assessment of the innovation activities of EU member states. The EIS is built on three blocks, which are formulated as “opportunities”, “business activity” and “results”. Knowledge Economy Index is a complex indicator characterizing the level of development of the knowledge-based economy in countries and regions of the world. This index is an average of four aggregates: economic incentives and institutional regime, education and human resources, innovation system, information and telecommunication technologies. The Global Innovation Index takes into account not only the innovative potential of the country and its resources, but also results of introduced innovations. The Bloomberg Innovation Index is based on the following categories: Research & Development, Manufacturing, High-tech companies, Postsecondary education, Research personnel, Patents.

According to the results of the comparison of the analyzed methods, the methodology for calculating the Global Innovation Index was chosen as a guideline, including a range of indicators that most fully and comprehensively characterize the innovative development of the country. The following factors were chosen as explanatory factors in order to develop econometric models: X1 - institutions (includes institutional environment, regulation), X2 - human capital and research, X3 - infrastructure, X4 - domestic market development, X5 - business development (innovative entrepreneurship), X6 - results in science and technology, X7 - results in the field of intangible assets and the development of creative activity. The factors hypothetically influencing the innovative development of the country as a whole also include the development of clusters (State of cluster development), employment in high-tech and knowledge-intensive industries,% (Knowledge-intensive employment,%), net exports of high-tech goods,% of total trade (High-tech net exports,% total trade), ICT accessibility, venture capital deals (Venture capital deals / bn PPP $ GDP). At the same time, it seems appropriate to apply more aggregated variables (previously considered X1-X7), which not only include a number of the factors listed above, but also take into account the relationship between them. For example, a model built with more detailed factors taken into account is characterized by an insufficiently high value of the coefficient of determination and a number of other characteristics of such a model are worse than those of a model with more generalized factors.

Of the general statistical aggregate, the first 30 countries were selected - the leaders with the highest rates of innovation development (in accordance with the GII innovative development rating of the world - 2018) to conduct further research, build econometric models and select the best regression. In the process of studying the available sample, the relationships between the variables, their economic nature and content, it was established empirically that the linear model approximates the actual data most accurately. Along with this, 3 more models (polynomial, hyperbolic and power) were specified and tested, which demonstrate results that are also closest to the initial data and linear regression, and subsequently the best model was selected according to the results of all tests.

To conduct an econometric study of the specified models, the GRETL software product and the MS Excel spreadsheet processor functions with their main tools - correlation and regression were used. The multicorrelation of the initial explanatory factors was checked and the parameters of the econometric models under consideration were evaluated, and the conditions of the Gauss-Markov theorem were tested.

In carrying out the specification of a multiple linear econometric model, 2 factors (X5 and X7) were initially excluded from consideration. However, in the subsequent comparison, the so-called “long” model consisting of 7 explanatory factors and the “short” one consisting of 5 explanatory factors, using the Akaike criterion and the Bayesian Schwarz information criterion, it was determined that the “long” econometric model should be chosen for further research. The performed VIF test for this model showed that there is no multicollinearity of the explanatory factors, since the VIF*i* value does not exceed the critical value equal to VIF = 10 (Dougherty, 2011), see Table **1**.

Table 1: Values of Inflation Factors

VIF_1 (X_1)	1,830
VIF_2 (X_2)	2,090
VIF_3 (X_3)	1,512
VIF_4 (X_4)	1,687
VIF_5 (X_5)	3,041
VIF_6 (X_6)	3,282
VIF_7 (X_7)	1,452

Source: compiled by the authors.

Before making estimates of the parameters of the specified econometric model using the Least Squares method, testing of the conditions of the Gauss-Markov theorem was carried out (Nevezhin, 2017). Verification of random perturbations of the obtained linear regression for heteroscedasticity using the Goldfeld-Quandt test and the Spearman's rank correlation test showed that they have a constant dispersion, that is, they are homoscedastic.

The results of the verification of residues for autocorrelation of multiple linear regression using the Durbin-Watson test, the Sved-Eisenhart series method and the Breush-Godfrey test showed no autocorrelation between them. Thus, the random residues (u*i*) and (u*j*) are independent of each other (Ando and Sueishi, 2019).

According to the results of the Helvig agreement test and the Shapiro-Wilk test, random residues of the obtained linear regression are distributed according to the normal law.

A similar order of methods and procedures was applied in the process of studying three non-linear multiple models. According to the results of checking the parameters of the models for statistical significance (t-test) and for adequacy, as well as checking the obtained regression models for statistical significance (F-test) and adequacy, it was found that all the parameters in the models are significant and adequate, and all regressions are meaningful and adequate. In particular, when comparing the obtained values of the parameters (a*i*) with the intervals calculated for them, it turned out that the intervals do not pass through a zero value, and therefore all the parameters of the model should be considered adequate. Table **2**. shows a fragment of the result obtained using the Regression function of the MS Excel spreadsheet processor.

As already mentioned, as a result of the study, four econometric multiple models were considered - one linear and three non-linear: polynomial, hyperbolic, power.

Table 2: Estimation of Linear Regression Parameters

	Coefficients	**Standard error**	**t- statistics**	**Lower 95%**	**Upper 95%**
Y- intersection	0,1145	0,0396	2,8884	0,0323	0,1967
X1	0,0996	0,0004	228,9105	0,0987	0,1005
X2	0,1003	0,0004	269,5033	0,0995	0,1011
X3	0,0986	0,0006	154,0975	0,0973	0,1000
X4	0,1001	0,0003	323,7060	0,0995	0,1008
X5	0,0990	0,0006	171,9819	0,0978	0,1002
X6	0,2502	0,0004	612,6620	0,2494	0,2511
X7	0,2505	0,0005	483,1552	0,2494	0,2516

Source: compiled by the authors.

As a result of drawing up the specification of a linear multiple model and estimating its parameters, a linear regression was obtained, which has the following form:

$$\begin{aligned}\hat{y} = &\ 0,1145 + 0,0996 \cdot x_1 + 0,1003 \cdot x_2 + 0,0986 \cdot x_3 \\ &(0,0396) \quad (0,0004) \quad (0,0004) \quad (0,0006) \\ &+ 0,1001 \cdot x_4 + 0,0990 \cdot x_5 + 0,2502 \cdot x_6 + 0,2505 \cdot x_7 \\ &(0,0003) \quad (0,0006) \quad (0,0004) \quad (0,0005) \quad (0,0128)\end{aligned}$$

The normalized coefficient of determination of this model is 0,9999, that is, the variation of the explained factor by more than 99,99% is due to the variation of the explanatory factors. The value of the average approximation error (Ā) is 0,02%, which indicates the good quality of the obtained regression. All parameters of this regression are statistically significant. The graph of the obtained linear multiple regression is shown in Figure **1**.

The constructed second-degree multiple polynomial econometric model is represented by the following regression equation:

$$\begin{aligned}\hat{y} = &\ 27,25 + 0,0005 \cdot x_1^2 + 0,00096 \cdot x_2^2 + 0,0009 \cdot x_3^2 \\ &(0,696) \quad (9,307E\text{-}05) \quad (0,0001) \quad (0,0002) \\ &+ 0,0008 \cdot x_4^2 + 0,0011 \cdot x_5^2 + 0,0024 \cdot x_6^2 + 0,0024 \cdot x_7^2 \\ &(8,137E\text{-}05) \quad (0,0002) \quad (0,0001) \quad (0,0002) \quad (0,432)\end{aligned}$$

The normalized coefficient of determination of this model is 0,9929, thus, the variation of the explained factor by more than 99,29% is due to the variation of the explanatory factors. The value of the average approximation error is 0,51%, which also indicates the good quality of the obtained regression. The graph of the obtained polynomial multiple regression is shown in Figure **2**.

In the process of analyzing the multiple hyperbolic econometric model, the parameter *a3* turned out to be statistically insignificant, and thus the data in column X3 was not taken into account in the newly specified model. After estimating the parameters of a multiple hyperbolic econometric model of 6 factors, the following regression was obtained:

$$\begin{aligned}\hat{y} = &\ 108,46 - 746,49 \cdot \frac{1}{x_1} - 320,75 \cdot \frac{1}{x_2} - 371,63 \cdot \\ &(2,22) \quad (163,91) \quad (62,67) \quad (76,76) \\ &\frac{1}{x_4} - 304,05 \cdot \frac{1}{x_5} - 509,05 \cdot \frac{1}{x_6} - 702,10 \cdot \frac{1}{x_7} \\ &(99,7) \quad (54,88) \quad (76,93) \quad (0,87)\end{aligned}$$

The calculated average error of the approximation of the regression model is 1,05%, which indicates its good quality, and the value of the normalized coefficient of determination is 0,9715 (97,15%), which also confirms the good quality of the constructed regression. Figure **3** shows a graph of the resulting hyperbolic multiple regression.

A multiple power econometric model is represented by the following regression equation:

$$\begin{aligned}\hat{y} = &\ 20,35298 \cdot x_1^{1,002} \cdot x_2^{1,002} \cdot x_3^{1,002} \cdot \\ &(1,014) \ (1,0002) \ (1,0001) \ (1,0002) \\ &x_4^{1,002} \cdot x_5^{1,002} \cdot x_6^{1,004} \cdot x_7^{1,004} \\ &(1,0001) \ (1,0002) \ (1,0001) \ (1,0002) \ (0,0045)\end{aligned}$$

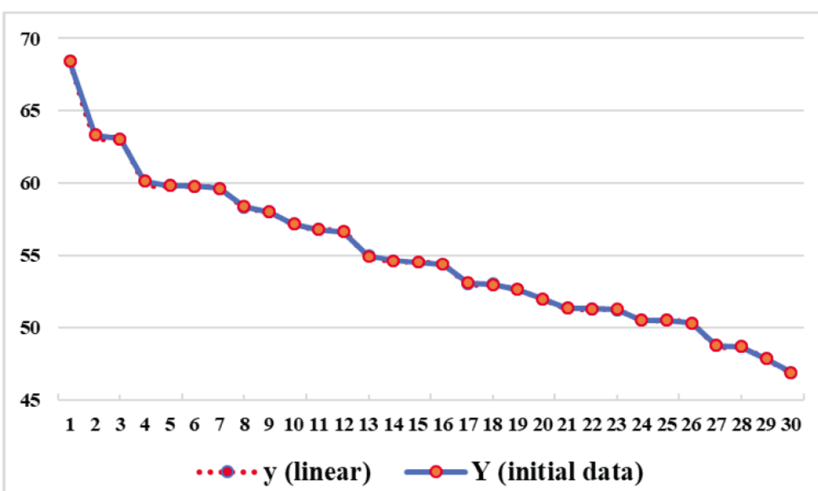

Figure 1: Linear multiple regression approximation graph.

Source: compiled by the authors.

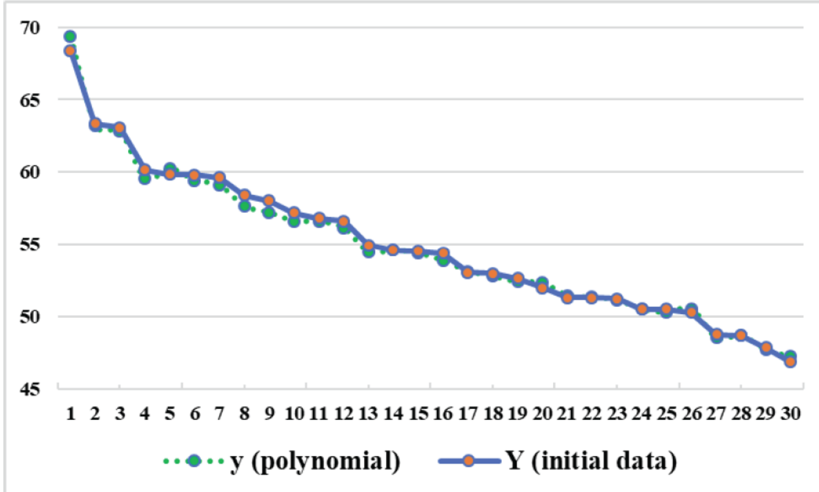

Figure 2: Graph of the approximation of the initial data by polynomial multiple regression.

Source: compiled by the authors.

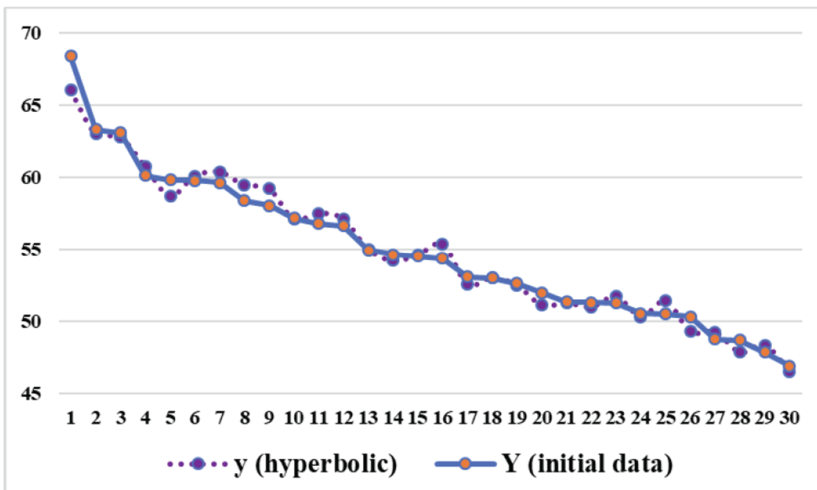

Figure 3: Graph of the approximation of the initial data by hyperbolic multiple regression.

Source: compiled by the authors.

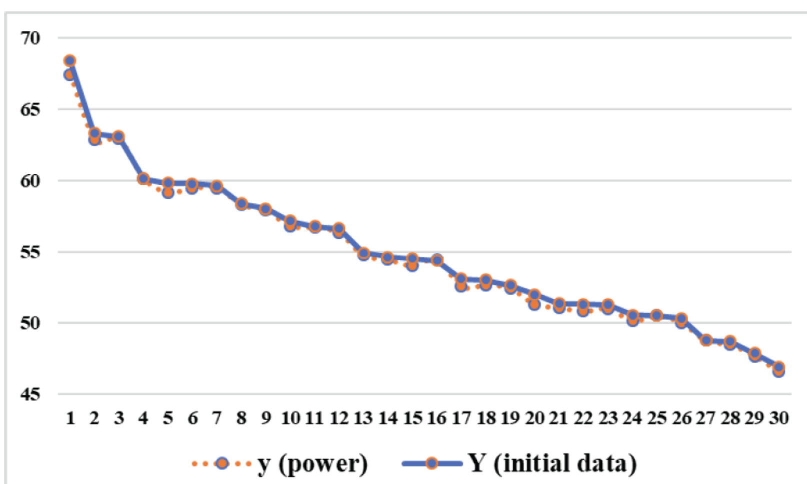

Figure 4: Graph of the approximation of the initial data by power multiple regression.

Source: compiled by the authors.

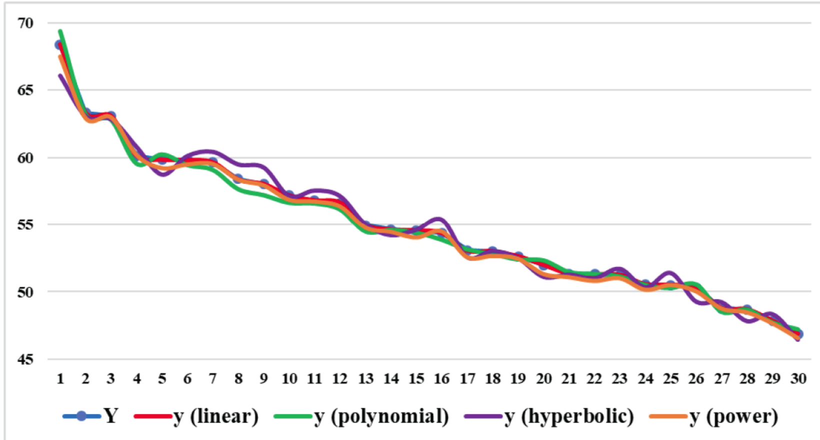

Figure 5: Comparison of regression graphs.

Source: compiled by the authors.

The normalized coefficient of determination of this regression is 0,9975, that is, the variation of the explained factor by more than 99,75% is due to the variation of the explanatory factors. The value of the average approximation error is 0,08%, which also indicates the good quality of the obtained regression. The graph of the obtained power multiple regression is shown in Figure **4.**

All graphs considered in the work, placed in the same space, are presented in Figure **5**.

3. CONCLUSIONS AND REMARKS

To select the best regression, the table containing the values of the normalized coefficient of determination was formed, since its value shows how explanatory factors influence the explained factor and the average approximation error (Ā) for each regression, see Table **3**.

Table 3: Parameters for Choosing the Best Regression

Regression type	Normalized R^2	Ā (%)
Linear	0,9999	0,02
Polynomial	0,9929	0,51
Hyperbolic	0,9715	1,05
Power	0,9975	0,08

Source: compiled by the authors.

Based on the data presented in the table, a multiple linear regression is selected, which makes it possible to approximate the original data better than others. This regression is statistically significant and adequate, is of good quality and can be used to predict the country's Global Innovation Index (GII). As a result of the study, the following results were also obtained. Of all the explanatory factors chosen and examined, the most important were X7 (results in the field of creative activity) and X6 (results in the field of science and technology), the numerical values of which are presented in the national innovation system. They reflect the results achieved earlier, the effectiveness of the innovation and scientific and technical policy pursued in the state. At the same time, the greatest contribution to the formation of the Global Innovation Index is made by the factors X2 (human capital and research) and X4 (development of the internal market). When implementing the state strategy of innovation development (innovation strategy), it is especially important to pay attention to the development of precisely these factors of the integrated innovation potential of the country (Licht and Zoz, 2000).

In order to determine the influence of explanatory factors (X) on the explained factor (Y), the values of average elasticity coefficients (AEC) were calculated based on linear regression, the results are presented in Table **4**.

Table 4: Calculated Values of Average Elasticity Coefficients

Average elasticity coefficients	Calculated values
AEC_1	0,1537
AEC_2	0,0983
AEC_3	0,1102
AEC_4	0,1105
AEC_5	0,0945
AEC_6	0,2104
AEC_7	0,2202

Source: compiled by the authors.

Based on the data in the above table, with an increase (X1) of 1%, the value (Y) increases by 0.15%, with an increase of (X2) by 1%, the value of the explained factor (Y) increases by 0.098%, and a similar interpretation for the rest elasticity coefficients. Thus, the explanatory variables X7 - the results in the field of creative activity and X6 - the results in the field of science and technology have the greatest influence on the explained variable. These factors relate to the "results of innovation", the pursued policy in the innovation and scientific and technical fields. In addition, among the controlled variables that can be purposefully changed by influencing them, factor X1 - institutions (institutional environment, regulation) has the greatest impact on the level of innovative development. Finally, the next after X1 in terms of importance for the country's innovative development are the factors X4 - the development of the domestic market and X3 - the infrastructure.

The obtained practical results are confirmed by theoretical works of a number of authors. So, the Russian researcher in the field of innovation and innovative development Zueva O.A. believes that it is human, scientific and technical elements-potentials that are central to the structure of the innovative potential of the country (Zueva, 2016). Shevchenko I.V., Aleksandrova E.N., Shlyakhto I.V. (Shlyakhto, 2007) emphasize that the most significant elements of the potential of the national innovation system are social and institutional components (Zhiglyaeva, 2018).

Analytically and empirically confirmed allocation of the most significant factors of innovative development X2, X4 (innovation resources), X6, X7 (achieved innovation results) will allow more efficiently and effectively allocate public funding, support innovation activities in the country. They are also "points of growth" that should be actively influenced in order to raise the country's innovation rating in the international community, as well as to ensure an increase in the contribution of innovation to GDP growth. The choice of the strategy of innovation development and, consequently, the efficiency of innovation activity directly depends on the possibilities of their use (Kozicina and Filimonenko, 2015).

The obtained and tested model of multiple linear regression can be applied not only to predict the values of the Global Innovation Index, for example, for the Russian Federation, but also to more effectively achieve a number of goals of the national innovation strategy. Using this regression, one can form scenario forecasts of the country's innovative development, for example, by predicting the values of individual factors using various modern methods of macroeconomic planning and forecasting. For forecasting at the regional level in Russia, in which there is a large inter-regional differentiation of socio-economic and innovative development, it is recommended to determine the Regional Innovation Index (RII), and for its forecast calculations, choose the main factors present in this model (Abdrahmanova *et al.,* 2017). Finally, along with the forecasting of innovative development using the constructed econometric model, it is recommended to analyze the changes in the relationship between indicators of resources and results as components of the GII. This will determine the trends of decline or increase in the effectiveness of innovations, compare the results obtained with the available resources.

As promising areas for further research, it is advisable to highlight the development of scenario forecasts with a description of the conditions for the implementation of scenarios in each particular case, as well as taking into account the specifics of innovative development in individual countries. In particular, a version of the typology of the countries of the world will be presented on the nature and quality of innovative development, innovative susceptibility based on testing results. Along with this, the construction of "decision trees" will be carried out in order to build a comprehensive innovation policy, taking into account various scenarios and hierarchizing the variables and goals of innovative development. A hierarchical cluster analysis procedure will also be implemented to identify relatively homogeneous groups of countries in terms of level, characteristic drivers and conditions for innovative development.

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