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Research paper



Mathematical Model of the Influence of Innovative Development Factors on the Economy of Leading Countries and Russia

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Abstract

This article is dedicated to the econometric analysis of the influence of different factors on the economic development. It has been proved that the gross domestic product is under the influence of exogenous variables such as value added of knowledge and technology intensive industries (KTI), number of patents granted in smart grid technology and expenditures on R&D. Creation of econometrical models provides an empirical evidence to support the evaluation of economic relationships, which occur in a modern economy in the era of development of digital technologies.

The penetration of information and communication technologies (ICT) into all sectors of the economy and the sphere of vital activity of the population is a key factor of scientific, technical and economic progress in the context of globalization. Opportunities and difficulties of the countries of the world in the transition to a post-industrial economy reflect international ratings. They characterize the unevenness of innovative development and the use of innovations and information technologies. For the analysis of Russia's positions in the world innovation economy, several international ratings of innovative development have been selected (The Global Innovation Index, The Networking Readiness Index, and The Global Competitiveness Index). The analysis showed not only the representativeness of the international innovation ratings chosen for the analysis, but also the high correlation between the indices in international innovation ratings and individual indicators of economic development of countries. The importance of policies in the use of ICT and the digital economy for structural changes in the economy is noted.

Russia is inferior to the world's leading leaders in terms of innovation activity and economic development. In the light of the economic sanctions of the economically developed countries of the West against Russia, this gap may even increase. Assessing Russia's position in international innovation development ratings, including R & D spending, has highlighted the need to take into account global trends and challenges, and econometric analysis helps to understand the world trends better and to offer reasoned recommendations for improving the situation in this area.

The recommendations will facilitate Russia's early transition to a socially-oriented innovative type of economic development. The main direction is the development of the national innovation system and the inclusion of Russia in the global innovation space.

The purpose of this research is to describe mathematically the influence of modern innovative factors on economy on the example of one of the leading countries, to characterize Russia's position in international innovation ratings and highlight Russia's problems in research and innovation. **Results and practical importance** are to issue recommendations for improving the activation of Russia's involvement in the process of internationalization in the field of research and innovation. It is necessary to adjust the direction of further development.

Keywords: *Russia, Germany, econometric model, internationalization of innovative activity, innovative economy, R&D, innovative development, ICT, KTI.*

1. Introduction

The strategy of scientific and technological development, as well as the development of innovative activity, requires that any state takes into account global trends and challenges. In this context, defining the future of the country for the Russian Federation is an extremely important step. At present, several legislative documents have been developed in the Russian Federation that approve the country's movement in line with the main trends in the development of the scientific world landscape. According to the authors, the most significant document is the "Strategy for Innovative Development of the Russian Federation for the Period to 2020 year". It is developed on the basis of the provisions of the Concept of Long-Term Social and Economic Development of the Russian Federation for the Period to 2020 year in accordance with the Federal Law "On Science and State Science and Technology Policy", which sets the task of the country's transition to a socially-oriented innovative type of economic development [1]. Within the framework of this Strategy, the task of forming the scientific and technological potential of our country adequate to modern challenges of world technological development is revealed.

It is noted that Russia sets long-term development goals, which are to ensure a high level of the well-being of the population and to consolidate the geopolitical role of the country as one of the leaders that determine the world political agenda. It is noted that the only possible way to achieve these goals is the transition of the economy to an innovative socially-oriented development model.

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That is why it is important, firstly, to reveal current positions of Russia in the world rankings by innovative indicators. Secondly, to reveal main factors which influence macroeconomic indicators in innovative countries (on case study of Germany), and then to formulate recommendations for improving Russian positions in the world economy.

2. Methodology of Research

For the analysis of Russia's positions in the world innovation economy, several international ratings have been selected. They show the degree of readiness of the countries for the post-industrial economy: Knowledge Economy Index, The Global Innovation Index (GII), The Networked Readiness Index (NRI), The Global Competitiveness Index (GCI) [2–5].

It should be noted that the experts of the UN and the World Bank are considering various aspects of innovative development. They form a chain of influence that examines the mechanisms through which access to ICT and their meaningful use can increase the "information capacity" of countries. At the same time, all this can lead to improvement of the scientific and social potential of people [6]. The importance of policies in the use of ICT and the digital economy for structural change, equality and social integration has been raised in many articles by domestic and foreign authors [7–15].

Throughout this work, an econometric model was created to assess the influence of different factors on GDP growth on the example of the one of the most technologically developed European countries – Germany. To our opinion, this model characterize modern tendencies of the world development of science and technologies most accurately.

There are four variables in this model. The first variable is Gross domestic product (GDP) (Y) – endogenous because it depends on different factors.

Other variables are independent on factors, they build a base for relationship analysis and are called exogenous.

In our case they are:

- Value added of knowledge and technology intensive (KTI) industries (X_1) – represents the development of high-technology industries and the rate of development of development knowledge economy.
- USPTO patents granted in smart grid technology (X_2).
- Gross expenditures for R&D as a share of gross domestic product (X_3) – represents the research intensity.

The resource of data is National Scientific Fund. The analyzed period is 2001–2016 [16].

Initial form of econometric model:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3$$

In the scientific research, econometric methods were used: correlation-regression analysis, least squares method, etc., and graphical methods.

3. Results

The calculations performed by the authors show the representativeness of the international innovation ratings chosen for the analysis (correlation coefficients 0.8 to 0.9), as well as the high correlation between the indices of the world indices in innovation ratings and individual indicators of the economic development of states (such as: per capita, expenditure on scientific research, the gross added value of industrial production, including high-tech products per capita) (See Table1).

Table 1: The results of calculations of correlation dependence between indicators by the countries of the world

	Global Innovation Index – GII	The ICT Development Index – IDI	Networked Reading Index – NRI	GDP (PPP) per capita	Manufacturing value added (MVA) per capita
Global Innovation Index – GII		0.87	0.88		0.86
The ICT Development Index – IDI	0.87		0.87	0.87	0.76
Networked Readiness Index – NRI	0.88	0.87		0.78	0.78
GDP (PPP) per capita	0.79	0.78	0.78		0.86
Value added of manufacturing industries per capita	0.81	0.76	0.78	0.86	

Source: calculated by the authors

Russia's positions in international innovation development ratings are shown in Table 2 [3–5, 17] (See Table 2).

Table 2: The positions of leaders and Russia in international innovation development ratings

The Global Innovation Index (GII), 2017		The Networked Readiness Index (NRI), 2016		The ICT Development Index (IDI), 2017		The Global Competitiveness Index (GCI), 2016	
1	Switzerland	1	Singapore	1	Iceland	1	Switzerland
2	Sweden	2	Finland	2	Rep. of Korea	2	Singapore
3	Netherlands	3	Sweden	3	Switzerland	3	Finland
4	USA	4	Norway	4	Denmark	4	Germany
5	UK	5	USA	5	UK	5	USA
…							
14	Japan	10	Japan	14	Japan	9	Japan
22	China	59	China	80	China	29	China
45	**Russia**	**41**	**Russia**	**45**	**Russia**	**45**	**Russia**

Source: compiled by the authors based on [3–5, 17]

The Global Innovation Index (GII) is a study where data on 80 indicators are collected for 127 countries. They cover a wide range of problems that allow analyzing global trends of innovative development in the countries of the world. In the rating table "GII, 2017" Russia is the 45th [5]. The leaders in this ranking are Switzerland, Sweden, Netherlands, USA, Great Britain, Denmark, Singapore, Finland, Germany, Ireland, Republic of Korea, Luxembourg, Iceland, Japan.

The Networked Readiness Index (NRI) is based on the calculation of three data blocks: 1) the availability of network infrastructure; 2) readiness for its use in civil society, business environment and state structures; 3) the real level of ICT use [4]. Russia in the rating table of 2016 year is only on the 41st place. But more important is a detailed analysis of the country's positions on individual components of the index, which characterize not only the level of use of network structures (the number of Internet users, mobile phones, personal computers, the access of the population to the Internet, etc.), but also factors contributing to this process. These are: a) the level of access to network technologies from the perspective of infrastructure development, availability of equipment, etc.; b) a policy in the field of network technologies (ICT and business economic environment); c) the level of development of the network society (training using network structures, ICT opportunities, social capital); d) the level of development of the networked economy (e-commerce, e-government, common infrastructure). It is for these positions that there are differences between the leading countries and Russia, which reflects it's not too high positions in this rating. And the leaders are: Singapore, Finland, Sweden, Norway, USA, Netherlands, UK, Luxembourg, and Japan.

The leading positions in the rating of the ICT Development Index are: Iceland, Republic of Korea, Switzerland, Denmark, Great Britain, Hong Kong, Netherlands, Norway, Sweden. Japan is located at the 14th position, the US – on the 16th. Russia holds the 45th position in the rating of 2016 year [17].

The World Economic Forum (WEF) defines competitiveness as a complex of institutions and institutions of authorities and factors of production on which the level of productivity of the economy depends. According to the WEF-calculated annual Global Competitiveness Index (further – GCI), the leading positions in this international ranking are taken by countries that have placed scientific knowledge in the service of their economy, widely implementing information and communication technologies (ICT) and innovations in all spheres of the population. In this Index, many components are grouped into 12 integral positions ("competitiveness bases"), compiled on the basis of a comparison of 113 indicators. One of the bases of competitiveness includes the indicators characterizing higher education in the country (the 5th group of 12). The rating includes data on 139 countries around the world. All of them in aggregate in detail characterize the level of competitiveness of the countries of the world in the global economy. In the group of leaders, as usual, there are developed countries: Switzerland, Singapore, Finland, Germany, the USA, Sweden, the Netherlands, etc. In the rating of 2010–2011, Russia took 63rd place, and now – In the 2015–2016 years rating – already 45th [3].

Russia's positions in international innovation development ratings have tended to grow slightly in recent years. Especially this draws attention to the background of the rapid growth of competitiveness of China, Brazil, India, etc. Russia's low position in the rating of global competitiveness (and in other innovation development ratings) proves the existence of problems in the development of the national innovation system of the country, and also shows that not all safely and with the implementation of the provisions of Strategy 2020.

You can also compare the costs of research. In the world GDP, R&D expenditures are about 2%, and that is mainly due to developed countries. The three-dimensional space of scientific research (USA-EU-Japan) is transformed into a four-dimensional one (USA-EU-China-Japan) [7, 8, 18–20]. Rapidly increases expenditure on R&D China. It is this fact that allowed China to take a leading position in the world economy and world industry. The quality of Chinese exports of high-tech products is also growing (China is now the world leader in this field as well).

Expenditures on scientific research in the world, in regions and countries are growing. But it is important to note the significant changes that have occurred in the countries of the Asian region in this sphere, including at the expense of Japan, China, India and the countries of the "new industrialization" (Republic of Korea, Singapore, etc.). At the same time, Asia's share rose to 44% of the world's volume. China's share has significantly increased – up to 20% of the world index. The role of Japan has slightly decreased (to 11%), but this is a very significant proportion (calculated by: [21]). But, as before, in terms of spending on R&D, the US is leading (26% of global spending, $ 514 billion, 2016 year). But it is important that China has already taken the second place in the table of ranks – about 396 billion dollars. Russia is among the leaders – 50 billion dollars. However, for expenditures on R&D per capita, China and Russia lag far behind the leaders [21, 22].

An econometric model specifies the statistical relationship that is believed to hold between the various economic quantities pertaining to a particular economic phenomenon under study.

First of all in order to provide relationship between endogenous and exogenous variables a correlation analysis was done (Table 3).

Table 3: Correlation matrix of Germany

	Lp,	industrial	or
Nominal GDP, mln $ (*Y*)	1		
Value added of KTI industries, mln $ (X_1)	0.997446823	1	
USPTO patents granted in smart grid technology, number (X_2)	0.529588899	0.54421057	1
Gross expenditures for R&D as a share of gross domestic product, % (X_3)	0.746482334	0.737777551	0.864548096	1

Calculated by the authors based on [16]

Correlation matrix (Table 3) shows if there is a linear relationship between each exogenous variable and the explained variable. The bigger the correlation coefficient, the more linearly dependent is *Y* from a specific *X*. Correlation coefficient lies between 0 and 1. If it equals 0, the variables are independent, while if it is equal to 1, the variables are perfectly dependent.

In our case variables have positive sign. That means a strong positive linear relationship between endogenous variables X_i and exogenous variable *Y*.

Then it was possible to estimate all coefficients by creating a regression econometric model. It can be done using Microsoft Excel, Analysis package. The estimated model helps to understand that in Germany the growth of value added of KTI industries, USPTO patents granted in smart grid technology and gross expenditures for R&D as a share of gross domestic product leads to the increase of GDP.

The Linest function was used to calculate the Slope and Intercept parameters for a linear function. Linest is an array formula which must be entered as an array formula to return all the values that it can return.

= LINEST (Known *Y* Values, Known *X* Values, Const, Stats)

We got the following numbers (Table 4).

Table 4: The results of the calculations

b_3 = 362904.0893	b_2 = -2173.098447	B_1 = 2.789609781	b_0 = -791504.8
Se_3 = 103100.4599	Se_2 = 617.0320538	Se_1 = 0.063217182	Se_0 = 211393.4
r_2 = 0.997613227	*Sey* = 32547.52181	-	-
F (stat) = 1671.902645	*df* = 12	-	-
ssreg = 5.31335E^{+12}	*ssresid* = 12712094115	-	-

Calculated by the authors based on [16]

Where:

ssreg – regression sum of squares;

ssresid – residual sum of squares;

Se – standard error.

So a liner model is the following:

$$Y = -791504.8 + 2.7896\,X_1 - 2173.09\,X_2 + 362904.09\,X_3$$

Then the model was tested by R^2-Test, *F*-Test, *T*-Test, Durbin-Watson –Test and generally, it passed all tests successfully.

R^2 test shows the percentage of estimation of the dependent variable: R^2 = 0.9976. This means that there is a 99.76% probability that the forecast built on this model will be truth.

F-test: Another way of checking R^2 is based on testifying *F*. *F* critical should be compared to *F* calculated in a model by Excel, using the formula: $Fcrit = Finv\,(0{,}05;\, df_1;\, df_2)$.

In Germany *Fcrit* < *Fstat*.

$Fcrit\,(0.05;\, df_1;\, df_2) = Fcrit\,(0.05;\, 3;\, 12) = 3.4903$

Fstat = 1671.9026

This means that R^2 is not random and quality of specification of econometric model is high.

T-test: in order to check the significance of coefficients Student's *t*-test was used. The inequality $|t| \leq t\ crit$, where *t* is the value of *t*-statistics had to be tested.

$t\ crit = 2.1788$
$|\ t\ (b_1)\ | = 44.12739827$
$|\ t\ (b_2)\ | = 3.521856658$
$|\ t\ (b_3)\ | = 3.519907571$

In Germany all variables are significant and should not be excluded from the model as they are higher than *T*-critical.
DW test checks a particular case of third assumption of the Gauss-Markov theorem about the absence of autocorrelation (a relationship between values separated from each other by a given time lag) between residuals in the model. The DW test does not follow a standard statistical distribution such as a *t*, *F*, or χ^2. DW has 2 critical values: an upper critical value (*dU*) and a lower critical value (*dL*), and there is also an intermediate region where the null hypothesis of no autocorrelation can neither be rejected nor not rejected!
We can calculate Darbin-Watson statistics using values of the residuals *εt* (Table 5). There are 16 observations in a model, hence intervals are the same:

Table 5: Intervals for Darbin-Watson statistics

0	*dl*	*du*	2	4-*du*	4-*dl*	4
0	0.74	1.25		2.75	3.27	4

Calculated by the authors based on [22]

DW = 1.50 => *du* < DW < 4-*du* – residuals are not autocorrelative.
The model shows that there is a strong correlation between, on the one hand, the economic development and, on the other hand, value added of KTI industries, USPTO patents granted in smart grid technology, gross expenditures for R&D as a share of gross domestic product.
It is worth mentioning that in modern conditions of digital economy patents granted in IT methods for management influence GDP and this connection can be described with the help of a logarithmic model.

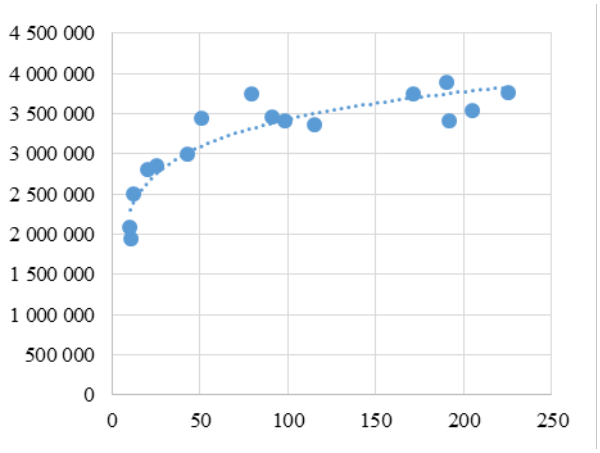


Fig. 1: Correlation between USPTO patents granted in IT methods for management influence (horizontal line) and GDP (vertical line) (*Calculated by the authors based on [16]*)

Assessing Russia's positions in the world rankings by the indicators used in the above model, we can make the following conclusions: in 2016 Russia occupies 1.7% of the world's GDP, its share in the global Value added of knowledge and technology intensive industries is 1.14%; world USPTO patents granted in smart grid technology 0.06% – in the world USPTO patents granted in smart grid technology; 0.18% – in the world USPTO patents granted in IT methods for management [16]; 1.13% – a share of research and development expenditures in GDP (% of GDP) in 2015 (according to the World Bank data) [23].
Considering that Russia is striking for intensive economic growth and development based on the development of high technologies, innovations, and the digitization of the economy, it is necessary to focus on the following:
– to build up technologies in the field of IT methods for management;
– to build up smart grid technology;
– to increase spending on R&D.
At present, several programs, concepts of innovative, scientific and research development for the period until 2020 year are being implemented in Russia. The main goal is to introduce clear unified rules for the implementation of innovative activities. The main direction is to build our own national innovation system and to include the Russian Federation in the emerging global innovation system.

4. Discussion

We have created an econometric model in order to estimate the situation in the modern economy and reveal the most important factors which influence macroeconomic indicators. We can see the following.
It proves that today R&D, ICT and innovative technologies determine the growth rates of the economy. Thus, we can say, that the creation of an econometric model gives an opportunity to forecast future changes of endogenous variable (in our model it is GDP), that is important in today's world economic uncertainty.
The involvement of Russia in the process of internationalization in the field of R&D is a labor-intensive process that requires active actions in the scientific sphere, adopting specialized measures to improve the innovation climate in the country. It is necessary to emphasize that Russia's entry into the emerging global innovation system is impossible without building its own innovation system and policy, as well as a developed research sector [8, 10, 14, 19, 20].
There should be a link in the chain "science-production" and state regulation of practical implementation of research and development results in Russia. Innovative policy requires interdepartmental control and coordination.
Based on the analysis of the current situation in the Russian Federation, it is possible to formulate recommendations on the activation of Russia's involvement in the process of internationalization in the field of research and innovation.
There are the following blocks of recommendations: institutional, socio-cultural, economic, and others that have a mixed character, but which have a synergistic effect [8, 19].
Undoubtedly, it is necessary to maintain and develop a competitive level of scientific research in universities and research centers related to universities, which is a prerequisite for competitive vocational education, especially science and engineering.
It is very important to provide state financial support for young researchers, to emphasize the attention of the government to the growth of the level of expenditure per one scientific researcher and to scientific activities, the restoration of the lost prestige of scientists. It is necessary to restore the demand for scientific research and development by the state, business, international partners, society.
It is necessary to pay closer attention to commercialization of the development of scientists by increasing the availability of financial resources, especially at an early stage. The key moment in this matter is the relationship between the researcher, the research institute and the intermediary introducing the product to the market. The experience of other states should be taken into account. In order to regulate these relations, many states legislatively ensured the distribution of profits among the participants. This issue is relevant in Russia, since the country has a large number of researchers whose inventions still do not enter the market. From our point of view, the creation and development of innovation centers and clusters on the territory of the Russian Federation will help to solve this problem, as there will be a platform for meeting and work of all stakeholders of the scientific community, and business

access to existing developments will be open, thereby increasing transparency and the competitiveness of research.

To implement the above-mentioned tasks, it is necessary to change and revise the law on technical regulation, which in practice is not being implemented, to update the legislation in the field of intellectual property, to reduce taxation in this area or to introduce a "tax holiday" for the possibility of promotional the start-up business.

It is necessary to emphasize one more important idea when formulating an innovation policy: financing science will increase the number of inventions but will not increase their investment attractiveness. That is why the creation of a system technology transfer is so important in creating an innovative economy. Only by solving these issues it will become possible to provide science with sufficient means for scientific and technological progress.

At the universities in Russia (according to the experience of the United States, Germany and other countries), technology transfer offices should be established. Their sphere of competence should include: preparation of documents for the protection of intellectual property, financial support for the patenting process, strategic planning for product promotion, commercialization of technologies, etc. Some examples of such organizations are the ANVAR (Agence Nationale de Valorisation de la Recherche) in France, the National Technological Agency (TEKES) in Finland, the British Technology Group in the UK, and others [19]. It is necessary to pay attention to the problems of patenting in the Russian Federation (in the USA, universities are patent holders of their own inventions).

So important to improve the system for obtaining grants for research in the Russian Federation. For everyone is necessary to develop market mechanisms: grant financing; return financing of commercially significant projects; co-financing (referring to the practice of agreements on joint research, subject to the transfer of rights to created objects to organizations of developers and industrial firms, including small businesses).

It is necessary to improve the forms and methods of public-private partnership. The commercialization of technology cannot be wholly tied to the state budget. Basically, it is determined by the demand for research and development from a private sector of economy, so this partnership should become a key component of Russia's new innovation policy. For example, in the Netherlands there are four main public-private partnership programs, for which about 11% of the government's budget allocated for the development of science and technology is envisaged [19].

State structures need to take appropriate measures to ensure that Russian scientific journals (from the list of Higher Attestation Commission) are widely known in the world (entered the system SCOPUS, Web of Science, etc.). And then it will be easier for Russian scientists to present the results of their research to a wider audience, including the foreign one. Moreover, scientific research and development of Russian scientists meet all the basic requirements for those abroad, in foreign scientific journals.

Of course, special attention should be paid to attracting Russian multinationals to participation in R&D and scientific activity of universities. It is necessary to reduce barriers to attracting highly qualified specialists from abroad, including the issue of issuing visas and labor legislation.

One of the elements of the innovation system of the Russian Federation can be an active joint work with international organizations on certain areas of innovation policy. For example, with the World Bank in the implementation of a project-oriented approach, elaboration of issues of preferential taxation; with the research and development elaboration (R&D) in the evaluation of selected areas of state innovation policy; with the World Intellectual Property Organization on the problems of regulation of this issue, etc.

It is necessary to increase public spending on R&D, especially applied R&D, that is proved by the econometric model. There should be a change in the vision of the problem of investing in R&D by private business.

Based on the analysis of the current situation, we systematize the recommendations on the activation of Russia's involvement in the process of internationalization in the field of research and innovation [8, 19].

The authors suggest the following institutional recommendations:

- Standardization of legislation in the field of education;
- Alignment with international standards of documentation on international cooperation of universities (special double diploma programs, bachelor's and master's degrees, postgraduates, etc.);
- Support for the competitiveness of scientific research in universities and research centers associated with universities both at the state (federal) level and at the level of power structures in the regions;
- Creation of management and technology transfer offices;
- Updating and improvement of legislation in the field of intellectual property;
- Strengthening the system of protection of intellectual property rights.

In the block of socio-cultural recommendations, it should be noted:

- Restoration of the prestige of the scientist, strengthening the demand for science by the state, business, society;
- Support and preservation of scientists and qualified specialists in the domestic scientific market, creating conditions for their full-fledged work;
- To improve of the system for obtaining grants for scientific research in the Russian Federation;
- Raising the level of international innovation cooperation and academic mobility of scientists.

Among the block of economic recommendations, we will outline the following:

- Building up technologies in the field of IT methods for management;
- Building up smart grid technology;
- Increase spending on R&D;
- Reduction of taxation in R&D;
- Ensuring demand for research and development from a private sector of the economy;
- Commercialization of R&D;
- Development of public-private partnership as a key component of Russia's innovation policy.

5. Conclusion

The model shows that there is a strong correlation between, on the one hand, the economic development and, on the other hand, value added of KTI industries, patents granted in smart grid technology, gross expenditures for R&D. So, Russia should take into account this correlation in order to transfer its economy to a digital one. Creation of a strong national innovation system, providing an effective innovation policy and a long-term strategy for the innovation course will allow Russia to take strong positions in the world economy. Although Russia's position in the global innovation system is far from desired.

To include Russia in the global innovation system, it is necessary to develop a national innovation system, especially taking into account the experience of developed countries. It's the time to move from theory to practice. It is important to change the legislative, tax base, reform the scientific community, involve the state and business in the process of more actively integrating Russia into the global innovation system. The Russian Federation can and should take a strong position in the world innovation economy.

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