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INNOVATION AND PRODUCTION POTENTIAL OF MESOSYSTEMS: ASSESSMENT AND MODELING OF DEVELOPMENT PROSPECTS

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Abstract--- *The relevance of the article is due to the fact that the issues of mobilization and effective use of the innovation and production potential of mesosystems are becoming particularly relevant in the context of the deployment of the fourth industrial revolution in the world economic system. The solution of these problems will reveal new opportunities and trajectories of qualitative and quantitative growth of innovative production activity of the industrial complex as a whole. The purpose of the article is, based on the systematization of statistical data on the development trends of the mesosystem, to conduct economic and mathematical modeling, which allows to identify factors of innovative production potential for the formation of their contribution to the development of high-tech and high-tech industrial products. As the main research methods, the article used the description method, which allowed to identify the development trends of mesosystems; the method of correlation analysis, which establishes the closeness of the relationship between the indicators of the use of innovative production potential and the achievement of the level of high technology and high technology production; regression analysis method for constructing economic and mathematical models of the dependence of high-tech production on the use of innovative production potential of the industry. The article describes the production and innovation potential of the mesosystem (for example, industrial complexes); on the basis of the regression model, the negative impact of the innovative potential of industry on the development of high-tech and high technology production was established; The forecast of an increase in the share of high-tech and high-tech products in GDP is constructed. The materials of the article can be used in developing strategies and programs to increase the efficiency of using the innovative production potential of the industrial complex in order to modernize the economic system as a whole.*

Keywords: *innovative production potential, mesosystem, metallurgical industry, industrial production index, innovative activity, high-tech and high-tech production, technological innovations, modernization*.

I. INTRODUCTION

In modern science, genetic information has become an object of detailed study not only within the framework of biological, chemical, medical and other scientific research but also a subject of world jurisprudence (Ernst, 1961; François, 1970; Michaud, 2001; Galloux, 1989). It is clear that genetic data need special legal and technical protection.

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The deployment of the fourth industrial revolution requires business entities to build up and effectively use innovative and production potential in order to produce competitive products that can satisfy not only the needs of the local market, but also be an element of import substitution policy and open the frontiers in new technology segments, including internationally. High-tech industry is a sector of industrial production where the Russian economy has a significant backlog and has advantages for a technological and innovative breakthrough. In addition, the formation of the foundations for the modernization of the entire industrial complex is possible in the industry, since it is it that is an example of sustainability and was present in many technological systems through which the Russian economy passed. In particular, among the key areas of introducing 4.0 industry technologies in the industrial sector are: digitalization of production, Big Date analytics, 3D printing, additive manufacturing, which contribute to the development of innovative production potential through the use of new design technologies and the creation of high-tech products (technological innovations), as well as improving management processes throughout the value chain.

Currently, the additive manufacturing group has a wide range of technologies. These technologies are used in high-tech industries and are innovative in nature. Among them are distinguished:

– UV irradiation: (SLA: Stereolithography, or stereo lithography, DLP: Direct Light Processing, or digital LED projection). This group of methods allows the polymerization process to be carried out while printing the necessary part;

– Extrusion: (FDM: Fused Deposition Modeling, or Modeling by layer-by-layer fusion from molten plastic filament, Fused particle fabrication (FPF) or particle fusion production. This technology group is divided into filament printing and extrusion printing (FPF), the second technology is more advanced, as it eliminates the need for filament, which eliminates the unnecessary production phase.In FPF technology, printing is carried out by an extruder directly from the granules of the printed material;

– Inkjet spraying (MJ: Material jetting, or 3D inkjet printing, NPJ: Nano particle jetting, or 3D inkjet printing with nanoparticles). This group of technologies opens up great opportunities in the additive small-run production of semiconductor materials and microchips;

– Fusion (MJF: Multi Jet Fusion, or multi-jet melting, SLS: selective laser Sintering, or selective laser sintering, DMLS / SLM: direct metal laser sintering, or direct laser sintering of metals and selective laser melting, or selective laser melting);

– Additive laminated (LOM: Laminated Object Manufacturing, or printing objects by lamination).

The following features of Industry 4.0 technologies that influence the development of industry should also be highlighted. We believe that we should take into account the relationship between the industrial sectors that form a single value chain. An example of such interaction can be the joint use of polymer products and semi-finished products of the metallurgical industry for other industries - for example, in the field of automotive, machinery and equipment, construction, etc. In this regard, we systematize the key trends in the impact of polymer production on their use in industry:

1. In scientific circles and patents, FFF / FDM printing technology, which prints with filament polymer thread, is widespread. At the same time, a number of researchers refer to the high cost of filament polymer filament, which is several times higher than the cost of the original polymer raw material, which in turn does not allow wider distribution of 3D printing, especially printing of large objects.

2. To overcome this problem, a number of researchers are of the opinion that it is necessary to move from a centralized processing of raw waste (processing at factories) to a distributed processing concept. This idea was supported by a number of engineers and was reflected in a number of patents on devices that can produce plastic filament for 3D printing from polymer granules or shredded plastic waste. As a number of studies have shown, the distributed processing of polymer materials reduces energy and pollution costs from unnecessary transportation by 90%.

3. However, this decision was not made unanimously in the scientific world, a number of researchers express the opinion that each melting / extrusion cycle reduces the mechanical properties of the polymer material.

4. In this regard, a number of researchers proposed the idea of abandoning 3D printing using a polymer filament to eliminate unnecessary stages of polymer melting / extrusion. In these studies, scientists proposed using an extruder as the nozzle head, similar to that used in injection molding machines, which will allow printing without using filaments directly from granules or shredded plastic waste. This type of technology is called FPF / FGF printing technology, which is currently extremely unexplored and conceptual. In Russian scientific literature, publications on this topic are absent, unlike foreign literature. This type of printing technology currently has many restrictions on print resolution (the printer cannot print small parts due to the large size of the nozzle) and a number of others, for example, the possibility of color printing.

– 5. In this regard, at this stage of research, a whole series of unexplored issues opens up, which include:

– What are the possibilities in increasing the resolution of printed objects using FPF / FGF technology and in what ways you can increase it.

– What are the mechanical properties of polymeric materials that were printed using these technologies, both primary and secondary materials (adhesion of the printing layers may beckon, depending on the technology used and the use of recycled materials).

– What is the degree of cost-effectiveness and environmental friendliness of FPF / FGF printing technology compared to its predecessors.

– Methods and possibilities of obtaining color FPF / FGF printing. In filament printing technology, color prints are obtained by printing with several polymer filaments of different colors, which are used in the necessary places of printing, thereby forming a color product. FPF / FGF does not have such a possibility, which makes the issue of finding color printing method FPF / FGF technology urgent.

– What are the opportunities to reduce energy consumption. The FPF / FGF extruder spends more energy on melting the polymer due to its larger dimensional characteristics.

– Actual questions on further methods of applying FPF / FGF printing and the possibility of its distribution.

Currently, the processing of polymer waste from a logistics point of view is centralized due to the fact that the processing takes place in factories that collect polymer waste. In this model, the consumer is not interested in the greater processing of polymer waste, since by sorting the waste the consumer does not receive personal benefits, as evidenced by the low degree of processing of polymer waste.

Modern additive manufacturing technologies such as FPF / FGF printing allow for the organization of distributed processing of polymer waste. In this model, polymer waste is not concentrated in the places of its processing, but can be processed by the consumer at home, which excludes a number of logistic operations related to transportation, processing, including sorting of waste by materials; their cleaning, drying and other technological processes associated with the processing, production of new products, as well as the distribution of these products. In this model, the consumer is personally interested in the processing of polymer waste, since at the end of this process the consumer receives a new product printed on a 3D printer is much cheaper than when using primary polymer raw materials using FDM / FFF printing technology.

Currently, polymer printing technology is represented by FDM / FFF printing technology. In this group of polymer printing technologies, an object is formed due to the deposition of polymer filament yarn. While FPF / FGF technology is currently poorly considered due to its novelty. In Russian literature, this issue is not disclosed at all. One of the nomadic problems of filament printing is a very expensive raw material, which significantly exceeds the cost of the original polymer.

The advantages of 3D printing using plastic granules (FPF / FGF technology) rather than filament yarn includes lower costs due to the lower cost of the source material, and also allows you to print large objects (for example, where more than 1 material coil is required) . This has sparked a recent surge in research related to three-dimensional printing on granules, including new printer designs: using a two-stage nozzle derived from RepRap injection-molded metal, as well as industrial three-dimensional printing robots, as well as a large range of polymers, including conventional filament materials and recycled materials, as well as polymer composites and flexible materials. All of these studies show that 3-D printing FPF will play a large role in the future 3-D printing industry and is supported by the results of this study.

In this regard, the primary issues of reforming the industrial complex, namely, optimization of equipment loading, increasing productivity and labor safety, increasing the competitiveness of products, logistics optimization, reducing the time to market for new products, introducing Industry 4.0 technologies, can be taken as a basis in the industrial sector as an accelerator of modernization of the mesoeconomics in general. In this regard, the issues of increasing the efficiency of using the innovative and production potential of the industrial production of mesosystems are of particular importance and relevance.

The purpose of the article is, based on the systematization of statistical data on the development trends of the industrial complex of the mesosystem, to carry out economic and mathematical modeling, which allows to identify factors of innovative production potential for the formation of their contribution to the development of high-tech and high-tech industrial products.

Description of the Statistical Base

The state of innovation and production potential of the industrial sector of the Russian economy is characterized primarily by the possibility of growth in the medium and long term industrial production of this type of activity (Glekov & Kryzhanovskaya, 2016; Lipatnikova & Shatilova, 2015; Galkin et al., 2018). By innovation and production potential we understand the totality of the characteristics of the industrial base of the industrial complex, including those that contribute to the introduction of technological innovations, which ensure an increase in the output of high-tech products. This production base, including the used material and technical resources, personnel, information, financial and logistical support, determines the specifics of the products and their level of competitiveness.

After a significant decline in 2009, the industrial production index (IPI) to 83.6% compared to the previous year, starting in 2010, industrial production has no clear trends in achieving sustainability: the growth rate of IPI is accompanied by a rate of decline, which is largely due to variability domestic and international market conditions. According to the results of 2018, IPI (for example, the mesosystem of the metallurgical complex) amounted to 101.7% (in 2017 - 100.1%); the volume of goods shipped - 5890.5 billion rubles. At the end of 2017, the industry produced: mirror and pig iron in pigs, ingots or in other primary forms - 52.1 million tons; unalloyed steel in ingots or in other primary forms and semi-finished products from unalloyed steel - 58 million tons; stainless steel in ingots or other primary forms and semi-finished stainless steel products - 0.2 million tons; other alloy steel in ingots or in other primary forms and semi-finished products from other alloy steel - 15 million tons; finished steel - 60.5 million tons; hollow pipes, steel profiles and their fittings - 11.8 million tons (Boyarko & Khatkov, 2018; Federal State Statistics Service, 2020; Kostyukhin et al., 2019).

The efficiency of using the production potential of the industry can be characterized by relative indicators. Over the past 5 years, there has been a decrease in the cost of production and sale of products - from 85.2 kopecks to 79.7 kopecks per 1 ruble of manufactured products. At the same time, the ratio of the volume of production of finished rolled ferrous metals to the volume of steel production increased from 85.3% to 86.6% (Hao, Li & Tang, 2017; Körner, 2016; Abspoel et al., 2017).

A positive dynamic is noted in the use of the innovative potential of the industrial complex as an object of the mesosystem. The share of industry organizations engaged in technological innovations increased from 13.2% in 2010 to 18.4% in 2017. However, the proportion of innovative goods in the total volume of goods shipped did not have unambiguous steady dynamics - an increase in the indicator alternated with its decrease: in 2010 - 4.8%, in 2013 - 7.5%, in 2015 - 8.3%. In 2018, the value of this indicator amounted to 5.4%, decreasing by 1.6 percentage points compared to 2017 (The World Bank, 2020; Hu, Yin & Zhao, 2017; Shinkevich et al., 2018). A decrease in the intensity of costs for technological innovations is noted: the share of costs for technological innovations in the total volume of goods shipped decreased from 2.6% in 2010 to 1.2% in 2017, according to the results of 2018, the value of the indicator increased to 1.5% (Figure 1).

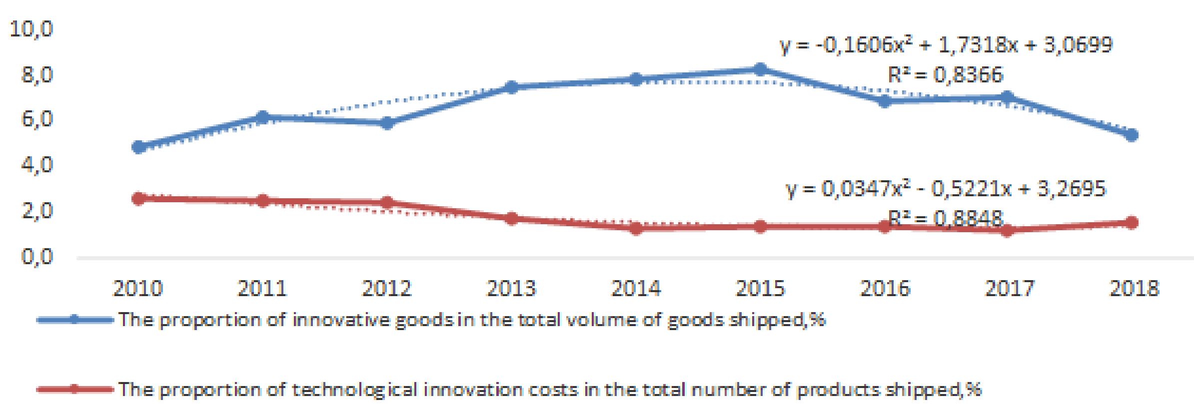

Figure 1. Indicators of industry innovation potential

Medium-tech sectors of the economy dominate in the Russian mesosystem, while technological modernization of production sectors implies an increase in the contribution of each type of economic activity to the increase in the share of output of high-tech and knowledge-intensive products in GDP. From 2010-2018 the average value of this indicator in the Russian economy increased from 19.7% to 21.1%, while the maximum was reached in 2017 - 21.6% (Shinkevich et al., 2019; Shinkevich et al., 2017; Skazochkin et al., 2016).

Exports of ores and metals from Russia to world markets on average for 2010-2018 amounted to 5.5% of total exports. The leaders in the global economy were Peru - 53.5%, Mongolia - 42.9%, Iceland - 41%, Zimbabwe - 41.6%, Armenia - 36.9%, Mozambique - 31.8%, Montenegro - 31, 2%, Namibia - 30.4% (Kiyutsina, 2012; Kuznetsova & Rud, 2013; Adno, 2016).

Thus, the analysis of statistical indicators of the innovative and industrial potential of the industrial sector of the Russian economy revealed the ambiguity of its development trends, which requires modeling of the prospects and trajectories of this sector for the formation of the innovative industrial framework of the industrial complex as an object of the mesosystem.

Research Methods

To build an analytical model for assessing the innovation and production potential of the metallurgical industry and its impact on increasing the high-tech level of GDP, the following research methods were used:

1) correlation analysis, which allows to establish the tightness of the relationship between the indicators of innovative and production potential with high-tech GDP;

2) regression analysis used to build a regression model of the dependence of high-tech GDP on the use of innovative production potential of industry.

To find the linear Pearson correlation coefficient, it is necessary to find the sample means x and y, and their standard deviations σx = S (x), σy = S (y), then use the formula:

$$r_{xy} = \frac{\overline{xy} - \overline{x} \cdot \overline{y}}{\sigma_x \sigma_y}$$

In our case:

y - the share of the high-tech sector in GDP (%); x1 - industrial production index (IPP), (%); x2 - the cost of production and sale of products per 1 ruble of manufactured products (cop.); x3 - the share of organizations implementing technological innovations (%); x4 - the proportion of innovative goods in the total volume of goods shipped (%); x5 - the proportion of costs of technological innovation in the total volume of goods shipped (%). All indicators are presented for the industrial complex of the Russian economy.

The most important task is to determine the form of communication with the subsequent calculation of the parameters of the equation, or, otherwise, finding the communication equation (regression equation). In our case, a multiple linear regression model will be used:

$\hat{y}_i = a_0 + a_1 x_{i1} + a_2 x_{i2} + \ldots + a_p x_{ip}$, where

$\hat{y}_i$ – approximate values of the dependent variable;

$a_0, a_1, a_2, \ldots, a_p$ – sample estimates of the corresponding coefficients .

To include variables in the model, the step-by-step method is used. In order to avoid the effect of multicollinearity, a step-by-step procedure for selecting the most informative variables is used. The variable xi is selected, which has the largest adjusted determination coefficient with the dependent variable y. After this, the next variable xj is added, which, together with xi, has the highest adjusted coefficient of determination with y, etc. The procedure for introducing new variables stops at the step when the coefficient of determination is maximum and does not increase at the next step.

Results and Discussion

In order to simulate the impact of the innovation and production potential of industry on achieving sustainable growth rates of high-tech and knowledge-intensive products in GDP, a regression analysis was used with step-by-step inclusion of variables in the model. The initial data for building the model are shown in the table.

Table 1. Initial data for modeling the innovative production potential of industry (Boyarko & Khatkov, 2018).

Year	The share of the high-tech sector in GDP,%	IPI, %	Costs of production and sale of products per 1 ruble of manufactured products, cents	The share of organizations implementing technological innovations,%	Share of innovative goods in the total volume of goods shipped,%	The share of costs for technological innovation in the total volume of goods shipped,%
	y	x_1	x_2	x_3	x_4	x_5
2010	19,7	112,4	83,6	13,2	4,8	2,6
2011	19,7	107,0	86,9	13,3	6,2	2,5
2012	20,3	104,8	89,1	13,9	5,9	2,4
2013	21,1	100,0	91,5	13,0	7,5	1,7
2014	21,5	107,2	85,2	13,0	7,8	1,3
2015	21,0	104,0	80,9	12,8	8,3	1,3
2016	21,5	99,7	82,3	11,7	6,9	1,4
2017	21,6	100,1	83,1	18,4	7,0	1,2
2018	21,1	101,7	79,7	18,4	5,4	1,5

At the first stage of the analysis, a multiple regression model was used with the step-by-step method, where the explanatory variables - x1-x5 were included in the model one by one until the value of the determination coefficient reached the maximum value (the significance level of the model coefficients - p-value, was set to 0.01). Thus, the following equation was obtained:

$y = 20{,}9 + 0{,}1 \times x_2 - 1{,}9 \times x_5$, where

y – the share of the high-tech sector in GDP, %;

x_2 – .costs of production and sale of products per 1 ruble of manufactured products, cents;

x_5 – the share of costs for technological innovation in the total volume of goods shipped, %.

In the presented economic and mathematical model, there are two components: the variable x2 - the cost of production and sale of products per 1 ruble of manufactured products (cop.), Characterizing the production potential and the variable x5 - the share of costs of technological innovations in the total volume of goods shipped (%) characterizing innovative potential. It is noteworthy that, due to the instability of the dynamics of innovative activity in the industrial complex, as an object of the mesosystem, this parameter is included in the model with a negative effect, although its modulus of elasticity is much higher in modulus than with a variable cost of production and sale of products per 1 ruble of manufactured products - 1.9 versus 0.1. The greatest influence on the growth of high-tech and knowledge-intensive products in GDP, namely, the innovative component of the potential of the industrial sector, is also confirmed by private one-parameter models, while the hypothesis of the negative impact of this parameter on the resulting factor is also confirmed, which allows us to conclude that the nature of innovative industry is not fully used to build up a high-tech component (Kablov, 2017; Vertakova, Mkrtchyan & Leontyev, 2019; Vertakova, Polyanin & Golovina, 2018).

Thus, with a high dependence of the high-tech sector of the economy on the innovative potential of the industrial sector, its negative impact on the achievement of the high-tech level is noted, while when determining the direct effect of the production potential of the industrial sector on the high-tech sector of the economy, this effect was not detected, only in the two-parameter model, in a combination of innovative and production potential in the industry as a whole (Figure 2).

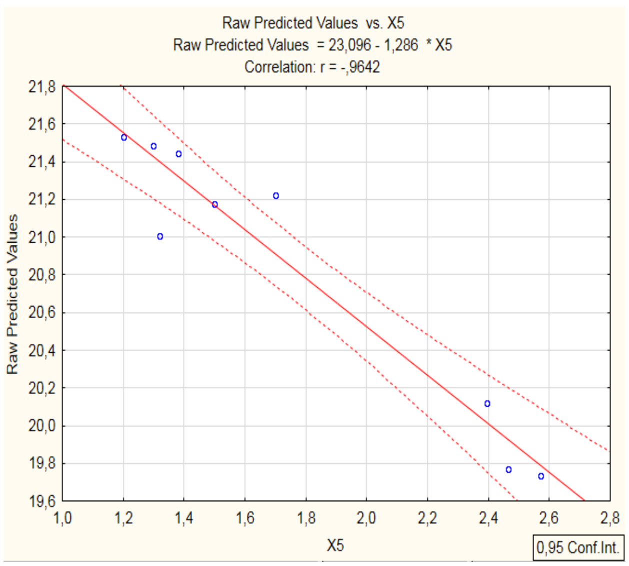

Figure 2a. Dependence of the high-tech sector of the economy on the innovative potential of the industrial sector

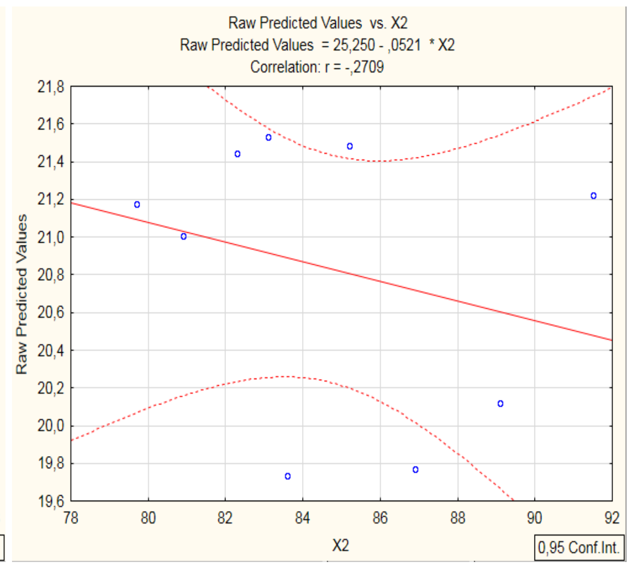

Figure 2b. Dependence of the high-tech sector of the economy on the production potential of the industrial sector

In order to identify further trajectories of industrial innovation and production development, a medium-term forecast was built on the basis of the presented economic and mathematical model. When forecasting, the following assumptions were used:

1) for the variable x2 - the cost of production and sale of products per 1 ruble of manufactured products (cop.) In the medium term, the average rate of decline of this indicator was used, which is for 2010-2018 amounted to 99.9%;

2) for variable x5 - the share of costs for technological innovations in the total volume of goods shipped (%) in the medium term, the average rate of decline of this indicator, which for 2010-2018, was used. amounted to 95%.

Thus, we believe that the value of the costs of production and sale of products will be reduced to 78.9 kopecks. 1 ruble of manufactured products in 2019, 78.1 kopecks. in 2020 to 77.3 kopecks. in 2021. In this case, according to the trend, a pessimistic development scenario will be noted, a decrease in the intensity of costs for technological innovations in the industrial complex from 1.43% in 2019, 1.35% in 2020 to 1.29% in 2021. However, aligning the innovative potential of the industrial sector as an average for the types of economic activities of the Russian economy, where the average growth rate of the intensity of costs for technological innovations for the analyzed period amounted to 110%, will reduce the gap in high technology and aukoemkosti products to GDP. Thus, the strengthening of the innovative potential of the industrial sector will make it possible, according to the optimistic forecast scenario, to increase the share of high-tech and high-tech products in GDP from 23.6% in 2019, 23.7% in 2020 to 23.8% in 2021 (according to the pessimistic forecast scenario, the value of this indicator will be, respectively, 21%, 21.1% and 21.2%). Consequently, the gap in high-tech production will average 2.6 percentage points (Figure 3).

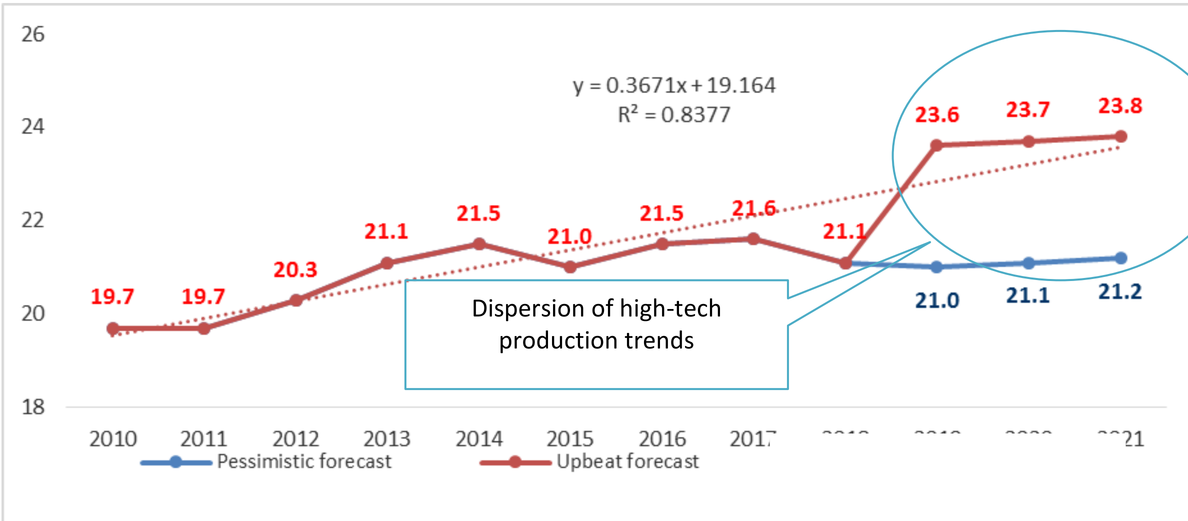

Figure 3. Forecast of high-tech production depending on the degree of implementation of the innovative production potential of the industry

Conclusion

Thus, the study allowed us to systematize the following conclusions.

1) Description of the industrial production potential in 2010-2018. It didn't have any definite trends, since the growth rate of the industrial production index and the volume of products shipped in industry alternated with the rate of decline.

2) An assessment of the innovative potential of industry made it possible to establish a significant breakthrough in increasing the share of organizations implementing technological innovations, however, there was a decrease in the intensity of costs for technological innovations and the share of shipped innovative products. Therefore, these trends allow us to conclude that there is insufficient mobilization and use of the innovative production potential of the industrial complex of the Russian economy.

3) On the basis of the regression model, due to the instability of the dynamics of innovative activity, a negative effect of the innovative potential of industry on the development of high-tech and high technology production was found to be positive, while there is a positive effect of the industrial potential on this resulting indicator, although its degree of impact is much weaker (1.9 and 0.1 percentage points, respectively).

4) Increasing the efficiency of using the innovative potential of the industrial sector will make it possible, according to the optimistic forecast scenario, to increase the share of high-tech and high-tech products in GDP from 23.6% in 2019 to 23.8% in 2021 (according to the pessimistic scenario, from 21% to 21.2%), which will reduce the gap in high-tech production by an average of 2.6 percentage points.

Thus, the medium-tech industry, as a traditional sector of the economy, will be focused on the development of production potential in the medium term, the innovative component of the sector's potential has shown insignificant changes with ambiguous trends in growth and decrease in its components (with an increase in the share of organizations engaged in technological innovations, a decrease in intensity costs of technological innovation and the share of shipped innovative products), which is not This allows you to talk about stabilizing the rate of increase output of high-tech products in this segment.

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