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Електротехнічні комплекси та системи

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EVALUATION OF THE INSTITUTIONAL DEVELOPMENT OF INNOVATIVE ACTIVITIES TO ENSURE THE ECONOMY OF THE STATE

Purpose. The purpose of the study is to develop a methodology for identifying the institutional development of innovative activity to meet the needs of the national economy.

Methodology. The following general scientific and special research methods were used in the research: monographic, logical-theoretical, statistical, economic-mathematical, system analysis, computational-analytical, abstract-logical methods, and generalization.

Findings. According to the methodology of the analysis of the operating environment, the state of institutional development of innovative activity in Ukraine is determined by the construction of the direction of effective development of the national economy in the context of the formation of GDP by capital investments and the number of people employed in the national economy. It was determined that the efficiency line indicates the trends in the formation of innovative activity in the operating environment, which corresponds to the theoretical basis of the Cobb-Douglas-Tinbergen production function for the economy of Ukraine.

Originality. For the first time, the mathematical apparatus of the Cobb-Douglas-Tinbergen production function has been tested to determine the level of scientific and technological progress of Ukraine. The methodological provisions of the analysis of the institutional development of innovative activity to meet the needs of the national economy on the basis of the formation of the functioning environment according to the macroeconomic indicators of Ukraine have gained further development.

Practical value. The results can be used in the design and implementation of effective strategies for innovative development, as well as the formation of a policy to promote innovation activity in the modern economy. The data obtained in the course of the study can serve as a basis for the development of recommendations and tools aimed at creating a favorable institutional environment for innovation activity, which will contribute to increasing the competitiveness of the national economy.

Keywords: *institutional development, innovative activity, state economy, evaluation*

Introduction. Innovation activity is one of the key factors in the development of the national economy. It provides an increase in the competitiveness of enterprises, the creation of new jobs, the development of knowledge-intensive industries, the formation of intellectual property, encourages new scientific developments to reduce production costs and increase profits, which is the main goal of entrepreneurial activity [1, 2]. Moreover, innovation activity is the basis for the generation of new knowledge and the development of modern approaches to solving global problems, which contributes to the development of science and technology and helps to ensure the sustainability of society [3, 4].

The modern nature of innovation activity is characterized by a complex structure of implementation and requires significant efforts, resources and expert knowledge for the successful implementation of an idea into a product or service [5]. This complexity not only creates a high level of uncertainty and potential risks, but also determines the need to improve the institutional environment to support innovative development.

In the modern world, where scientific progress and technological innovation are the engine of economic growth, the development of institutions aimed at supporting and stimulating innovation is a necessary factor for the successful development of the national economy [6, 7]. Institutional development of innovation activity becomes an important factor, as it affects the conditions in which innovative ideas are formed and implemented, as well as the effectiveness of their implementation in the economy. Institutional development of innovation activity involves the creation of a favorable environment for its implementation, which includes a regulatory framework, financial support, staffing, information support, etc. Taking into account the institutional aspect allows one not only to adapt innovative approaches to the realities of modern business, but also reduces risks and contributes to the creation of a favorable environment for the development of innovative ideas and technologies [8].

Thus, the institutional development of innovation activity is a complex process that consists in creating a favorable environment where innovation can have a significant impact on social development. Definitions of institutional development in the context of meeting the needs of the national economy determine the prospects and opportunities for ensuring the development of new sectors of the economy that can become strategic for the sustainable growth of the country in the future.

Literature review. The introduction of innovations and the creation of a favorable institutional environment for their development determine the efficiency and competitiveness of countries in the modern world. Institutional development of innovation activity is an important factor influencing the country's ability to meet the challenges of technological and economic development. In this regard, the issue of institutional development of innovation activity is in the focus of many both Ukrainian and foreign scientists.

The analysis of the works of scientists in the field of institutional development of innovative activity showed that, in the vast majority, research is conducted in a theoretical and methodological direction, which includes the study of the main

principles, models and mechanisms of institutional regulation of innovative activity, as well as the development of methodological recommendations for their practical application.

In particular, it was established that full-fledged functioning and purposeful development of the sphere of innovation is impossible without an appropriate institutional base – a set of conditions and factors for stimulating research and development [9]. At the same time, it was determined that in order to create an appropriate institutional environment for the development of innovative activities, a radical reorientation of state policy to support and stimulate innovation, the development of scientific and technical potential, ensuring the effective interaction of all participants in the innovation process and the formation of a favorable investment climate for the private sector is required [10]. According to Lee W. and Law S., the quality of institutions and social capital have a direct impact on the level of innovativeness, which means that strong human capital and a regulatory framework are equally important for promoting innovation [11]. Such scientists as Su Xin and Fu Wenxiu believe that institutional development provides the conditions for technological innovation by optimizing the policy, market and factor environment, thereby changing the profit generation mechanism of economic entities by moving into the plane of innovative and competitive economic units [12]. According to the position of scientists Kaletnik H. and Zdyrko N., it is only through state intervention that it is possible to achieve the creation of such a level of institutional environment where innovative projects determined by practice, which flourish in the world of exponential changes, will be implemented [13]. In this context, it was established that, subject to the political and organizational support of the state, financial, tax, material, and technical orientation, it is possible to create a model of the functioning of the national economy taking into account the principles of sustainable development on an innovative basis [14, 15]. According to Honcharuk I. and Tomashuk I., the implementation of state policy to stimulate innovative activity should be based on the concept of differentiation of innovative activity, which takes into account various stages of innovation implementation, from the idea to its practical application and commercialization – this will allow more precisely directing resources and efforts to the most promising and effective areas of innovative activity [16].

The presence of a significant number of publications in the field of institutional development of innovation activity indicates the relevance of this issue in modern conditions. However, despite the significant scientific achievements of scientists, today there are no methods for identifying the institutional development of innovation activity in traditional quantitative units, with the help of which it would be possible to clearly analyze the effectiveness of the implementation of state initiatives in the field of scientific research.

The purpose of the article. The aim of the study is to develop a methodology for identifying the institutional development of innovation activity to meet the needs of the national economy and to assess the level of impact of scientific and technological progress on innovation and economic development.

Methods. When studying the institutional development of innovative activity, general scientific and special research methods were used. Among which are:

1) monographic – when analyzing the scientific literature on the chosen topic;

2) logical-theoretical – when posing scientific problems, putting forward hypotheses and justifying them;

3) statistical, economic and mathematical – when processing statistical data;

4) visualization – for visual demonstration of research results;

5) system analysis – in the formation of methodological bases for identifying the institutional development of innovative activity;

6) computational and analytical – when determining the level of scientific and technical progress using the Cobb-Douglas-Tinbergen production function and building an operating environment for the institutional development of innovative activity;

7) abstract-logical method and generalization – when forming recommendations and conclusions based on research results.

The information base of the research was made up of the materials of the State Statistics Service of Ukraine, the indicators of the annual reports of the Global Innovation Index, scientific developments of foreign and domestic scientists on the specified subject.

Results. The efficiency and dynamism of the innovation sphere have become a decisive factor in ensuring the competitiveness of the economy and largely determining the market position of each country in the world. The experience of developed countries confirms that the success of innovative development of sectors of the national economy is determined not only by the volume of financing of innovations, but also by the ability to generate ideas that are embodied in new competitive products or services aimed at meeting the needs of the modern consumer [17].

In international practice, the Global Innovation Index (GII), which reflects the main components of the innovation potential of countries, is a generalizing indicator for assessing the level of activity and effectiveness of innovation activity, as well as the effectiveness of the implementation of the country's innovation potential. The main goal of the GII is a detailed analysis of the innovation environment of the countries of the world and the analysis of indicators of activity and efficiency of innovation policy. The GII data is published jointly by Cornell University, the European Business School INSEAD, the World Intellectual Property Organization, and the United Nations specialized agency [18].

The more innovatively developed a country is, the higher place it occupies in the ranking of innovatively active states. Let us take a look at Ukraine's place in the GII ranking and how the situation changed during 2011–2023 (Fig. 1) [18].

From 2011 to 2018, Ukraine saw a noticeable improvement in its position in the Global Innovation Index, which indicates significant progress in the field of innovative development. This period is determined by active measures and specific actions aimed at stimulating innovative activity, which has already contributed to increasing the country's competitiveness in the global innovation environment.

However, since 2018, there has been a sharp decline in positions, so 2022 is especially important, when Ukraine dropped to 57^{th} place in the ranking. This decline cannot be explained by general economic difficulties alone; it is also the result of the influence of geopolitical factors, namely the open aggression unleashed by Russia against Ukraine. The military conflict has led to serious challenges for both the economy and the innovation sector of Ukraine – interruptions in production, reduced investment and loss of human capital have significantly affected innovation activity. Reduced funding for research and delays in the implementation of innovative projects are also the result of a downgrade in Ukraine's rating.

Analyzing the economy of Ukraine in terms of the system of sub-indices, in particular the indicator "Institutional environment", it is possible to obtain detailed information about the state of institutional development of innovative activity during the period under study. In this way, a better idea of the quality of the economic, political, and regulatory environment for innovation in the country is formed (Fig. 2) [18].

Institutional environment of Ukraine during 2011–2023 is marked by a certain development with marked fluctuations. There is an increase in this indicator during 2011–2018, which indicates certain positive transformations and reforms in this area. However, in 2019 and 2020, there was a recession, which is associated with economic and political difficulties. It is im-

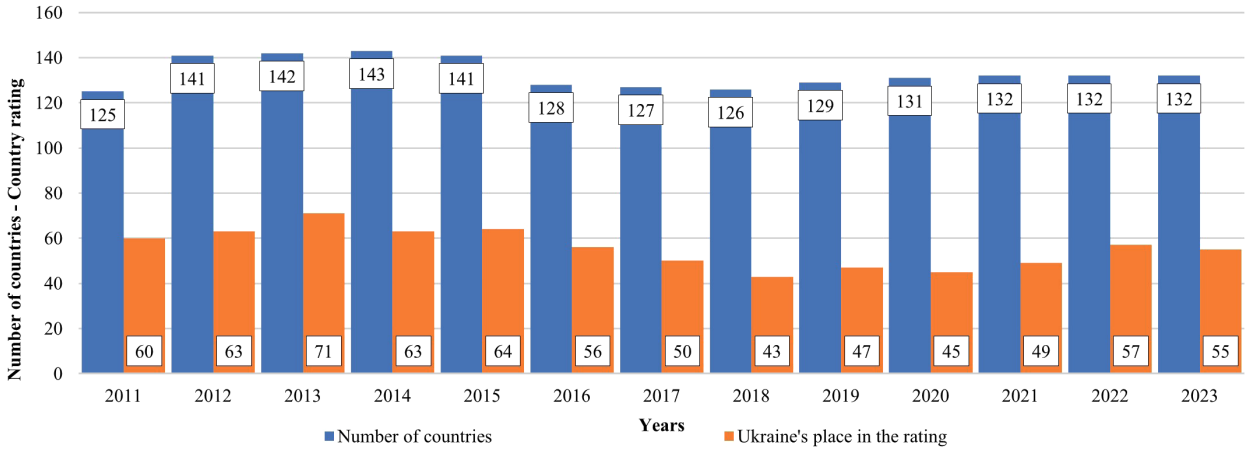

Fig. 1. Dynamics of the Global Innovation Index of Ukraine, 2011–2023

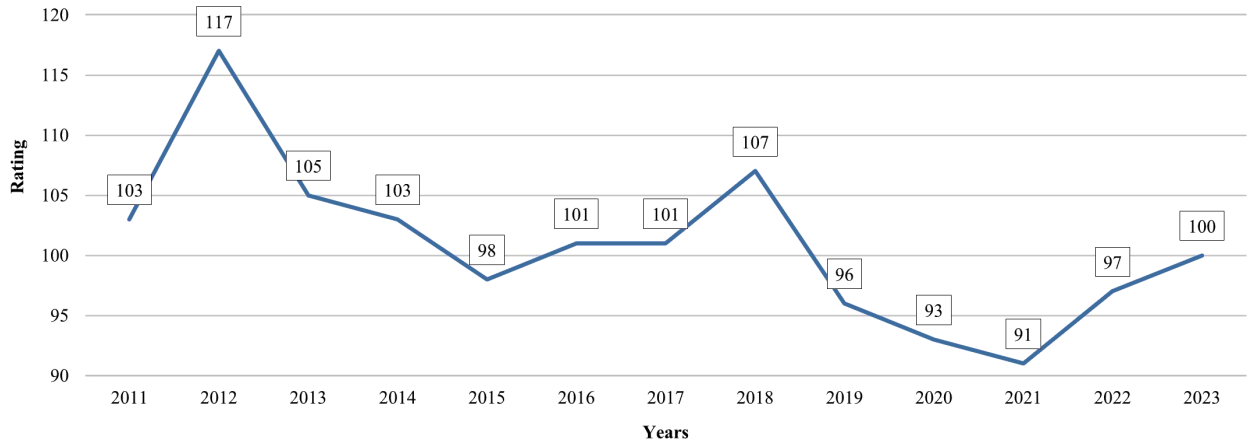

Fig. 2. Dynamics of positions of the subindex «Institutional environment» of Ukraine, 2011–2023

portant that after a period of recession in 2019–2020, the institutional environment is recovering, which is reflected in the growth of values during 2022–2023. This is the result of the implementation of economic reforms, political and other fundamental changes aimed at improving the institutional framework for innovative development of the country.

The key indicator that characterizes the country as innovative and active, shapes its innovative potential and the image of a developed state, is the knowledge intensity of GDP. The scientific intensity of GDP is the share of expenditures on scientific research activity in the total volume of GDP of the country, and therefore it can be considered a reflection of interest in scientific research activity (due to the amount of expenditures in research) and effective institutional support (due to the system of laws, norms, and tools) (Table 1) [19].

In this case, we observe a situation of discrepancy between R&D expenditures and GDP. Despite the stable growth of Ukraine's GDP from year to year (until 2022), the increase in R&D expenditures is not enough to ensure effective research activities. Based on the fact that there is a tendency to increase the knowledge intensity of GDP in the context of a noticeable increase in expenditures on innovation, there is a problem of underfunding of scientific research and irrational allocation of resources, which leads to a decrease in the knowledge intensity of GDP.

Thus, on the basis of the above, it can be concluded that there are a number of problems in Ukraine at the national level that affect the institutional development of the innovation sphere. Financing of scientific research and innovative projects is characterized by problems in the effective distribution and use of budget funds. A noticeable problem is also the lack of effective mechanisms for public-private partnership and co-financing, which would help attract private investment in the scientific and technical sector. The lack of stable financial support has a negative impact on the innovative activity of

Table 1

Research and development costs in Ukraine, 2010–2022

Year	GDP, UAH billion	R&D costs, UAH billion	R&D intensity of GDP, %	Deviation of R&D intensity of GDP to the previous year, +/–
2010	1,082.57	8.11	0.75	–
2011	1,316.60	8.51	0.65	–0.1
2012	1,408.89	9.42	0.67	0.02
2013	1,454.93	10.25	0.70	0.03
2014	1,566.73	9.49	0.61	–0.09
2015	1,979.46	11.01	0.56	–0.05
2016	2,383.18	11.53	0.48	–0.08
2017	2,982.92	13.38	0.45	–0.03
2018	3,558.71	16.77	0.47	0.02
2019	3,974.56	17.25	0.43	–0.04
2020	4,194.10	17.02	0.41	–0.02
2021	5,459.57	16.02	0.29	–0.08
2022	5,191.03	16.97	0.33	–0.01

enterprises and strikes a blow to their competitiveness in the international market.

It should be understood that this analysis only indicates some trends, and for a complete understanding of the state of the institutional environment of innovation activity, a detailed study and consideration of contextual factors is necessary.

In the system of institutional development of innovation activity, scientific and technological progress is the main catalyst for the transformation of structures and mechanisms that form and support innovative development. Its influence on the formation of strategies, legislative acts, financial mechanisms and staffing in the field of innovation determines not only the pace, but also the direction of development of this area. Strategies in innovation are often determined by the technological capabilities provided by scientific and technological progress. The formulation of strategies taking into account the latest technologies allow enterprises and institutions to direct their activities to those sectors of the economy that in the future can be saturated with changes and innovations [20].

Scientific and technological progress makes significant changes in this state of affairs due to:

1) changes in the nature of innovation activity – scientific and technological progress leads to the creation of new types of innovations that require new approaches to their development, implementation and commercialization. For example, the development of information technologies leads to the creation of new types of digital innovations, which require new approaches to their development and implementation;

2) changes in the state's role in innovative development – scientific and technological progress requires the state to intervene more actively in innovative development, including by creating a favorable environment for innovation, providing financial support, and developing innovative infrastructure;

3) changes in interaction between subjects of innovative activity – scientific and technical progress leads to closer interaction between scientific institutions, enterprises, investors, state bodies, etc.

These changes force the state and subjects of innovation activity not only to react, but also to actively influence the new conditions that are formed by scientific and technological progress. Adaptation to these changes involves, in addition to the assimilation of new technologies, also the search and implementation of new strategies and approaches to the development of innovative activities. To achieve this, determining the directions of scientific and technological progress becomes a key component.

Determining the directions of scientific and technological development contributes to the concentration of efforts in scientific research and the development of modern technologies in strategically important areas. As a result, opportunities are opening up for the creation of new products, services, technological solutions, which in turn contribute to increasing the competitiveness and innovativeness of the economy. It also forms a basis for the creation of scientific programs, the definition of priorities in the financing of research and development, as well as the directed management of resources to achieve specific innovation goals.

Thus, through the identification of directions of scientific and technological progress, it is possible to achieve greater direction and efficiency in the strategic management of innovation activity. Also, new opportunities are opening up for the state and subjects of the innovation sphere in achieving success in implementing the results of scientific and technological progress and ensuring sustainable development.

The institutional development of innovation activity is characterized by the effectiveness of scientific and technological progress as the main factor in the existence of the national economy in general and business structures in particular. Scientific and technological progress can be considered as an objective social phenomenon that arises as a result of the realization of the needs of economic entities in more advanced production systems, which significantly reduce labor costs and increase the final result.

The main feature of scientific and technological progress is its connection with the economy of the state, industries, and business structures. Scientific and technological progress increases the capabilities of the economy by reducing costs and increasing added value.

At the same time, the presence of scientific and technological progress is the basis of the institutionalization of economic development in the form of innovative activity. At present, the manifestation of the institutionalization of innovative activity is observed in efforts to achieve success in technological markets thanks to innovative competition. For this purpose, various approaches are used for the formation of institutional support for innovative activity [21, 22]: at the state level – these are normative legal acts that stimulate innovative activity; at the business level – these are approaches to the formation of technoparks, technopolises, research centers; at the level of business structures – these are innovation departments, research centers, design bureaus, etc.

Institutionalization of innovation activity in the system of economic relations is formed as an interconnection of regularities in the form of parametric and non-parametric models. Parametric and nonparametric models are two types of mathematical models that are used to describe the relationships between different factors. Parametric models assume that these relationships can be described using a specific mathematical function that has certain parameters, while nonparametric models do not make any assumptions about the form of the mathematical function that describes the relationships.

Thus, the use of parametric and non-parametric models allows obtaining a more complete understanding of the relationships between the factors influencing the development of innovations in the economy. The use of parametric and nonparametric models allows one to obtain many relationships between various factors and identify important patterns of influence on the development of innovations in the economy.

We propose to apply the approach of identification of the process of innovation activity to meet the needs of the national economy in the context of achieving the regularities of institutional development of the economy, based on the synthesis of the use of the Cobb-Douglas-Tinbergen production function and the method of analysis of the operating environment.

Much of the current research on the impact of scientific and technological progress on economic growth is carried out using the Cobb-Douglas production function and its modifications, for example, using the Cobb-Douglas-Tinbergen production function. The economic content of Cobb-Douglas' production functions is to identify the level of influence of each factor of economic growth and their cumulative effect on the volume of the national product. It has become the most widespread because it takes into account the asymmetric laws of social production, the uneven distribution of economic resources between the structural components of the national economy, and thus provides the most accurate macroeconomic forecasts. The model shows the effect of such factors as capital and labor under conditions of extensive economic growth [23]. It should be noted that the theoretical and methodological foundations for the use of the Cobb-Douglas production function as a tool for assessing the management of the national economic system of Ukraine were laid at the beginning of the twentieth century. and are still developing.

The first attempt to "dynamize" the Cobb-Douglas production function was the Cobb-Douglas-Tinbergen production function. The Dutch economist, having studied the Cobb-Douglas production function, formed his own modification, which, in addition to the classical indicators of capital and labor, contains another synthetic dynamic factor – "neutral scientific and technological progress". This indicator makes it possible to identify the level of influence of "outside

force" on output Y, optionally without taking into account the influence of capital and labor.

The Cobb-Douglas-Tinbergen production function is as follows

$$Y = Ae^{\delta t}K^{\alpha}L^{\beta},$$

where Y is GDP; A – a free member; exhibitor e indicates the level of technological progress that affects the volume of production e; δ – growth rate Y due to all factors except; K – the volume of capital; L – the volume of labor; t – time factor (research period); α, β – coefficients of the production function, which characterize the elasticity of the volume of production in terms of capital and labor costs.

Therefore, we propose to test the theoretical basis of the Cobb-Douglas-Tinbergen model and determine the level of scientific and technological progress of Ukraine for the period 2010–2022. based on three macroeconomic indicators: GDP – Y; volume of capital investments in the economy – K; the number of people employed in the national economy – L (Table 2) [19].

Taking into account the fact that scientific and technological progress is reflected by the level of innovation activity, we propose to first analyze its institutional development based on the formation of the operating environment according to the indicators of the Cobb-Douglas-Tinbergen production function for the economy of Ukraine for 2010–2022. To do this, we will use the method of analysis of the functioning environment (M. Farrell's method) [24].

The advantage of this method lies in the possibility of using nonparametric boundary approaches, which will allow assessing the development of institutionalization based on the effectiveness of the studied positions (in our case, the positions are 13 periods from 2010 to 2022). Such calculations were tested for different cases of the operating environment, in particular:

1) when evaluating the efficiency of enterprises [24, 25];

2) when determining the efficiency of enterprise liability management [26];

3) when assessing the impact of digitalization of the economy on the growth of agriculture [27];

4) when identifying the possibilities of increasing the yield of biofuel of agricultural crops [28];

5) when evaluating the effectiveness of providing excursion services [29].

This made it possible to determine the available resources (two names) and the effective indicator for each position in the context of achieving efficiency.

Cut-off approaches are based on the presence of one performance indicator (Y) and two resource (factor) indicators (L and K). M. Farrell, in his example, used the volume of products sold as an effective indicator, and the factor indicators are labor costs and the cost of capital [25]. Thus, among the studied indicators, the indicators of financial results (profits and losses) of economic entities were excluded.

Since the indicators of the financial result for enterprises are not defined as effective, the assessment of their activities is carried out not from the point of view of profit maximization, but on the basis of the marginal indicator of efficiency and expediency of functioning. That is why, initially, the method of functioning environment was used to assess the effectiveness of natural monopolies, since it is not so much their economic efficiency that is important for society as social justice for the population.

Subsequently, the method of analysis of the operating environment gained considerable popularity in the study of the efficiency of enterprises operating in competitive markets in all sectors of the national economy, since it was not the financial result that was analyzed, but the significance of the type of economic activity itself as the main component in the economic system of the state.

The scheme of the analysis of the operating environment is shown in Fig. 3 [25].

Based on Fig. 3, the following explanations can be made: L/Y and K/Y are the coefficients of the ratio between the factor and the effective indicator; A, B, C, D, E – positions of "reference" enterprises in the operating environment; F, G, H, I, J – positions of inefficient enterprises in the operating environment.

The level of efficiency (inefficiency) of the enterprise is determined using the efficiency coefficient (by the example of position H)

$$E_f = \frac{0K}{0H}, \quad (1)$$

where $0H$ is the distance from the origin to the position of the inefficient enterprise; $0K$ is the distance from the origin to the point of intersection of the $0H$ line with the CD segment.

Thus, "reference" enterprises are enterprises whose positions are as close as possible to the abscissa and ordinate lines, respectively, the A-B-C-D-E line is the efficiency line. In this case, the efficiency coefficients for the positions of each enterprise are equal to one ($E_f = 1$). Efficiency coefficients for other enterprises can vary from 0 to 0.9 and are calculated using formula (1). The closer the position is to the efficiency line, the higher the efficiency ratio.

In our case, the use of the method of analysis of the operating environment, in contrast to the developments of M. Far-

Table 2

Indicators of the Cobb-Douglas-Tinbergen production function for the economy of Ukraine, 2010–2022

Year	Period, t	GDP, million UAH, Y	Volume of capital investments, million UAH, K	Number of people employed in the national economy, million people, L
2010	1	1,082,569	180,575.5	19.18
2011	2	1,316,600	241,286.0	19.23
2012	3	1,408,889	273,256.0	19.26
2013	4	1,454,931	249,873.4	19.31
2014	5	1,566,728	219,419.9	18.07
2015	6	1,979,458	273,116.4	16.44
2016	7	2,383,182	359,216.1	16.27
2017	8	2,982,920	448,461.5	16.15
2018	9	3,558,706	578,726.4	16.36
2019	10	3,974,564	623,978.9	16.57
2020	11	4,194,102	508,217.0	15.91
2021	12	5,459,574	673,899.3	15.61
2022	13	5,191,028	409,660.0	12.01

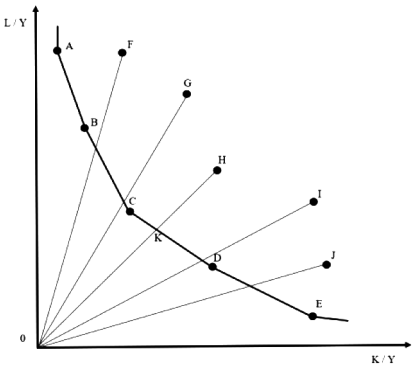

Fig. 3. Scheme of analysis of the functioning environment

rell and other studies, is based on the fact that the positions are the time period between 2010 and 2022, within which the national economy is analyzed in the context of the correspondence between the volume of GDP attracted capital investments and the number of people employed in the economy.

Based on Table 2, the resource (factor) indicators are K (Volume of capital investments) and L (Number of people employed in the national economy). The effective indicator is Y (GDP volume). Thus, the calculated coefficients are the coefficient of coverage of the volume of GDP of capital investments $\left(\frac{K}{Y}\right)$ and the ratio of the number of people employed in the national economy to the volume of GDP $\left(\frac{L}{Y}\right)$ (Table 3).

The environment of institutional development of innovation activity for 2010–2022 is formed on the basis of the efficiency line 13 (2022) – 1 (2010) (Fig. 4).

Thus, efficiency was not achieved in 2011–2021. We propose to assess the level of efficiency (inefficiency) for these years using Table 4.

Based on the calculated efficiency (inefficiency) coefficients, the following conclusions can be drawn:

1) the level of efficiency for all years is not less than 0.50, respectively, the inefficiency does not exceed 0.50;

2) the maximum level of efficiency was observed in 2014 (0.91) with an inefficiency level of only 0.09;

3) the minimum level of efficiency was observed in 2012 (0.50) with an inefficiency level of 0.50.

In this context, indicators of the level of efficiency (inefficiency) characterize the structured basis for institutionalization of the development of innovation activity. There are quite reasonable limits to the expediency of stimulating scientific and technological progress to ensure GDP growth by attracting the necessary amount of capital investment and a sufficient number of people employed in the national economy.

The limits of the expediency of stimulating scientific and technological progress to ensure GDP growth are proposed to be substantiated on the basis of determining the total value of the interval:

- the first interval (we choose the two smallest efficiency coefficients 0.50 and 0.51, respectively, the difference is 0.01);
- second interval: 0.51–0.57 = 0.06;
- third interval: 0.57–0.58 = 0.01;

Table 3

Coverage ratio of GDP of capital investments (K/Y) and ratio of the number of people employed in the national economy to GDP (L/Y), 2010–2022

Year	Period, t	K/Y	L/Y
2010	1	0.167	0.0000177171154910218
2011	2	0.183	0.0000146058028254595
2012	3	0.194	0.0000136703459250515
2013	4	0.172	0.0000132721070621218
2014	5	0.140	0.0000115335910253726
2015	6	0.138	0.00000830530377507378
2016	7	0.151	00000082700691764204
2017	8	0.150	0.00000541415793920051
2018	9	0.163	0.00000459717661419628
2019	10	0.157	0.00000416901073929115
2020	11	0.121	0.00000379342228682087
2021	12	0.123	0.00000285919743921412
2022	13	0.079	0.00000231360724607247

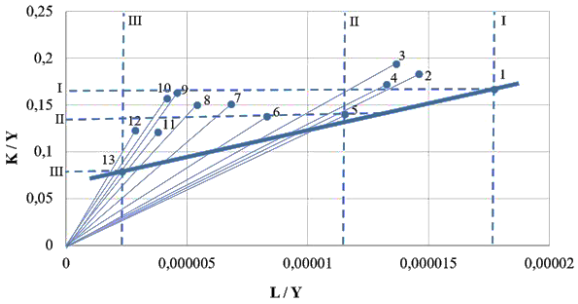

Fig. 4. Institutional development of innovation activity by analysis of the functioning environment, 2010–2022

- fourth interval: 0.58–0.60 = 0.02;
- fifth interval: 0.60–0.65 = 0.05;
- sixth interval: 0.60–0.65 = 0.05;
- seventh interval: 0.65–0.67 = 0.02;
- eighth interval: 0.67–0.68 = 0.01;
- ninth interval: 0.68–0.76 = 0.08;
- tenth interval: 0.76–0.91 = 0.15.

The total value of the differences is 0.46 less than the "benchmark" efficiency coefficient 1, and therefore we believe that the institutional development of innovation activity is expedient from the point of view of the time factor.

The line of efficiency testifies to the trends in the formation of innovative activities in an environment that meets the requirements of the Cobb-Douglas-Tinbergen function for the economy of Ukraine for 2010–2022. This means that the base years from the study interval are 2010 and 2022. All other years correspond to the existing situation to varying degrees. The closer the position of the period t to the line of efficiency, the more significant its importance in the system of institutional development. Studying the given operating environment visually, we can conclud that the year 2014 had the most significant impact on its formation.

On the basis of the line of efficiency, three stages of the formation of institutionalization of innovation activity can be distinguished:

- the first stage, from 2010 to 2014, was determined based on the position of 2010 and the period that had the lowest inefficiency among other periods (in 2014, the inefficiency was 0.09) in terms of GDP on capital investments and the number of people employed in the national economy;

- the second stage – from 2014 to 2022 was determined with the results of 2011–2013, 2015–2018 and 2020 (intersection of segments 1–13 of the efficiency line with segments 0–2, 0–3, 0–4, 0–6, 0–7, 0–8, 0–9, 0–11) in terms of GDP

Table 4

Level of efficiency (inefficiency) of ensuring the institutional development of innovation activity

No.	Years	Efficiency Factor	Inefficiency Ratio
2	2011	0.67	0.33
3	2012	0.58	0.42
4	2013	0.68	0.32
5	2014	0.91	0.09
6	2015	076	0.24
7	2016	0.60	0.40
8	2017	0.57	0.43
9	2018	0.50	0.50
10	2019	0.51	0.49
11	2020	0.65	0.35
12	2021	0.65	0.35

by capital investments and the number of people employed in the national economy;

- the third stage – since 2022, the intersection of lines 0–10 and 0–12 with the efficiency line was determined based on the results of 2019 and 2021 in terms of GDP by capital investments and the number of people employed in the national economy.

It should be noted that the institutional development of innovation activities was significantly affected by Russia's full-scale invasion of the Ukraine in 2022, which was reflected in the following:

- the line of efficiency, unlike other years, consists of only two positions;

- the last position coincides with the last year of the study, since the number of people employed in the national economy is the lowest for the entire period of the study (12.01 million people);

- using the position of 2014, which is not part of the efficiency line, but is characterized by maximum efficiency (possible discrepancy – distance 5–51).

Thus, thanks to the carried-out research using the method of analysis of the environment of functioning, the institutional development of innovation activity in Ukraine has been determined by building a direction for the effective development of the national economy in the context of the formation of GDP in terms of capital investments and the number of people employed in the national economy. At the same time, the development of innovation activities includes technological progress, and therefore we will build the Cobb-Douglas-Tinbergen production function for the economy of Ukraine for 2010–2022.

The application of this methodology allows us to assess the efficiency of the use of different factors of production and understand how the productivity of the economy has changed during this period. To understand the initial data, we visualize a static data cluster and identify patterns that are not always visible in tables and numerical indicators (Fig. 5) [19].

Based on the logarithm of the table data and multiple regression, the equation was obtained

$$Y = 21{,}831.0526 e^{0.082t} K^{0.451} L^{-0.574}.$$

The obtained model accurately describes the dynamics of GDP (Y) for the studied period: the coefficient of determination indicates that 99.6 % of the variation of Y is explained by three factors of the Cobb-Douglas-Tinbergen function – to describe the dependence between the dependent variable (GDP) and independent variables. The mean absolute error of the equation is a measure of the accuracy of the predictions that the regression model makes. The smaller the value of the standard error, the more accurate the predictions. In our case, the indicator is UAH 0.042 million, which indicates that the projected values of GDP may differ from the actual values by an average of UAH 0.042 million.

The coefficients of elasticity α, β show that during 2010–2022, with an increase in the volume of investments by 1 %, there is an increase in the volume of production by 0.451 %. The value of the labor elasticity indicator, in turn, means that an increase in the number of employees of the national economy by 1 % leads to a decrease in GDP by 0.574 %. This indicates that the labor factor is less elastic compared to investment. In other words, an increase in the number of employed people does not give the national economy as much growth in GDP as an increase in investment. This may be due to the fact that an increase in the number of workers may lead to a decrease in labor productivity if investment does not increase proportionately.

A value of 0.082 in the exponent indicator $e^{0.082}$ indicates technical progress that affects the volume of production. The value of $e^{0.082}$ is about 1.085, which means that with the gradual implementation of the results of technological progress, output can increase by 8.5 % from the initial level if the amount of capital and labor remains unchanged. Technical progress can act as an improvement in technologies, production methods, improvement in the quality of raw materials, etc., which can lead to an increase in the productivity of labor and capital.

It is worth noting that the level of scientific and technological progress, due to its complex structure as a scientific category, cannot be measured by traditional units of measurement. Its level of influence can be measured solely as the relative increase in the productivity of labor and capital in an industry during a given period compared to the previous period. Thus, to determine the coefficient of technical progress (level of scientific and technological progress), we suggest using the following formula

$$C_{tp} = \left(\frac{Y_1}{Y_0}\right) \Bigg/ \left[\left(\frac{K_1}{K_0}\right)^{\alpha} \cdot \left(\frac{L_1}{L_0}\right)^{\beta}\right],$$

where C_{tp} is the coefficient of technical progress; Y_1 – GDP in the current period; Y_0 – GDP in the previous period; K_1 – Capital investments in the current period; K_0 – Capital investments in the previous period; L_1 – the number of people employed in the national economy in the current period; L_0 – the number of people employed in the national economy in the previous period; α, β – coefficients of elasticity of capital and labor.

Results of calculations for determining the coefficient of technical progress for 2011–2022 are presented in Fig. 6.

Let us take a look at the dynamics of indicators for each year and formulate the reasons for the rise and fall in the level of scientific and technological progress:

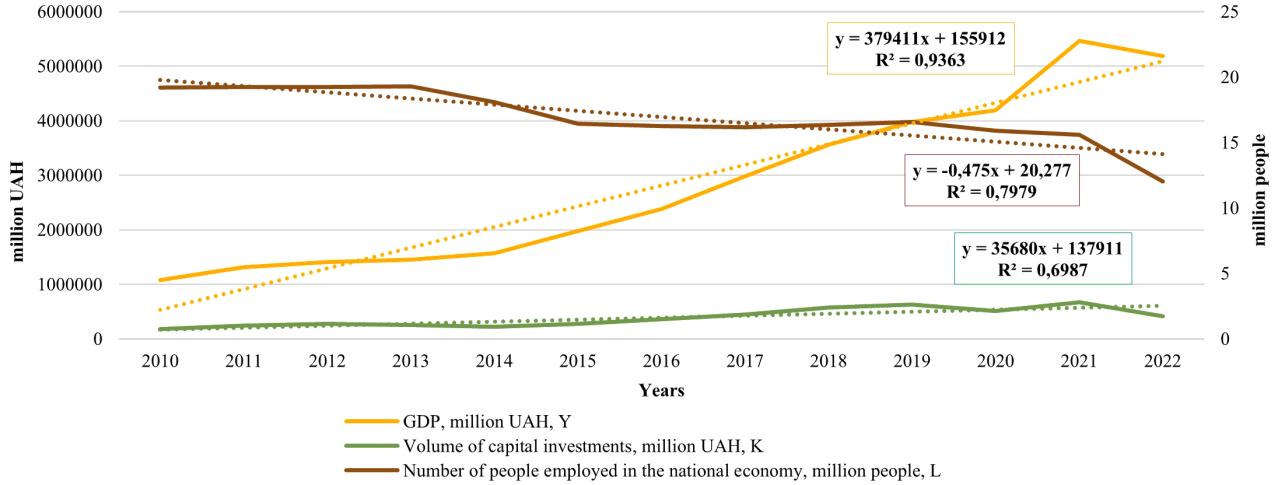

Fig. 5. Dynamics of Macroeconomic Indicators for Building the Cobb-Douglas-Tinbergen Production Function, 2010–2022

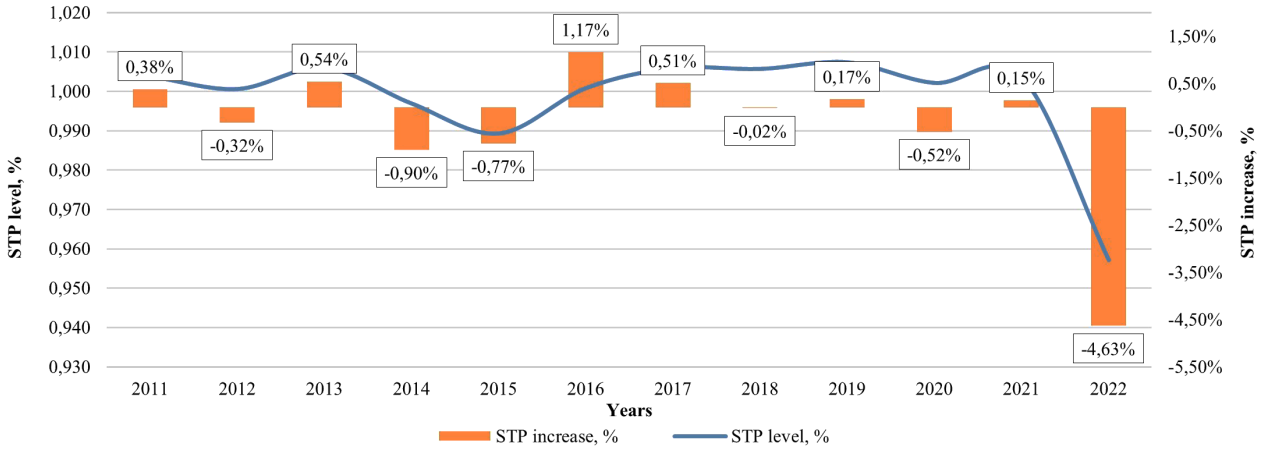

Fig. 6. Dynamics of the level of scientific and technological progress of Ukraine, 2011–2022, %

1) in 2011, the level of scientific and technological progress increased by 0.38 % compared to the previous year. However, the reasons for such growth are difficult to characterize, since the decrease in the indicator in 2012 by 0.32 % suggests that the growth may have been too sharp and unstable and was associated with specific factors that did not affect the further development of scientific and technological progress;

2) in 2013, the level of scientific and technological progress increased by 0.54 %, which can be explained by the overall growth of GDP, the attraction of new technologies and the growth in the number of people employed in the national economy related to science and technology;

3) in 2014, the level of scientific and technological progress decreased by 0.90 %, which may be possible due to a decrease in the financing of R&D and the number of people employed in the national economy;

4) in 2015, the level of scientific and technological progress decreased by 0.77 %, which can be explained by a decrease in the number of people employed in the national economy, although there is a significant increase in investment in R&D;

5) in 2016, the level of scientific and technological progress increased by 1.17 %, which can be explained by the further growth of investments in research;

6) in 2017, the level of scientific and technological progress increased by 0.51 %, which is explained by an increase in investment in R&D, the accelerated development of industries related to science and technology, as well as positive trends in the country's economy;

7) in 2018, the level of scientific and technological progress decreased by 0.02 % – this can be explained by the uneven growth of investments in R&D and the number of people employed in the national economy (as evidenced by a less elastic coefficient of this factor), which led to the lack of necessary incentives for innovation and development of technological solutions, as well as uneven distribution of resources and qualified specialists in the national economy;

8) in 2019, the level of scientific and technological progress increased by 0.17 %, which can be explained by an increase in investment in R&D, an increase in the number of people employed in the national economy, the attraction of new technologies, as well as the accelerated development of industries related to science and technology;

9) in 2020, the level of scientific and technological progress decreased by 0.52 %, which can be explained by a decrease in the number of people employed in the national economy, the deterioration of the economic situation in the country, as well as a decrease in interest in research and development, as well as the possible insufficient introduction of new technologies in industry;

10) in 2021, the level of scientific and technological progress increased by 0.15 %, which is explained simultaneously with GDP growth and increased investment in R&D, but there is a decrease in the number of people employed in the national economy;

11) in 2022, the level of scientific and technological progress decreased by 4.63 %, which is the lowest figure for the study period. This decline is explained by a sharp decline in all three macroeconomic indicators, which was provoked by Russia's military aggression against Ukraine.

Scientific and technological progress is undoubtedly a key catalyst for the successful institutional development of innovation. Its impact on creating an enabling environment for innovation can be explained by several aspects: first, scientific research and technological discoveries often serve as the basis for the creation of new legislation and policies governing innovation. The development of new technologies requires updating security standards, rules for the use and distribution of intellectual property, and this, in turn, requires updating the regulatory framework. Secondly, scientific achievements are a motivation for the development of financial mechanisms aimed at supporting innovative initiatives. Investors, funds, and government programs are often geared toward projects based on cutting-edge scientific discoveries, which stimulates the development and support of innovation. Thirdly, scientific progress is changing the requirements for staffing. New technologies create a demand for specialists in various fields. Therefore, institutions that provide education must adapt their programs to train future professionals in view of new technological needs. Fourthly, scientific and technological progress provides information content. The speed of change in science and technology requires constant updating and access to up-to-date information. This means that institutions must have access to the latest research and technological developments to perform their functions effectively.

Conclusions. The results of the study show that the calculated level of scientific and technological progress has a disproportionate increase and decrease during the study period. Experimentally, it was determined that an increase in macro indicators in Ukraine by 1 % from their current value leads to the following:

1) an increase in capital investment by 1 % leads to a decrease in the level of scientific and technical progress by ≈0.03 % – it can be justified by the fact that when focus on increasing capital investment, attention is paid to resources to ensure physical growth of production without attention to needs in scientific and technological research);

2) an increase in the volume of GDP by 1 % leads to an increase in the possibilities of scientific and technical progress by ≈0.06 % – may indicate that economic development stimulates investment in research, which in turn promotes scientific and technical progress;

3) an increase in the number of employees by 1 % leads to an increase in the possibilities of scientific and technical prog-

ress by ≈0.22 %, which leads to the appearance of new questions.

In this case, the question of the doubtfulness of the conclusion about the inelasticity of the indicator of the number of employees in the national economy (–0.57) is debatable, since in turn growth leads to an increase in the level of scientific and technological progress. In our opinion, there are several possible explanations for this situation:

1) "scale effect" – an increase in the number of people involved in scientific and innovative activities can lead to a more intensive exchange of knowledge and ideas, which will stimulate scientific and technological progress, but it can also lead to its slowdown due to a decrease in competition for grants and other resources;

2) "new ideas" – an increase in the number of employees can lead to the emergence of new ideas and approaches to solving problems, which can stimulate innovation; at the same time, there may be a fact of "dilution" of resources – available resources are distributed disproportionately, thus causing danger due to their lack for conducting qualitative research;

3) "specialization" – an increase in the number of people can lead to deeper specialization, which makes research and development more efficient; on the other hand, the increase in the number of employees will lead to the fact that the available skills may not meet the needs of the labor market over time, slowing down scientific and technological progress.

Considering the obtained research results, we can also conclude that it is necessary to take into account the dynamics of changes and the peculiarities of the contextual environment when applying the obtained model of economic growth in Ukraine. At the same time, it is necessary to take into account that additional factors affecting scientific and technological progress and the economic situation in general are the growth of hidden unemployment, significant labor migration of the population, which is difficult to reflect in statistical data, as well as full-scale Russian aggression, damages from which are currently not amenable to assessment.

The study proved that the level of scientific and technological progress in the country has fluctuated over the past 12 years. During this period, there was both growth and decline of the indicator, which is associated with various factors, such as investment in scientific and technological development, the development of new technologies and innovativeness of industries, and the economic situation in the country after the military invasion of Russia. However, in general, it can be argued that in recent years there has been an increase in interest in scientific and technological progress, which is reflected in the increase in investment and the development of new technologies. It is also worth paying attention to the need to further increase the innovativeness of industries related to science and technology in order to ensure sustainable development of the country and competitiveness in the international market.

Thus, scientific and technological progress acts as an important factor that forms conditions for the institutional development of innovation activity. Its influence determines the direction and speed of evolution of the structures that facilitate and regulate the innovation process, providing the necessary environment for the creation, implementation and successful development of innovations.

The method of analysis of the environment of functioning allowed us to identify the regularity of the process of innovation activity from the point of view of institutional development by applying the criterion of efficiency as an evaluative factor of changes in the volume of capital investments and the number of people employed in the national economy in the context of GDP growth. Time space (12 years) made it possible to substantiate institutional development in terms of positioning in the environment of functioning, where the years of the "standard" position for innovation activity in the existing conditions and the possibility of forming this process in the future depending on the level of efficiency (inefficiency) were determined.

In this work, although the separation of factor and performance indicators by specific characteristics was not carried out, because the time interval was chosen as the position of the operating environment – from 2010 to 2022, which to a greater extent excludes significant and unreasonable deviations in the specifics of the indicators, since a general binding to a single criterion is built – the marginal efficiency of the time interval intervals in relation to the volume of GDP. The proposed approach has a number of limitations, which are the basis for further research. Thus, the aspect of the approach in the context of focusing on relative indicators – coefficients $\frac{L}{Y}$ and $\frac{K}{Y}$, requires additional research. These coefficients, by their very nature, do not take into account the volume of capital investments by industries, objects, completed works, etc. Likewise, those employed in the national economy may have different professions, wages, and income levels. Therefore, it is more rational to select indicators based on clearly defined characteristics of the phenomenon being studied, otherwise there is a risk of obtaining dubious results. For example, where an employee who receives a low salary can be more effective than a manager who makes million-dollar deals.

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Оцінка інституційного розвитку інноваційної діяльності для забезпечення економіки держави

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Мета. Розробка методології виявлення інституційного розвитку інноваційної діяльності для задоволення потреб національної економіки.

Методика. У дослідженні використані такі загальнонаукові та спеціальні методи дослідження, як: монографічний, логіко-теоретичний, економіко-математичний, системний аналіз, розрахунково-аналітичний, абстрактно-логічний та узагальнення.

Результати. Відповідно до методики аналізу середовища функціонування, стан інституційного розвитку інноваційної діяльності в Україні визначається побудовою напряму ефективного розвитку національної економіки в контексті формування ВВП за капітальними інвестиціями та чисельністю зайнятих у народному господарстві. Визначено, що лінія ефективності свідчить про тенденції формування інноваційної активності в середовищі функціонування, що відповідає теоретичному базису виробничої функції Кобба-Дугласа-Тінбергена для економіки України.

Наукова новизна. Для визначення рівня науково-технічного прогресу України вперше апробовано математичний апарат виробничої функції Кобба-Дугласа-Тінбергена. Розроблені методичні положення аналізу інституційного розвитку інноваційної діяльності для задоволення потреб національної економіки на основі формування середовища функціонування за показниками виробничої функції Кобба-Дугласа-Тінбергена для економіки України.

Практична значимість. Результати можуть бути використані при розробці й реалізації ефективних стратегій інноваційного розвитку, а також формуванні політики сприяння інноваційній діяльності в сучасній економіці. Отримані у ході дослідження дані можуть слугувати основою для розробки рекомендацій та інструментів, спрямованих на створення сприятливого інституційного середовища для інноваційної діяльності, що допомагатиме підвищенню конкурентоспроможності національної економіки.

Ключові слова: *інституційний розвиток, інноваційна діяльність, економіка держави, оцінка*

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