Scientific Bulletin
of Mukachevo State University

Series
Economics

Volume 12, No. 2, 107-120
Journal homepage: https://economics-msu.com.ua/en

UDC 338.245(477)
DOI: 10.52566/msu-econ2.2025.107

Modelling economic productivity of Ukraine in the context of military challenges

Tatyana Shtal
Doctor of Economics, Professor
Simon Kuznets Kharkiv National University of Economics
61166, 9A Nauka Ave., Kharkiv, Ukraine
https://orcid.org/0000-0003-1256-9854

Olena Butenko*
PhD in Economics, Associate Professor
Simon Kuznets Kharkiv National University of Economics
61166, 9A Nauka Ave., Kharkiv, Ukraine
https://orcid.org/0000-0002-2151-8410

Olena Kot
PhD in Economics, Associate Professor
Simon Kuznets Kharkiv National University of Economics
61166, 9A Nauka Ave., Kharkiv, Ukraine
https://orcid.org/0000-0002-6403-4766

Viktoria Kozub
PhD in Economics, Associate Professor
Simon Kuznets Kharkiv National University of Economics
61166, 9A Nauka Ave., Kharkiv, Ukraine
https://orcid.org/0000-0002-0402-8508

Valerii Malakhov
PhD in Economics, Associate Professor
Simon Kuznets Kharkiv National University of Economics
61166, 9A Nauka Ave., Kharkiv, Ukraine
https://orcid.org/0000-0002-8024-3998

Received: 07.02.2025, Revised: 05.05.2025, Accepted: 30.06.2025

Suggested Citation: Shtal, T., Butenko, O., Kot, O., Kozub, V., & Malakhov, V. (2025). Modelling economic productivity of Ukraine in the context of military challenges. *Scientific Bulletin of Mukachevo State University. Series "Economics"*, 12(2), 107-120. doi: 10.52566/msu-econ2.2025.107.

*Corresponding author

Abstract. Military challenges have transformed the economy of Ukraine, stipulating the necessity of revaluating the sources of its productivity. An attempt was made to model the impact of these factors on Ukraine's GDP using the Cobb-Douglas production function and the Solow residual. Statistical data for 2014-2024 were analysed, regression analysis was performed to determine the relationship between the main economic variables and the elasticity of capital and labour was estimated. The Solow residual was used to estimate the technological level of the economy and identify exogenous factors affecting productivity. The results of the study suggest that spending on scientific and technical activities had a negative impact in the short term due to insufficient funding and macroeconomic instability. Military expenditures failed to provide a significant increase in productivity due to their unproductive focus. In contrast, international aid contributed to macroeconomic stability, although failed to stimulate long-term growth. The partial contribution of factors to the formation of the Solow residual made up 27.92% for innovation, 25.95% for military spending and 20.99% for international aid. The model indicated a high R^2 value (0.96), suggesting its validity in explaining changes in TFP. Recommendations were developed to improve economic productivity of Ukraine, which include improving scientific and technical activity through improved funding for scientific research, rationalising defence spending by integrating military investments into the overall economic strategy, as well as effectively attracting international aid for structural reforms and human capital development. The obtained results can serve as the foundation for shaping economic policies aimed at the country's post-war recovery

Keywords: Cobb-Douglas production function; employment; international aid; expenditures on scientific and technical activities; Solow residual

Introduction

Economic growth and productivity remain central issues in economics, as they determine the nation's well-being and its place in the global economy. The study of productivity and key factors of its growth is particularly relevant for Ukraine, being in the process of profound economic transformation. In the context of modern challenges, such as a full-scale Russian invasion, post-war recovery and integration into the European market, the analysis of economic productivity is becoming an important tool for developing effective economic strategies.

The signing of the Association Agreement with the European Union has created new opportunities for Ukrainian companies to expand access to EU markets, while at the same time emphasising the need to assess resource efficiency and the contribution of technological innovation to increasing economic productivity. According to the State Statistics Service of Ukraine, foreign investment in the technology sector grew steadily until 2021 and decreased by 28% in 2022 due to the full-scale Russian invasion (Minfin, n.d.a; n.d.b). These data emphasise the urgency of adaptation of the economy to the crisis and the need to innovate. Infrastructure destruction and instability have had a significant impact on the level of employment and domestic demand. Thus, the level of employment has fallen from an average of 91.64 million people in 2014-2021 to 84.65 million in 2022-2023 (OECD, 2023). At the same time, Ukraine's level of innovation, as recorded in the Global Innovation Index (GII), continues to grow even in the face of military challenges, suggesting the country's technological potential. According to this index, Ukraine maintains positive trends and ranks 60th in the world (Global Innovation Index 2024, 2024).

In response to the challenges, caused by the full-scale Russian invasion, as well as the tasks of post-war recovery and integration into the European market, scholars are increasingly focusing on exploring ways to improve economic productivity of Ukraine in the globalised world. Authors M. Bril & I. Pyvavar (2022), L. Deineko *et al.* (2022) studied the impact of economic factors on the country's innovation level, using the instrumental approach to assess the influence of investments, scientific research and technological projects. Their findings emphasised the role of innovation as a key element of the overall factor productivity. L. Bielousova *et al.* (2022) drew attention to the need of integrating international standards and technologies to ensure economic growth in the post-war period. The authors emphasised that strategic planning is a key factor for restoring infrastructure and reintegration of production processes.

O. Mykolenko (2025) studied the importance of supporting high-value-added industries in the post-war recovery. A special emphasis was placed on stimulating the export of technological products as one of the directions of economic growth and directing international aid to strategic projects, such as the modernisation of energy systems and the development of transport. V. Zakharchenko *et al.* (2021) pointed out in their paper that the overall economic growth of the country cannot be offset solely by the increase in labour and total capital, whereas modern scientific and technological progress is of particular importance. P. Makarenko *et al.* (2023) and I. Babets (2023) examined the dependence of gross domestic product (GDP) on the volume of capital, labour, and financing of the scientific and technical sphere. Their findings confirmed the idea of insufficient financing of science and technology hampering long-term economic growth.

Summarising the findings of scientific research, it can be argued that the recovery of the Ukrainian economy provides for the introduction of innovations, attracting investments in high-tech industries and adaptation to global economic conditions. A special emphasis is placed on the use of economic analysis tools to assess the role of production factors and technological progress. In this respect, the Cobb-Douglas function, combined with the Solow residual, provides a powerful analytical approach for modelling economic productivity. This methodology provides for both assessing the impact of major factors of production, such as labour and capital and identifying the contribution of technological progress and other external factors, such as scientific and technical activity, military spending or international aid. This is extremely important for Ukraine, since its economy is concurrently experiencing the influence of destructive military actions and stimulating technological changes.

Given the complexity of the problem, for modelling the economic productivity of the Ukrainian economy in the context of military challenges, it is advisable to use the Cobb-Douglas function, as a well-known mathematical model for determining economic productivity, which makes it possible to estimate the contribution of capital and labour to the GDP dynamics. The aim of the present paper is to model the economic productivity of Ukraine using the Cobb-Douglas production function and the Solow residual to determine the impact of major factors of production, estimate the role of technological innovations and external factors in the context of military challenges.

Materials and Methods

Assessing Ukraine's economic productivity using Cobb-Douglas and Solow residual modelling is an important stage in the analysis of structural changes in the economy, as these methods allow for a deeper understanding of the main factors determining the current state of the economy and its growth, which in turn contributes to the development of recommendations for increasing Ukraine's economic productivity. The methodology for analysing technological shifts and structural changes in the Ukrainian economy in the context of military challenges included such stages as data collection, estimation of the parameters of the Cobb-Douglas production function and Solow residual, comparative analysis and interpretation of the results for 2014-2023. The analysis was conducted based on official statistical indicators of the Ministry of Finance of Ukraine (Minfin, n.d.a; n.d.b), the Ministry of Economy of Ukraine (Ministry of Economy of Ukraine, 2024), the National Bank of Ukraine (2023) and scientific and analytical reports of UkrISTEI (Pysarenko *et al.*, 2021; 2024). The Excel spreadsheet was used to determine the unknown parameters of the model and to check its adequacy.

At the first stage, a comparison of structural changes in the economy of Ukraine before and after the start of full-scale military operations was made. The main data for comparison include the following indicators: Gross domestic product (n.d.); the volume of capital investments in the economy of Ukraine (Minfin, n.d.a); data on the number of people employed in the national economy of Ukraine (Ukrstat, n.d.; State Employment Service, 2023); the indicator of the technological level of Ukraine – the GII index for the period of 2014-2024 (Global Innovation Index 2024, 2024); the volume of spending on scientific and technical activities to the GDP (Pysarenko *et al.*, 2021; 2024); the volume of funds from foreign countries and international organisations, the share of military spending in the defence budget of Ukraine (Minfin, n.d.b). The given set of data allowed for an accurate assessment of structural changes in the economy of Ukraine, taking into account the impact of military challenges on investment, employment and the shift in production to innovative industries and sectors with high added value, as well as identifying key aspects for further modelling of economic productivity using the Cobb-Douglas function and the Solow residual.

A comparative analysis method was used to assess changes in the structure of the Ukrainian economy before and during martial law. Thus, major structural changes, resulting from military actions, were presented, in particular, the shift towards strategic and innovative sectors of the economy, and employment decline trends and investment activity under martial law were identified. This approach contributed towards identifying consequences of the full-scale Russian invasion for the Ukrainian economy, as well as made it possible to assess the opportunities for its recovery and development through adaptation to new conditions.

At the second stage, the Cobb-Douglas production function modelling was used to analyse Ukraine's economic productivity. This function allowed for assessing the relationship between capital, labour and technological progress, and determining the elasticity of capital and labour. The calculations were performed using the following formula (1):

$$Y = a^0 K^{\alpha_1} L^{\alpha_2}, \tag{1}$$

where Y is the volume of production (GDP); L is the amount of labour; K is the amount of capital; a^0 is the technological level (efficiency parameter); α_1 and α_2 are labour and capital elasticity. At the third stage, the Cobb-Douglas function was linearised using logarithmic transformation and calculation of the corresponding differentials. As a result, the following linear function was obtained (2):

$$lnY = Y';\ lna^0 = a';\ LnL = L';\ Y' = a_0' + a_1\ K^1 + a_2\ L' \tag{2}$$

where Y' is the volume of nominal GDP of Ukraine; K' is the volume of capital investments in the economy of Ukraine; L' is the number of those employed in the national economy of Ukraine; α_1 is capital elasticity, a parameter that characterises the quantitative impact of the volume of capital investments in the economy of Ukraine on the dynamics of its economic growth; α_2 is labour elasticity, a parameter that characterises the quantitative impact of the number of employees in the national economy of Ukraine on the dynamics of its economic growth; a_0' is a free term of the equation.

The methodology for estimating capital and labour elasticity is based on regression analysis of logarithmic values, which allowed for a more accurate assessment of the impact of each factor on the GDP. The calculations were performed using the regression analysis tools of the Excel 2020 software package ("Service" – "Data Analysis" – "Regression"), as well as using other software tools, such as Stata. Logarithmic transformation of data and the use of regression analysis made it possible to calculate capital and labour elasticity, which is an indicator of their relative importance in production. This approach allowed for discovering that under martial law, the role of labour and capital is changing, while the importance of technological development is concurrently increasing.

At the fourth stage, the Solow residual (TFP) was applied to gain a deeper understanding of the impact of exogenous factors, which traditional indicators of capital and labour fail to explain. This residual represents the part of economic growth resulting from external changes, such as innovations, support from international partners and adaptation to external shocks. The calculation was carried out according to the following formula (3):

$$TFP = \frac{Y}{K^{\alpha_1}(L*N)^{1-\alpha_1}}, \tag{3}$$

where N is the indicator of the technological level of the Global Innovation Index (GII)

At the fifth stage, a regression analysis was applied, in which the Solow residual was the dependent variable, and the actual data for the specified factors were independent. It made it possible to estimate the share of influence of each factor on the total Solow residual. The calculations were performed according to the following formula (4):

$$TFR = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon, \tag{4}$$

where α_0 is the Solow residual; β_0 is a free term (constant), determining the initial value of the Solow residual when all independent variables are equal to zero; β_1, β_2, β_3 are regression coefficients, showing the influence of each independent variable on the Solow residual; X_1 is expenditures on scientific and technical activities to the GDP; X_2 is military expenditures; X_3 is funds from foreign countries and international organisations; ε is the residual error.

At the sixth stage, the shares of influence of each factor on the dependent variable were identified, using the coefficients of the regression model, expressed in percentages, according to the corresponding formulas (5; 6):

$$Sa.k = /\beta_0/ + /\beta_1/ + /\beta_2/ + /\beta_3/, \tag{5}$$

$$Share_{\,i} = \frac{/\beta i/}{Sa.k} * 100, \tag{6}$$

where $Sa.k$ is the sum of absolute values of the coefficients; β_i is the coefficient for each variable in the regression model.

Data normalisation for calculations was performed using the minimum-maximum method, reducing all variables to a scale from 0 to 1. For each value of the variable x, the following formula was used (7):

$$x_{norm} = \frac{x - x_{min}}{x_{max} - x_{min}}, \tag{7}$$

where is the normalised value; x is the original value; x_{min} is the minimum value of the variable; x_{max} is the maximum value of the variable.

Based on the results of the research, recommendations were made regarding Ukraine's current economic policy, with the focus on such key priorities as stimulating innovation, optimising defence spending and strategic planning of international aid.

Results

The study began with a quantitative assessment of the impact of main factors of production on the economic productivity of Ukraine under martial law. A comparison of structural changes in the Ukrainian economy before and after the start of the full-scale Russian invasion, presented in Figure 1, revealed differences in the economic dynamics of both periods in terms of the GDP and human capital.

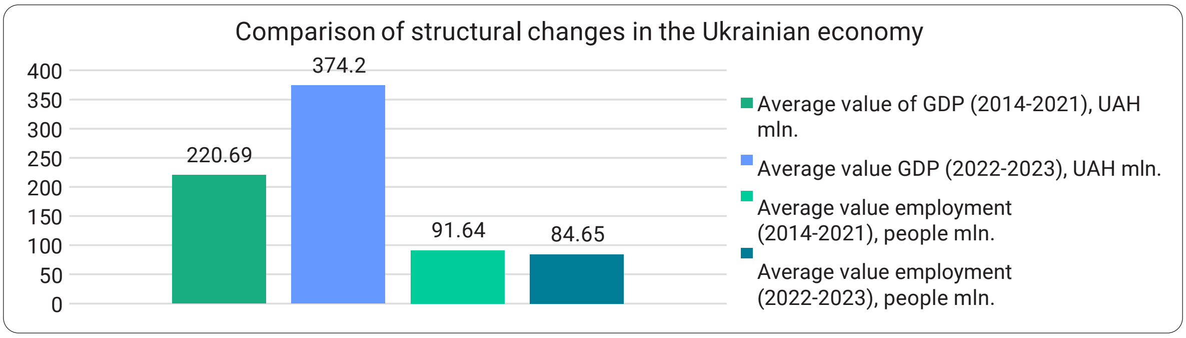

Figure 1. A comparison of structural changes in the Ukrainian economy (average GDP and employment) for the periods (2014-2021) and during full-scale military operations (2022-2024)
Source: calculated by the authors, based on Minfin (n.d.a; n.d.b)

As Figure 1 suggests, the average GDP value increased, indicating a certain revival of economic activity, despite the challenges of wartime. This suggests the ability of the economy to adapt to crisis, as well as a possible reallocation of resources to more productive sectors, in particular, the defence and innovation industries. At the same time, the average employment level decreased during this period, which may indicate a reduction in the labour force caused by both the direct impact of hostilities and general economic instability. The decrease in the employment level may also result from structural changes, when significant spending on the defence sector and other priority areas requires significant human resources, causing a redistribution of labour. The analysis of these structural changes contributes to better understanding of key trends in the national economy, in particular, the piculiarities of the redistribution of labour resources and the dynamics of economic activity in certain sectors. This lays the foundation for a deeper study of the factors of economic growth, clarification of reasons for the increase in the GDP and assessment of the impact of various factors on its dynamics. Based on statistical data on the GDP, capital investment and employment level in the economy, the parameters of the Cobb-Douglas production function were calculated. The obtained data are summarised, logarithmised and presented in Table 1.

Table 1. Calculation of parameters of the Cobb-Douglas production function based on statistical data on the GDP, capital investment and employment level in the Ukrainian economy

Years	Ukraine's GDP, million UAH. (*Yi*)	$Ln_{(Yi)}$	Volume of capital investments in the economy of Ukraine, million UAH (*K*)	$Ln_{(K)}$	Number of those employed in the national economy of Ukraine, million people (*L*)	$Ln_{(L)}$
2014	1566728	14.3	219419.9	12.3	18.1	2.89
2015	1979548	14.5	273116.4	12.5	16.44	2.799
2016	2383182	14.7	359216.1	12. 8	16.28	2.78
2017	2982920	14.9	448461.5	13.0	16.16	2.78
2018	3558706	15.0	578726.4	13.3	16.36	2.79
2019	3974564	15.2	623978.9	13.3	16.58	2.80
2020	4194102	15.2	508217	13.1	15.92	2.76
2021	5459574	15.5	673899.3	13.4	15.61	2.74
2022	5191028	15.5	409660	12.9	15.36	2.73
2023	6537825	15.7	425060	12.9	15.23	2.72

Note: $Ln_{(Yi)}$, $Ln_{(K)}$, $Ln_{(L)}$ – natural logarithms of the GDP, capital investment and those employed. The data does not include the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and part of the temporarily occupied territories in Donetsk and Luhansk regions
Source: calculated by the authors on the basis of statistical Minfin (n.d.a; n.d.b)

Further, the calculation of capital and labour elasticity was carried out by constructing a linear regression on logarithmic data. The obtained coefficients had the following values: capital elasticity (α_1) was 0.511; labour elasticity (α_2) was -6.145. These parameters were non-standard, since (α_2) is a positive value as a rule. Negative labour elasticity may indicate certain economic or methodological peculiarities, in particular, that an increase in the volume of labour may have a decreasing effect on total production due to oversaturation of the labour force or inefficient use of labour resources. This result indicated the need for further analysis or revision of the economic model to clarify the impact of labour on economic productivity, in particular, under conditions of an unstable economic situation. The obtained calculated parameters made it possible to compare the real and estimated values of Ukraine's GDP (Table 2). A graphical interpretation of the dynamics comparison of GDP dependence on capital and labour, both before and during hostilities, is presented in Figure 2.

Table 2. Calculated data for comparing the actual and estimated GDP of Ukraine

Years	Ukraine's GDP, million UAH (*Yi*)	Estimated GDP volume (*Y'*)
2014	1566728	1245553.3
2015	1979548	2492748.4
2016	2383182	3045010.2
2017	2982920	3569234.7
2018	3558706	3769967.2
2019	3974564	3609072.8
2020	4194102	4171243.9
2021	5459574	5437044.2
2022	5191028	4655784
2023	6537825	4998795.6

Source: calculated by the authors on the basis of Minfin (n.d.a; n.d.b), Ukrstat (n.d.)

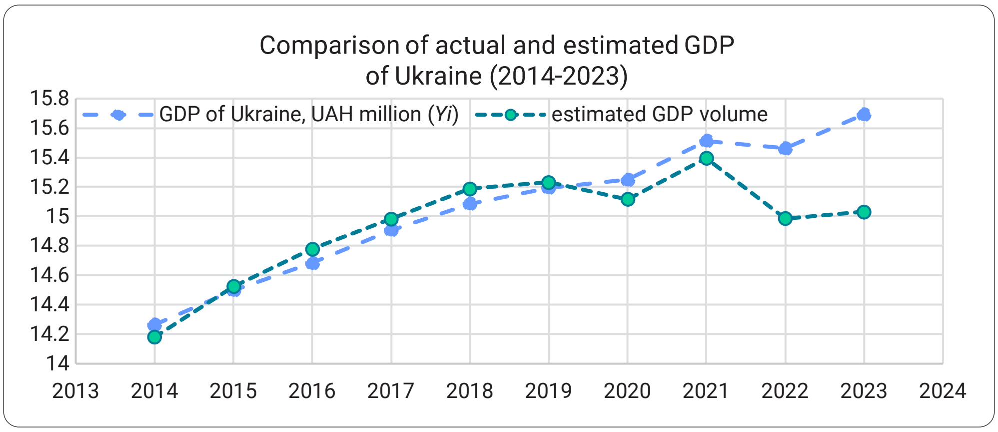

Figure 2. Comparison of actual and estimated GDP of Ukraine (2014-2023)
Source: calculated by the authors

The graph shows the dynamics of the actual and estimated GDP of Ukraine for the period of 2014-2023. Both lines demonstrate the growth of the GDP from 2014 to 2023, which indicates the overall positive dynamics of the country's economic development during this period, despite economic difficulties. The period of 2014-2019 is characterised by a stable Cobb-Douglas model, which almost completely corresponds to the actual GDP indicators and already in the period of 2019-2020 a certain lag of the actual GDP from the calculated by the model can be traced. This can be explained by the effect of COVID-19 pandemic, which disrupted economic cycles. In the period of 2021-2023, the Cobb-Douglas model demonstrates greater volatility. In particular, in 2022, the actual indicators are significantly lower than the estimated ones. This situation reflects the impact of martial law on the economy of Ukraine. Reduced investment, infrastructure destruction and unstable employment have significantly affected the country's economic performance. The actual GDP shows growth, unlike estimated values, which may indicate the impact of factors not depending on the values of capital and employment of the population, as well as unforeseen adjustment factors or external assistance that supported the economy more than expected.

Since 2022, there has been an increase in the negative impact of employment in the national economy, as well as a deterioration in the investment climate. However, it should be mentioned that significant deviations of the model in recent years indicate that the standard Cobb-Douglas production function fails to take into account the impact of external shocks, such as military challenges and global crises. Economic reality is becoming much more complex and traditional models can generate significant errors. Therefore, it can be concluded that the Cobb-Douglas Production Function model operates well in more stable periods, whereas its accuracy is significantly reduced during periods of military operations, significant economic changes and other possible stressful conditions.

Based on the obtained results, the Solow residual (TFP) was calculated using expression (3). According to the characterisation provided by W. Kenton (2023), the Solow residual is the growth of output, taking place beyond the simple growth of costs. Thus, the Solow residual is described as an indicator of productivity growth due to technological innovation. It is proposed to adopt the Global Innovation Index (GII) as the TFP indicator, which is a comprehensive indicator, according to the methodology of the World Intellectual Property Organisation (WIPO) (Global Innovation Index 2024, 2024). The GII is based on more than 80 indicators of innovation potential, including investment in research and development, education spending and high-tech products (see Table 3). The calculation results are graphically presented in Figure 3.

Table 3. Statistical values for determining the Solow residual

Years	Ukraine's GDP, million UAH (*Yi*)	Volume of capital investments in the economy of Ukraine, million UAH (*K*)	Number of those employed in the national economy of Ukraine, million people (*L*)	Technological level indicator of GII (*N*)
2014	1566728	219419.9	18.1	63
2015	1979548	273116.4	16.44	64
2016	2383182	359216.1	16.28	56
2017	2982920	448461.5	16.16	50
2018	3558706	578726.4	16.36	43
2019	3974564	623978.9	16.58	47

Table 3, Continued

Years	Ukraine's GDP, million UAH (*Yi*)	Volume of capital investments in the economy of Ukraine, million UAH (*K*)	Number of those employed in the national economy of Ukraine, million people (*L*)	Technological level indicator of GII (*N*)
2020	4194102	508217	15.92	45
2021	5459574	673899.3	15.61	49
2022	5191028	409660	15.36	57
2023	6537825	425060	15.23	55

Source: developed by the authors based on statistical data from the Ministry of Finance (n.d.a; n.d.b), Scientific, scientific-technical and innovative activity in Ukraine in 2023 (Pysarenko *et al.* 2021; 2024), Ministry of Finance (Financing of the state budget of Ukraine, 2025)

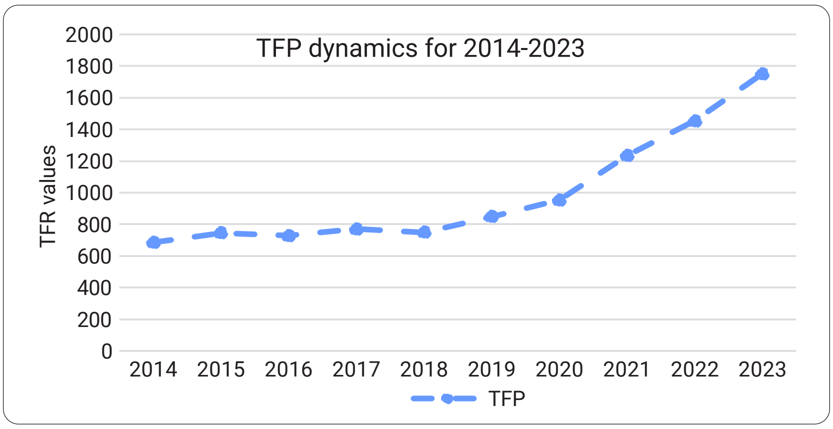

Figure 3. TFP dynamics (technological factor or productivity that cannot be attributed to labour and capital indicators)
Source: calculated by the authors

As it can be seen from Figure 3, TFP changes over time and in recent years the indicators have been gradually increasing, which indicates an increase in indicators that do not depend on the magnitude of the values of capital (K) and labour (L). Observations suggest that the technological level or productivity, which do not depend on changes in labour and capital indicators, are of great importance for explaining economic shifts in Ukraine. Since standard capital and labour factors fail to explain the GDP growth, the Solow residual indicates a significant impact of technology and other factors and the authors suggest that this may be innovative development, military spending or international aid. Therefore, it is proposed to consider the Solow residual as a set of components such as innovation, military spending and international aid.

Further, a regression analysis is carried out, where the Solow residual is the dependent variable and the actual data for the specified factors are independent. This will allow for assessing the share of impact of each factor on the total Solow residual. The data representing innovation, military spending and international aid over the years are summarised in Table 4. The data is indexed in order to clearly see how spending on scientific and technical activities, military spending and international aid have changed over the years, comparing them in relative values.

Table 4. Statistical values for determining the components of the Solow residual (TFP)

Years	GDP, million UAH		Expenditures on scientific and technical activities to GDP		Ukraine Military Spending/ Defence Budget		Funds from foreign countries and international organisations, UAH million	
	GDP	(Yi)	(X1)	(X1i)	(X2)	(X2i)		(X3i)
2014	1566728	0	0.60	1	0.023	0	5383.0	0.009
2015	1979548	0.083	0.55	0.815	0.033	0.025	1800.3	0.002
2016	2383182	0.164	0.48	0.556	0.032	0.022	4109.4	0.006
2017	2982920	0.285	0.45	0.444	0.029	0.015	1607.4	0.001
2018	3558706	0.401	0.47	0.519	0.032	0.022	1464.8	0.001
2019	3974564	0.484	0.43	0.37	0.035	0.029	1139.9	0

Table 3, Continued

Years	GDP, million UAH		Expenditures on scientific and technical activities to GDP		Ukraine Military Spending/ Defence Budget		Funds from foreign countries and international organisations, UAH million	
	GDP	(*Yi*)	(*X*1)	(*X*1i)	(*X*2)	(*X*2i)		(*X*3*i*)
2020	4194102	0.529	0.41	0.296	0.038	0.037	1029.7	0
2021	5459574	0.783	0.38	0.185	0.032	0.022	1289.9	0.001
2022	5191028	0.729	0.33	0	0.33	0.754	481090.7	1
2023	6537825	1	0.33	0	0.43	1	433404.5	0.901

Source: developed by the authors based on statistical data from the Ministry of Finance (n.d.a; n.d.b), Scientific, scientific-technical and innovative activity in Ukraine in 2023 (Pysarenko et al. 2021; 2024), Ukraine military spending/defence budget 1992-2025 (n.d.)

The dynamics of the components (X1, X2, X3) according to the data presented in Table 4 reflects the main trends in the specified indicators. There is a gradual decrease in spending on scientific and technical activities, which indicates their significant reduction. Defence spending (X2) demonstrates a sharp increase, especially in 2022 (33% of GDP) and 2023 (43% of GDP). The volumes of funds provided by foreign countries and international organisations have changed significantly, in particular, in recent years their significant growth has been observed. This suggests the increased international support for Ukraine, as well as an increase in dependence on foreign aid. After calculations, the following main parameters of the TFP function (4) were obtained, which are summarised in Table 5.

Table 5. Main parameters of the TFP function

TFP function parameters	TFP function parameter value
R-squared	0.962212405
Multiple coefficient	0.925852713
Normalised R-squared	0.888779069
Standard error of approximation of 1	0.108183523

Source: created by the authors

Main parameters of the TFP function demonstrated a high R-squared value, which suggests that the model explains accurately the dependence of the Solow residual (TFP) on the variables $X1$, $X2$, $X3$. Approximation of 1 means a high correspondence of the actual and estimated values. The multiple coefficient revealed a strong correlation between the dependent variable (TFP) and the independent variables. The obtained value of the normalised R-squared proved that the model retains high accuracy even after correction. The standard error of approximation testified a low level of dispersion of the residuals, which highlighted the reliability of the model. The estimated values of the basic level of TFP and the coefficients are summarised in Table 5.

Table 6. Results of values of the Solow residual components with coefficients

Indicators	Coefficient	Standard Error	t-Statistic	P-Value	Confidence Interval (95%)
Y-intercept	0.777	0.090	8.592	0.00014	[0.556, 0.999]
β_1	-0.864	0.153	-5.664	0.0013	[-1.237, -0.491]
β_2	0.803	0.458	1.754	0.1300	[-0.317, 1.923]
β_3	-0.649	0.413	-1.572	0.1671	[-1.660, 0.362]

Source: created by the authors

The coefficient characterising the impact of expenditures on scientific and technical activity is statistically significant, despite having a negative value. This suggests that contrary to expectations, this component has a negative impact on economic productivity in the model. At the same time, the coefficient reflecting the impact of military spending is not statistically significant, which indicates the absence of a considerable impact of this factor on economic activity. Similarly, the coefficient characterising international aid is also statistically insignificant, which indicates the minimal impact of this indicator within the analyzed model. Then, the share of impact of each factor on the dependent variable was found using the coefficients of the regression model. The share of impact of each factor is determined by the ratio of its coefficient to the sum of the absolute values of all coefficients (including the constant) according to equation (5) (see Table 6).

Table 7. Results of the analysis of the share of impact of factors on the dependent variable (Solow residual)

TFP function parameter name	TFP parameter value, %
Share of basic productivity level of Yp	25.13
Share of *X*1	27.92
Share of *X*2	25.95
Share of *X*3	20.99

Source: created by the authors

The sum of the absolute values of the coefficients is as follows:

$$Sa.k = 0.777 + 0.864 + 0.803 + 0.649 = 3.093476$$

The obtained results of the shares of impact of factors on the Solow residual demonstated a balanced distribution between components. The basic productivity level provides a quarter of the impact on the total Solow residual. This level reflects the basic productivity, which does not depend on changes in factors and indicates a significant contribution to internal stability due to factors ignored by the variables. For example, adaptive capacity, infrastructure reforms or other non-economic factors that are of a significant impact. Expenditures on scientific and technical activities (variable *X*1) play a considerable role in the model, although this impact is negative, which suggests that insufficient funding for scientific and technical activities complicates their positive effect. The value of variable *X*2 indicates its significant, although balanced impact on the economy productivity. At the same time, the results suggest that high spending is not compensated by productivity growth in other sectors, which may negatively affect the overall economic dynamics.

The value of variable *X*3 reflects a significant impact of international aid, which highlights its important role in maintaining economic stability. However, the aid is mainly directed towards humanitarian purposes, its impact on economic productivity is significant due to its support of infrastructure projects and satisfaction of basic needs, which indirectly contributes to economic stability. Thus, the obtained values indicate a relative uniformity of the impact of factors on the Solow residual. Expenditures on scientific and technological activities (*X*1) remain a key driver of productivity, validating its importance for long-term development. A visual representation of the impact of factors on overall productivity is given in Figure 4.

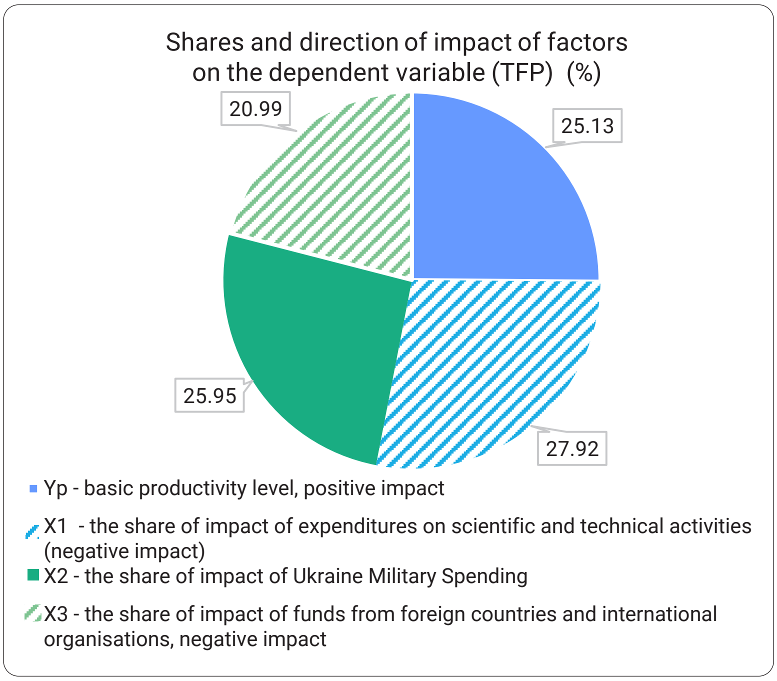

Figure 4. Shares of impact of each factor on the dependent variable (TFP)
Source: calculated by the authors

Reduction in spending on scientific and technical activities decreases the positive potential of innovation, which explains the negative impact of *X*1. Increased military spending and international aid do not lead to a significant increase in the basic level of productivity, since these funds are aimed at ensuring stability and security, rather than supporting economic growth. Thus, it can be concluded that under conditions of military challenges and crises, innovative investments can have an unexpected negative impact and military spending and international aid do not have a significant impact on economic productivity in the short term.

Based on the conducted analysis and considering the current conditions of economic instability in Ukraine, a number of recommendations are proposed aimed at increasing innovative activity, optimising defence spending, effectively using international aid and solving the problem of returning the working population:

1. It is necessary to develop a long-term strategy for integrating defence spending into general economic policy, in particular, in the field of developing the latest defence technologies that can become competitive export goods. An important task is to create a system for assessing the effectiveness of defence spending, which will ensure their maximum economic return. Moreover, it is worth attracting private investment in the defence industry through public-private partnership mechanisms.

2. International aid should be directed to the restoration of critical infrastructure, in particular, energy and transport, as well as to support the population affected by the war. It is also advisable to use international aid for the development of innovation and production infrastructure, including the creation of new industrial zones and technological clusters. It is important to ensure transparent reporting to donors on the targeted use of funds and demonstrate the effectiveness of implemented projects, which will help strengthen the trust of international partners.

3. To encourage the return of migrant workers, it is necessary to implement programs that provide decent working conditions, competitive wages and new jobs. A special attention should be paid to investing in programs to improve the skills of workers, particularly in technological and strategic sectors. Moreover, ensuring access to quality medical, social and educational infrastructure will contribute to the reduction of the outflow of skilled personnel abroad.

4. To stimulate investment in the Ukrainian economy, it is necessary to guarantee transparency, efficiency and accountability of economic policy. Important steps include strengthening the protection of investors' rights, reducing administrative barriers and minimising corruption risks, which will create favorable conditions for attracting domestic and foreign investments.

This study analyzes Ukraine's economic productivity using the Cobb-Douglas model and the Solow residual. The main attention is paid to the impact of scientific and technological activity, military spending and international aid on economic growth under martial law. The conducted analysis demonstrates both consistency with previous studies and certain specifics related to technological and structural changes in the Ukrainian economy. The level of GDP growth is defined as one of the key factors of economic development. This is consistent K. Redko's *et al.* (2024), also T. Stahl *et al.* (2019) findings, suggesting that the real GDP is a critical indicator for assessing economic growth. Similar results were obtained by T. Cherkashyna (2019), estimating the dynamics of Ukraine's economic development. The results of the current research prove that the GDP is an important factor, although its growth does not always correlate with productivity in other sectors.

The results of the calculations suggest that, contrary to expectations, scientific and technical activity has a negative impact on the economic productivity of Ukraine in the model. This can be explained by the deferred effect of innovations that require a long-term payback period, suboptimal financing of innovative projects under conditions of economic instability and the outflow of qualified personnel due to the war. This is consistent with W. Kenton's assertion (2023) that the Solow residual reflects both technological changes and resource efficiency, which may be reduced under unstable conditions. As W. Kenton (2023) points out, the Solow residual is a key indicator of the overall factor productivity, which provides for assessing the contribution of technological progress regardless of changes in capital and labour. The results of the current study suggest that expenditures on scientific and technical activities, which in a stable economy usually contribute to increasing productivity, may not have an immediate positive effect during a crisis.

The results of the study also support J. Brusuelas & T. Nguyen's findings (Solow residual…, n.d.), suggesting that in the economies of developed countries, the Solow residual remains stable even under crisis conditions, since significant investments in technology and efficient resource management support productivity. However, in the case of Ukraine, the results of the current study demonstrate that the impact of innovative investments is negative, which may result from their insufficiency, inappropriate distribution or lack of proper institutional support. The analysis of military spending revealed their statistical insignificance in the model. This implies that they do not have a direct impact on economic productivity. At the same time, military spending can contribute to the development of the defence industry, although under war conditions, the main funds are directed to current operational needs, rather than to technological developments.

Despite significant external support, international aid failed to demonstrate a statistically significant impact on economic productivity. This may result from insufficient integration of external financial resources into strategic sectors, the use of aid mainly for social benefits rather than development programs, as well as the lack of an effective resource allocation mechanism.

The above findings partially overlap with the recommendations of the OECD (2023) on the need to restore Ukraine's innovation ecosystem and develop digital infrastructure. At the same time, the CSIS (2023) emphasises that international assistance should be accompanied by structural reforms to maximise its impact.

The results of the current analysis correlate with O. Sokolova' (2022), V. Momot & O. Lytvynenko's findings (2023), V. Ivanchenkov *et al.* (2024) studying the modelling of macrosystem economic stability, emphasising the importance of the stable functioning of main economic sectors. They emphasised that under instability conditions, the adaptive potential of the economy depends on the efficiency of resource management and investment allocation. Similar conclusion was made by A. Ostapenko & D. Zalevska (2024), claiming that short-term innovative investments do not always have a positive effect due to unpredictable changes in the economic environment. The results of the current study, giving evidence for the limited effectiveness of innovative investments during martial law, are consistent with the findings of the above-mentioned authors about the need for a comprehensive approach to economic development, particularly under crisis conditions.

O. Suntcova's (2022) and I. Pidoricheva's (2022) studies focused on the impact of financial technologies and virtual assets on economic growth. The authors studied the ability of new financial instruments to contribute to increasing the overall productivity, despite the fact that their impact largely depends on the effectiveness of regulation and the level of integration into the financial system. The current results suggest that ineffective management of innovation costs can reduce their positive role in the model of economic productivity. It is consistent with O. Suntcova's (2022) and I. Pidoricheva's (2022) findings, suggesting that the role of technological changes in economic development is determined both by their availability and the ability of the system to adapt them to current conditions, therefore Ukraine should insist on a post-war development scenario aimed at creating an innovative industrial economy, having developed a comprehensive plan for the post-war reconstruction of the country based on new technological foundations.

The use of the Cobb-Douglas function and the Solow residual in this study proves their effectiveness in modelling economic productivity, which is consistent with S. Shumska's (2007), V. Volkova's *et al.* (2024) findings. V. Kapustian *et al.* (2022) and S. Turlakova (2022) also emphasise the need to adapt classical economic models to the realities of Ukraine and O. Hirina *et al.* (2024) emphasised the role of technological innovations in adjusting traditional approaches to economic analysis.

Thus, the results of the study are consistent with Ukrainian scientists' findings on the complexity of the impact of scientific and technical activities and economic factors on economic productivity under conditions of military challenges. They emphasise the need to improve innovation management mechanisms, optimise resource allocation and increase the effectiveness of state policy on economic stability

Conclusions

The use of the Cobb-Douglas production function revealed a change in the role of capital, labour, and innovation in the formation of Ukraine's GDP, especially under martial law. It has been discovered that traditional factors, such as labour, in some cases have a negative impact, which can be explained by a decrease in the efficiency of their use. The Solow residual indicates the significant role of technological progress, which, although not immediately affecting productivity, is a key to long-term development. Innovation remains a significant factor, although in the short term its impact may be negative due to insufficient funding and economic instability. Defence spending and international aid have a minimal impact on productivity in the short term, which highlights the need for strategic planning of their use. Based on the results of the research, a number of recommendations are proposed to increase Ukraine's economic productivity. First of all, it is necessary to increase the share of investments in scientific developments, as well as actively stimulate international cooperation in the field of innovation. An important step is the integration of defence spending into the economic strategy in order to promote the development of a high-tech defence complex, which provides for the introduction of a mechanism for monitoring the effectiveness of defence investments, as well as directing part of the costs to the development of dual technologies that can be used in civilian industries.

Moreover, international aid should be focused on strategic projects, in particular, the modernisation of energy systems, the development of transport infrastructure and ensuring the livelihoods of the affected territories. Another important aspect is increasing the transparency of the use of international aid, which will help strengthen the trust of donors. Taking into account the problem of inefficient use of labour resources, it is advisable to create favourable conditions for returning labour migrants. It is also worth implementing state programs aimed at attracting young people to scientific and technical specialties, which will become the basis for long-term strengthening of the country's human capital. The results of the study suggest that innovation remains a key factor in productivity, even despite the negative impact in the short term, which proves the need to stimulate innovative development for economic recovery. The introduction of innovative technologies and the implementation of structural reforms will ensure sustainable economic growth. In the context of military challenges, the Ukrainian economy is undergoing significant changes in the structure of production, which can be traced in changes in capital and labour elacticity. The identified increase in the technological level, which is not connected with the growth of traditional factors, indicates the significant role of innovation processes and adaptation to external challenges.

As far as the impact of defence spending on productivity is concerned, based on the reasearch results the need is emphasised to implement a system for monitoring the effectiveness of these expenditures. The reasearch results indicate the need to integrate military investments into the overall economic strategy, particularly in the field of defence technologies, as well as the need for strategic planning of aid use, focusing it on long-term investments in infrastructure, technology, and human capital. Further research should include adapting models to unstable conditions by integrating additional factors, such as global shocks and socio-economic changes.

Acknowledgements

None.

Funding

None.

Conflict of Interest

None.

Reference

[1] Babets, I. (2023). Modelling the impact of foreign direct investment on the economy of Ukraine in the conditions of post-war reconstruction. *Galician Economic Herald*, 1(80), 130-143. doi: 10.33108/galicianvisnyk_tntu2023.01.131.

[2] Bielousova, L.I., Litvinova, I.M., & Bielousov, Y.I. (2022). Rebuilding Ukraine's economy in the post-war period: Essays. *Time Description of Economic Reforms*, 2, 6-12. doi: 10.32620/cher.2022.2.01.

[3] Bril, M., & Pyvavar, I. (2022). Instrumental analysis of the impact of economic factors on the level of a country's economic innovativeness. *Development Management*, 21(3), 44-54. doi: 10.57111/devt.20(3).2022.44-54.

[4] Cherkashyna, T. (2019). Cobb-Douglas production function as an instrument of economic growth policy of Ukraine under market reforms. *Economy and Society*, 20. doi: 10.32782/2524-0072/2019-20-15.

[5] Deineko, L.V., Kushnirenko, O.M., Tsyplytska, O.O., & Gakhovych, N.H. (2022). Consequences of the full-scale military aggression of the Russian Federation for the Ukrainian industry. *Economy of Ukraine*, 5, 3-25.

[6] Financing of the state budget of Ukraine since the beginning of the full-scale war. (2025). Retrieved from https://mof.gov.ua/uk/news/ukraines_state_budget_financing_since_the_beginning_of_the_full-scale_war-3435.

[7] Global Innovation Index 2024. (2024). *GII 2024 results*. Retrieved from https://www.wipo.int/web-publications/global-innovation-index-2024/en/gii-2024-results.html.

[8] Hirina, O., Merkt, O., & Zahorodnia, K. (2024). Using economic growth models to justify sustainable development of maritime industry enterprises. *Transport Development*, 3(22), 7-19. doi: 10.33082/td.2024.3-22.01.

[9] Ivanchenkov, V., Vovk, V., Yermolenko, O., Prusova, G., & Revenko, O. (2024). Innovative factors ensuring strategic changes in sectors of the national economy. *Economics of Development*, 23(4), 20-37. https://doi.org/10.57111/econ/4.2024.20

[10] Kapustian, V., Mazhara, H., & Fartushnyi, I. (2022). *Economic modeling*. Kyiv: KPI named after Igor Sikorskyi.

[11] Kenton, W. (2023). Solow residual: Definition, example, vs. TFP. *Investopedia*. Retrieved from https://www.investopedia.com/terms/s/solow-residual.asp.

[12] Makarenko, P., Bielov, O., Makarenko, Yu., Dorohan-Pysarenko, L., & Bezkrovnyi, O. (2023). Dependence of a country's GDP on the value of physical and human capital and financing of the scientific and technical sector. *Financial and Credit Activity: Problems of Theory and Practice*, 5(52), 268-282. doi: 10.55643/fcaptp.5.52.2023.4174.

[13] Minfin. (n.d.a). *Foreign direct investment (2002-2024)*. Retrieved from https://index.minfin.com.ua/ua/economy/fdi/.

[14] Minfin. (n.d.b). *Gross domestic product (2002-2023)*. Retrieved from https://index.minfin.com.ua/ua/economy/gdp/.

[15] Ministry of Economy of Ukraine. (2024). *Information materials on the state of innovation activity*. Retrieved from https://me.gov.ua/documents/detail?lang=uk-ua&id=69b9a9bf-5fbc-4035-8c0f-ac26b853c0eb&title=informatsiinimaterialischodostanuinnovatsiinoidiialnosti.

[16] Momot, V., & Lytvynenko, O. (2023). Modeling changes in the activity of domestic business in wartime. *Academic Review*, 2(59), 173-189.

[17] Mykolenko, O. (2025). Developing the scale for measuring SMEs' performance in times of crisis. *Sustainable Development of Economy*, 1(52), 5-13. doi: 10.32782/2308-1988/2025-52-1.

[18] National Bank of Ukraine. (2023). *Simply about the economy (based on the January 2023 Inflation Report materials)*. Retrieved from https://bank.gov.ua/ua/news/all/prosto-pro-ekonomiku-na-osnovi-materialiv-inflyatsiynogo-zvitu-za-sichen-2023-roku.

[19] OECD. (2023). *Assessing the impact of Russia's war against Ukraine on Eastern Partner countries*. Paris: OECD Publishing.

[20] Ostapenko, A., & Zalevska, D. (2024). Research of complex systems using simulation modeling based on system dynamics. *Science and Production*, 27, 77-84. doi: 10.31498/2522-9990272024303193.

[21] Pidoricheva, I. (2022). Post-war recovery of Europe: Experience and lessons for Ukraine. *Journal of European Economics*, 21(2), 190-207.

[22] Pysarenko, T., *et al.* (2024). *Scientific, scientific-technical, and innovative activity in Ukraine in 2023 (scientific-analytical report)*. Kyiv: UkrINTEI.

[23] Pysarenko, T., Kvasha, T., Kuranda, T., Musina, L., & Paladchenko, O. (2021). *The state of scientific and innovative activity in Ukraine in 2020 (scientific-analytical note)*. Kyiv: UkrINTEI.

[24] Redko, K.Y., Garnik, O.A., & Lukyanikhin, V.O. (2024). Assessing the impact of innovation potential on economic development: The Ukrainian context. *Academic Visions*, 32. doi: 10.5281/zenodo.12069688.

[25] Shumska, S.S. (2007). The production function in economic analysis: Theory and practice. *Economy and Forecasting*, 2, 138-153.

[26] Sokolova, O. (2022). Simulation of changes in the sectoral structure of Ukraine's economy. *Problems of a Systematic Approach in Economics*, 2(82), 54-61. doi: 10.32782/2520-2200/2021-2-7.

[27] Solow residual: Total factor productivity and the U.S. economy. (n.d.). Retrieved from https://rsmus.com/insights/economics/solow-residual.html.
[28] Shtal, T., Polyakova, Y., Proskurnina, N., Dobroskok, I., & Kot, O. (2019). Modeling of Convergence of the Economic System of Ukraine with G20 Countries Based on the Analysis of Structural Changes in Ukrainian Foreign Trade. *Journal Of Advanced Research In Law And Economics*, 9(6), 2129-2145. doi:10.14505//jarle.v9.6(36).28
[29] State Employment Service. (2023). *The situation on the labour market and the activities of the state employment service in January-August 2023*. Retrieved from https://old.dcz.gov.ua/sites/default/files/infofiles/08_sytuaciya_na_rp_ta_diyalnist_dsz_2023_0.pdf.
[30] Suntcova, O. (2022). Assessing the impact of financial technologies and virtual assets on a country's economic growth. *Business, Innovations, Management: Problems and Perspectives*, 2022, 139-140. doi: 10.5281/zenodo.7556751.
[31] Turlakova, S. (2022). Research of mathematical methods and models of long-term industrial development. *Ekonomika Promyshlennosti*, 4(100), 53-77.
[32] Ukraine military spending/defence budget 1992-2025. (n.d.). Retrieved from https://www.macrotrends.net/global-metrics/countries/UKR/ukraine/military-spending-defence-budget.
[33] Ukrstat. (n.d.). *Employed population by type of economic activity*. Retrieved from https://www.ukrstat.gov.ua/operativ/operativ2014/rp/zn_ed/zn_ed_u/zn_ed_2013_u.htm.
[34] Volkova, V., Ohlikh, V., & Trosko, S. (2024). Using the Cobb-Douglas function to analyze economic dynamics. *Economic Space*, 191, 406-411. doi: 10.32782/2224-6282/191-69.
[35] Zakharchenko, V.I., Kandeeva, V.V., & Oneshko, S.V. (2021). Comprehensive analysis of the state of the main elements of the mechanism of development of the economic potential of the enterprise. *Market Economy: Modern Theory and Practice of Management*, 20(2(48)), 46-65. doi: 10.18524/2413-9998.2021.2(48).243679.

Моделювання економічної продуктивності України в умовах воєнних викликів

Тетяна Шталь

Доктор економічних наук, професор
Харківський національний економічний університет імені Семена Кузнеця
61166, просп. Науки, 9А, м. Харків, Україна
https://orcid.org/0000-0003-1256-9854

Олена Бутенко

Кандидат економічних наук, доцент
Харківський національний економічний університет імені Семена Кузнеця
61166, просп. Науки, 9А, м. Харків, Україна
https://orcid.org/0000-0002-2151-8410

Олена Кот

Кандидат економічних наук, доцент
Харківський національний економічний університет імені Семена Кузнеця
61166, просп. Науки, 9А, м. Харків, Україна
https://orcid.org/0000-0002-6403-4766

Вікторія Козуб

Кандидат економічних наук, доцент
Харківський національний економічний університет імені Семена Кузнеця
61166, просп. Науки, 9А, м. Харків, Україна
https://orcid.org/0000-0002-0402-8508

Валерій Малахов

Кандидат економічних наук, доцент
Харківський національний економічний університет імені Семена Кузнеця
61166, просп. Науки, 9А, м. Харків, Україна
https://orcid.org/0000-0002-8024-3998

Анотація. Воєнні виклики трансформували економіку України, що актуалізувало потребу у переоцінці джерел її продуктивності. Метою було змоделювати вплив цих факторів на ВВП України за допомогою виробничої функції Кобба-Дугласа та залишку Солоу. Проаналізовано статистичні дані за 2014-2024 роки, виконано регресійний аналіз для визначення взаємозв'язку між основними економічними змінними, а також оцінено еластичність капіталу та праці. Залишок Солоу використовувався для оцінки технологічного рівня економіки та ідентифікації екзогенних факторів, що впливають на продуктивність. Результати дослідження показали, що витрати на науково-технічну діяльність мали негативний вплив у короткостроковій перспективі, що пов'язано з недостатнім рівнем фінансування та макроекономічною нестабільністю. Військові витрати не забезпечили значного приросту продуктивності через їхню непродуктивну спрямованість. Натомість міжнародна допомога сприяла макроекономічній стабільності, однак не стимулювала довгострокове зростання. Частковий внесок факторів у формування залишку Солоу склав 27,92 % для інновацій, 25,95 % для військових витрат та 20,99 % для міжнародної допомоги. Модель показала високе значення R^2 (0,96), що свідчить про її надійність у поясненні змін TFP. Було розроблено рекомендації для підвищення економічної продуктивності України, які передбачають покращення науково-технічної діяльності через покращення фінансування наукових досліджень, раціоналізацію оборонних витрат завдяки інтеграції військових інвестицій у загальну економічну стратегію, а також ефективне залучення міжнародної допомоги для проведення структурних реформ і розвитку людського капіталу. Отримані результати можуть слугувати основою для формування економічної політики, спрямованої на післявоєнне відновлення країни

Ключові слова: виробнича функція Кобба-Дугласа; залишок Солоу; зайнятість населення; витрати на науково-технічну діяльність; міжнародна допомога