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ASSESSMENT OF FACTORS OF SUSTAINABLE DEVELOPMENT OF THE AGRICULTURAL SECTOR USING THE COBB-DOUGLAS PRODUCTION FUNCTION

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Abstract. *The aim* of the article is to assess the impact of various factors (forms of capital) on the formation of gross value added and gross output of the agricultural sector of Ukraine's economy under sustainable development using the modified Cobb-Douglas production function. *Methods*. The theoretical and methodological basis of the study consisted of the papers on economic growth, sustainable development and forecasting by scientists in classical and modern economics. A monographic method was used to cover the scientists' views on the research issue. The parameters of the production function describing how variables (physical and human capital, pollutant emissions) act on gross value added and gross output of the agricultural sector of Ukraine were estimated on the basis of the modified Cobb-Douglas production function. Statistics for agriculture covering the period 2008–2018 were used for the assessment. The correlation and regression analysis was used to determine and verify the parameters of the production function. Equations of balance and construction of isoquants were used to foresight the optimal combinations of factors of the production function. *Results*. Using the Cobb-Douglas production function, econometric analysis with eco-socio-economic factors has shown that economic growth in agriculture is associated with improved quantitative and qualitative characteristics of labour potential, growing capital investment and reducing pollutant emissions. Estimation of the elasticity coefficients of the constructed Cobb-Douglas function (the sum exceeds 1) justifies that the economic development of agriculture mainly contains the features of a large-scale economy: modern level of science and technology provides advantageous expanding production to increase output. *Practical significance*. The constructed models allow to forecast assessment of the development of the agricultural sector's components and can be used to develop the basic directions of the state agricultural policy to manage the formation and use of resource potential. *Value/originality*. Modelling how the resource factors act on output using the method of construction and calculation of parameters of the production function allows to predict the sustainable development of agricultural production under quantitative and qualitative changes in the use of labour and capital, as well as environmental factors. Further research ensures obtaining a dynamic multi-factor model of sustainable development of the agricultural sector and determining the main mechanisms of influence on the levers of economic growth.

Key words: sustainable development, agriculture, economic growth, labour potential, Cobb-Douglas function, elasticity coefficients, isoquants.

JEL Classification: C23, E13, O11, O13

1. Introduction

The conceptual change of understanding the priorities of social and economic goals of development, the search for ways to move to the principles of sustainability are urgent for global development. According to modern scientists, it is possible to achieve sustainable development in three scenarios (Hopwood, 2005): 1) reducing the government regulation, increasing the role of informatization and implementation of new technologies will help achieve sustainable development goals without significant changes in government relations (liberal approach); 2) increasing the role of government regulation, technology and science through public administration reform (reformist approach); 3) transforming society's interaction with the environment through radical changes (transformist approach). The sustainable development mechanism for the agricultural sector should be considered through the interconnected structural components: economic, environmental, social, institutional and legal.

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Sustainable development of the agricultural sector not only guarantees food security as one of the components of general economic security of the state but also provides economic growth, rural development, stimulates the progress of other industries through a multiplier effect. The agricultural sector of Ukraine demonstrates positive dynamics due to the significant natural and human potential, as well as favourable climatic conditions. The objective construct "agricultural sector" is a system of agricultural production, environment and rural population; therefore, the agricultural sector is as close as possible to environmental and food challenges. The agricultural sector combines social, production, and environmental functions, sectoral and territorial aspects: the basic agricultural sector which generates the rural environment with the appropriate resource base (spatial, natural, and labour).

Ukrainian agricultural products occupy a significant share in the gross value added, which gives grounds for arguing about the prospects of increasing the volume of exported agricultural products under the optimal combination of production factors (Vasylieva, 2017). The transition to sustainable development principles, a new paradigm of social development, mainstreams the issue of effective interaction of production factors in the process of making a product in the economy. Sustainable economic growth is based on the involvement of endogenous factors that depend on human economic activity; their interaction within the endogenous theory can be described using the apparatus of the production function.

The article is aimed at assessing the impact of various factors (forms of capital) on the formation of gross value added and gross output of the agricultural sector of Ukraine's economy under sustainable development using the modified Cobb-Douglas production function.

2. Theoretical framework and related studies

Scholars consider sustainable development from the standpoint of preserving and increasing all types of capital for future generations (human, natural, and material) (Khvesyk, 2012).

The three-pronged concept of sustainable development originated from the provisions in the Proclamation of Teheran, Final Act of the International Conference on Human Rights in 1968; here, economic and social development was declared as imperatives for sustainable progress, as "ensuring human rights to life, consistent with freedom and dignity, contributing to physical, social and spiritual well-being" (Proclamation of Teheran, 1968). For the first time, development was additionally considered a means to ensure human rights and freedoms, including peaceful and secure existence.

Originating of the modern concept of sustainable development is associated with the Declaration of the UN Conference on the Human Environment (Stockholm, 1972), which emphasizes the relationship of economic and social development with environmental issues, and the famous report to the Club of Rome "The Limits to Growth" (1972) prepared by Dennis Meadows, which addresses the impact of global environmental constraints on resource use and emissions in the 21st century on global development. D. Meadows' study concludes that humanity needs to make a "controlled orderly transition from growth to global equilibrium" (Meadows, 1991). "The Limits to Growth" formulates the ideas of the transition of civilization from quantitative growth to "organic" (qualitative) and "new world economic order" with deep, proactive social innovation through technological, cultural and institutional changes to avoid the growth of negative environmental impact without respecting the Earth's ecological limits (Meadows, 2018).

Accelerated degradation of the natural environment as a result of human activities poses a global threat to humanity. In 1987, the UN World Commission on Environment and Development, in a report by the Chairman of the World Commission on Environment and Development, Prime Minister of Norway Gro Harlem Brundtland "Our Common Future", justified the need to find a new model of civilization development. The model indicated that the needs of modern generations should not jeopardize the interests of future generations in the realization of their needs and opportunities. According to G. H. Brundtland, the history of humankind reached a level at which a change in political priorities was inevitable: savings from arms reduction can be used to finance environmental security measures. G. H. Brundtland introduced the term "sustainable development", which implied a "model of development, where the satisfaction of the vital needs of the present generation was achieved without depriving future generations of such an opportunity" (Koptug, 1997). The Brundtland Commission defined the concept of sustainable development under globalization, technological and social factors from the standpoint of overcoming poverty through respecting ecological limits to meet the needs of present and future generations. Consequently, G. H. Brundtland's anthropocentric approach to sustainable development, in which the environment was a means of human existence, comprised a relationship of needs and constraints (Slavgorodska, 2016).

The participants of the UN Conference on Sustainable Development "Rio+20" (2012) in the Rio de Janeiro Earth Summit recognize that fair and sustainable use of resources is the key factor in choosing a path to a safer, cleaner and more prosperous world for all (United Nations Conference on Sustainable Development, 2012). The Resolution "The Future We Want" adopted by the General Assembly (Resolution adopted by the General Assembly, 2012) emphasizes the following aspects: the recognition of the need to further promote the idea of sustainable development at all levels; integration of its economic, social and environmental components; taking into account the relationship of the latter in order to achieve the goals of sustainable development in all the aspects.

Consequently, sustainable development should not focus exclusively on environmental aspects; it is considered in terms of harmonization of resource use, innovation and investment processes, institutional change with the needs of present and future generations.

The positive dynamics of the economic potential of the agricultural sector as a set of all available means, opportunities, productive forces, resources, stocks, competencies that can be used in production and realize market opportunities to achieve socio-economic development is a necessary condition for sustainable development (Vasylieva, 2019).

The production potential of agricultural production can be determined in terms of a hybrid approach, which includes resource (as a set of production resources) and effective (as the creation of a certain amount of material goods) approaches: the ability to produce a certain amount of material goods through the use of limited interconnected resources (Suvorov, 2020).

For forecasting in macroeconomics, the apparatus of production functions describing complex production processes is used. The production function is a complex model of economic dynamics that characterizes the economic and mathematical dependence of output (quantity of products) on the factors of production used (resources, technology). The classical equation of the production function for agricultural production includes factors of economic growth: production assets K (area of agricultural land, the number of fixed and production assets in value form), total living labour costs L (number of employees in agriculture, working time) and other factors that take into account technical progress N:

$$Y = f(K,L,N) \quad (1)$$

In the macroeconomic analysis, CES-function (Yankovyi, 2015) with constant elasticity of substitution of resources is used for economic and mathematical modelling:

$$Y = A[aK^{-\rho} + (1-a)\,L^{-\rho}]^{-\gamma/\rho}, \quad (2)$$

where Y is the production in monetary terms, K is a cost of capital, L is labour costs, A is a scale factor, a is a weighting coefficient of the production factor, γ is an indicator of the degree of uniformity, ρ is a production function parameter.

At ρ = -1, CES-function has the form of a linear equation (elasticity of substitution is unlimited):

$$Y = a_1K + a_2L\,, \quad (3)$$

where a_1, a_2 are parameters that characterize the qualitative impact of each factor.

At $\rho \to 0$, CES-function becomes the Cobb-Douglas production function (elasticity of substitution tends to 1):

$$Y = a_0\,K^{a_1}\,L^{a_2}, \quad (4)$$

where a_0 is a parameter that characterizes the level of technology, a_1 and a_2 are coefficients that characterize the contribution of capital and labour to output growth. a_1, a_2 parameters of the estimation model characterizes the production elasticity by resources, i.e., the quantitative relationship between production volumes in accordance with resources in relative (percentage) terms.

At $\rho \to \infty$, CES-function becomes the Leontief production function with constant proportions of production factors (zero elasticity of substitution):

$$Y = A\min(\frac{K}{K_0};\frac{L}{L_0}) \quad (5)$$

For the classical Solow growth model that considers the influence of key production factors on output dynamics, Solow (1961), Barro (2010), and Lyashenko (2013) propose to use the Cobb-Douglas production function with the possibility and limitation of substitution, which is the most adequate model in terms of identifying potential sources of growth. The two-input Cobb-Douglas production function is considered classic; here capital and labour are considered resources (Cobb, 1928). Further research leads to the creation of a modified production function that takes into account the exogenous neutral factor (Solow, 1957; Arrow, 1961), entrepreneurial skills and innovation (Schumpeter, 1934), human capital (Romer, 1986; Lukas, 1988), intellectual and social capital (Kramin, 2016). In the model of economic growth, the American economists Mankiw, Romer and Weil (1992) focuse on the quality of the workforce and introduce a factor of intellectual capital which includes the cost of education and science. Romer (1996) believes that the emergence of new ideas and technologies (intangible resources) leads to the creation of more valuable material resources. Oliner and Sichel (2000) consider information technology an important factor in economic growth and technological progress. Solow (Solow, 1956, 1957) proposes to take into account technological progress, which is the main reason for productivity growth and development of the US economy in the first half of the 20th century by changing the quality characteristics of labour potential and improving labour organization (training, improving production etc.). In this case, the endogenous production function may include three main factors: labour (L), physical capital (K) and skill level (H) (Moreno-Hurtado, 2018, p. 172).

In the economic literature there is a general consensus on innovations that play an important role in increasing the competitiveness of firms, industries, regions, and countries (Asheim et al., 2011, p. 1133–1139; Tödtling

& Grillitsch, 2015, p. 1741-1758; Zygmunt, 2019, p. 292), and contribute to sustainable development (Klewitz & Hansen, 2014; Zygmunt, 2020). It is the availability of intellectual assets as important indicators of innovation efficiency that is crucial for economic growth (Zygmunt, 2019). Novakova (2020, p. 11) also concludes on the importance of increasing investment in human development, improving cognitive skills as a prerequisite for sustainable economic development. Marynych (2017) confirms the positive effect of education as a factor of human capital and the untapped potential of the technological factor in ensuring sustainable development of the region. To determine the growth model of the Russian economy Glinskiy et al. (2018) uses the modified Cobb-Douglas production function that includes an innovation factor. For forecasting the economic growth of Ukraine's agricultural sector, Odintsov et al. (2020, p. 153) propose to expand the typical Cobb-Douglas production function due to the "exponential factor of land resources, the cost of innovation and the parameters of state regulation of the tax system (the function includes salary, capital investments, land resources, financing of innovation activities in the agricultural sector of the economy and the tax burden on the industry)".

Sustainable development involves the relationship between economic benefits and environmental impacts. Lyashenko (2012, p. 187) proposes to use the ecological and economic balance taking into account the efficient use of resources and minimization of pollutant emissions. The agricultural sector produces 90% of nitric acid emissions, 70% of methane and 20% of carbon dioxide emissions worldwide (Çetin, 2020). In this case, we believe that to study the factors of sustainable development it is advisable to use environmental and economic production function, including an indicator of environmental pollution as an exogenous factor that negatively affects the results of agricultural production. Yang et al. (2020, p. 166) use both the quantitative and qualitative parameters of labour and environmental impact in the Cobb-Douglas production function to study the sustainable development of China's economy. The authors believe that the main drivers of China's economic growth are physical and human capital, as well as the minimization of environmental pollution to achieve sustainable development. In "The core function of sustainable development" (2015), Tkach proposes a basic function of sustainable development under the information economy, a partial case of which is the modified Cobb-Douglas function, which includes different types of capital: physical, natural, human and information. Dedrick (2003) and Gosinska (2020) use gross value added, which is the main indicator for assessing the performance of the industry and the economy as a whole, as a performance indicator.

3. Methods

To obtain maximum profit in terms of sustainable development we should apply the methodology of construction of the production function, which allows to determine the optimal combination of resources taking into account economic, social and environmental factors. Based on previous studies, we propose to use the four-input Cobb-Douglas production function in terms of sustainable development of agriculture to take into account not only the quantitative parameters of labour potential but also its qualitative indicators (integral coefficient of intellectual assets), as well as environmental impact:

$$Y = a_0 K^{a_1} L^{a_2} I^{a_3} E^{a_4} \quad (6)$$

where Y is the performance indicator (output), K is a fixed capital or fixed assets used (capital investment), L is the living labour costs (number of employees in agriculture), I is an integral coefficient of intellectual assets, E is the pollutant emissions, a_0 is a technological coefficient that characterizes the efficiency of production, takes into account the complex influence of qualitative determinants of labour potential, the influence of factors that cannot be quantified (a technical progress indicator); a_i are the coefficients of elasticity that characterize the contribution of capital, labour, intellectual assets and pollutant emissions to growth of the output Y (i.e., a_i are fractions of factors).

The sum of the elasticity coefficients $a_1 + a_2 + \ldots + a_n$ characterizes the economies of scale (Kuzmin, 2020, p. 787):

– increasing returns to scale if $a_1 + a_2 + \ldots + a_n > 1$ (intensive economic growth), the function grows disproportionately, product growth outpaces the growth of factor costs;

– constant returns when changing the scale of production if $a_1 + a_2 + \ldots + a_n = 1$ (extensive economic growth), the Cobb-Douglas production function is linearly homogeneous, the level of resource efficiency does not depend on the scale of production;

– returns to scale decrease if $a_1 + a_2 + \ldots + a_n < 1$ (lack of economic growth), the function decreases disproportionately, the increase in the factor costs is accompanied by a slowdown in output growth.

Kuzina (2018, p. 73) defines the main characteristics of the Cobb-Douglas production function: it is increasing, has no extremes, the rate of output slows down with increasing resources, output increases indefinitely with unlimited growth of one of the resources.

The advantages of the Cobb-Douglas production function include the following aspects:

– the form of the Cobb-Douglas production function is relatively simple to use, which allows you to easily determine the indicators of productivity and return

on assets, the output elasticity for all parameters, the marginal rates of substitution;
– the Cobb-Douglas production function is able to describe the state of returns to scale, regardless of they increase, are stable or decrease;
– practical universality and adequacy: the Cobb-Douglas production function coefficients directly describe the elasticity of each input factor used;
– macroeconomic orientation: it is based on real economic indicators of official statistical reporting and can be easily parameterized using correlation and regression analysis;
– realism: the functional dependence of the result on costs is nonlinear and does not contain the shortcomings characteristic of linear production functions that describe the processes of an ideal economy.

Despite these advantages, the production function also has a number of disadvantages:
– the production function with the constant economies of scale may inadequately reflect the production process (in conditions of intensive growth of factors, the economies of scale are greater than 1);
– this is based on the assumption of full interchangeability of production resources;
– determining the parameters of the production function is based on marginal prices of factors equal to average prices and calculated on the basis of market prices; this is possible in conditions of perfect competition and market, not in the real economy;
– the principle of complementarity that takes into account the capital structure is ignored.

4. Results and discussion

4.1. The construction of the Cobb-Douglas production function for agricultural production in Ukraine

For conducting an empirical study of the agricultural sector of the economy and the construction of the production function, the relationship between the basic production resources (labour, capital, intellectual assets and emissions of pollutants) and output was used. In a market economy, the main indicator of the degree of development of the industry is gross value added, which reflects the possibility of expanding production. In this case, gross value added and gross output of agriculture are considered performance indicators.

The model considered in the work uses the data of the annual reports of the State Statistics Service of Ukraine (2020): gross value added, gross output of agriculture $Y(T)$, the amount of fixed capital $K(T)$, the number of employees in agriculture $L(T)$ and pollutant emissions $E(T)$; indicators of the integral coefficient of intellectual assets $I(T)$ given in the paper by Karpenko (2018). The statistics shown in Table 1 were used to calculate the Cobb-Douglas production function with the performance indicator "gross value added".

Correlation and regression analysis is used to determine and verify the parameters of the production function. The approximation of well-known power functions in the Cobb-Douglas production function helps mitigate mistakes and close in on real values.

For the calculation, the logarithm of both parts of the equation of the production function is taken:

$$\ln Y = \ln a_0 + a_1 * \ln K + a_2 * \ln L + a_3 * \ln I + a_4 * \ln E .$$

After appropriate replacements, a linear function is obtained:

$$Y_1 = a_0 + a_1 * X_1 + a_2 * X_2 + a_3 * X_3 + a_4 * X_4 ,$$

where $a_0 = \ln a_0$.

After calculations using linear regression analysis by the method of least squares, the values of the coefficients of the Cobb-Douglas production function are determined. The production function obtained takes the form:

$$Y = 422388 K^{0,34474} L^{2,63344} I^{1,60806} E^{-2,86638} \quad (7)$$

Table 1
Statistics for calculations of the production function ($Y(T)$ is the gross value added)

T, year	$Y(T)$, mln UAH	$K(T)$, mln UAH	$L(T)$, thous persons	$I(T)$	$E(T)$, thous t	y_1=ln$Y$	x_1=ln$K$	x_2=ln$L$	x_3=ln$I$	x_4=ln$E$
2008	65148	16682	3322.1	0.5	7210.3	11.1	9.7	8.1	-0.6	8.9
2009	65758	9295	3152.2	0.5	6442.9	11.1	9.1	8.1	-0.7	8.8
2010	82948	11311	3115.6	0.6	6678.0	11.3	9.3	8.0	-0.4	8.8
2011	109961	17981	3410.3	0.6	6877.3	11.6	9.8	8.1	-0.6	8.8
2012	113245	18564	3506.7	0.6	6821.1	11.6	9.8	8.2	-0.5	8.8
2013	132354	18175	3389	0.6	6719.8	11.8	9.8	8.1	-0.5	8.8
2014	161145	18388	3091.4	0.6	5346.2	12.0	9.8	8.0	-0.5	8.6
2015	239806	29310	2870.6	0.5	4521.3	12.4	10.3	8.0	-0.7	8.4
2016	279701	49660	2866.5	0.5	4498.1	12.5	10.8	8.0	-0.7	8.4
2017	303949	63401	2860.7	0.5	3879.1	12.6	11.1	8.0	-0.8	8.3
2018	360757	65059	2937.6	0.4	3866.7	12.8	11.1	8.0	-0.8	8.3

To assess the calculated production function (7), the parameters of regression analysis are studied. The multiple correlation coefficient is R = 0.983, the standard approximation error is 0.148. Fisher's F-criterion calculated is 46.71 and is greater than Fisher's F-criterion tabular (99% confidence, reliability), which is 8.45 (Table 2). Therefore, the regression equation obtained can be considered significant. This means that with a 99% probability the found Cobb-Douglas production function (3) corresponds to the initial data of the problem.

Table 2
Regression analysis parameters for $Y(T)$ (gross value added)

Multiple correlation coefficient R	0.983
Coefficient of determination R^2	0.966
Standard approximation error	0.148
Fisher's F-criterion calculated F_{calc}	46.71
Fisher's F-criterion tabular F_{tab}	8.45
Number of observations	11

Thus, the constructed production function has reliable statistical characteristics. The value of the multiple correlation coefficient indicates a high close relationship between the performance indicator and the selected factors, the variation of gross value added by 98.3% depends on the fluctuations of the factors included in the equation and only 1.7% depends on factors that are not taken into account. The value of the coefficient of determination R^2 (0.966) is quite close to 1, so the regression model is successful, and the relationship between the resulting indicator of the production function and the input factors is strong. Variance of the output $Y(T)$ is due to the regression of the selected levers of influence (K, L, I, E) by 96.6 %. This confirms that the model takes into account the most important factors. In addition to the multiple correlation coefficient, the adequacy of the equation is evidenced by the small value of the average approximation error, which characterizes the average relative deviation between the actual and theoretical values based on the equation constructed (Figure 1). Thus, equation (7) meets all the requirements and can be used for economic analysis.

The analysis shows that the growth of quantitative and qualitative indicators of labour potential of the agricultural sector has a direct impact on the growth of gross value added of agricultural products, as there is a direct relationship between them.

The economic analysis of the Cobb-Douglas production function can be performed on the basis of elasticity coefficients that reflect the nature of the influence of factors on performance. For example, the elasticity coefficient $a_1 = 0.34474$ (7) shows the elasticity of agricultural production relative to capital investment with a constant number of employed persons in rural areas, the integral coefficient of intellectual assets and pollutant emissions. If capital investment increases by 1%, the gross value added of agriculture should be expected to grow by 0.34474%. The elasticity coefficient $a_2 = 2.63344$ (7) indicates the output elasticity relative to the number of employed persons in rural areas with constant capital investment, the integral coefficient of intellectual assets and pollutant emissions, i.e., with an increase in the number of employed persons in rural areas in agriculture by 1% gross value added of agriculture should increase by 2.63344%. The elasticity coefficient $a_3 = 1.60806$ (7) reflects the elasticity of production relative to the integral coefficient of intellectual assets with a constant amount of capital investment, the number of employed persons in rural areas and the number of pollutant emissions, i.e., if the integral coefficient of intellectual assets increases by 1%, an increase in gross value added by 1.60806% should be expected. The elasticity coefficient $a_4 = -2.86638$ (7) shows the elasticity of production relative to pollutant emissions with constant capital investment, employed persons in rural areas and the integral coefficient of intellectual assets, i.e., with an increase in pollutant emissions by 1%, reduction of agricultural output by 2.86638% should be expected. The value of the technological coefficient a_0 obtained (422388) is much more than 1. We can justify a significant impact of technical progress on the growth of gross value added in agriculture.

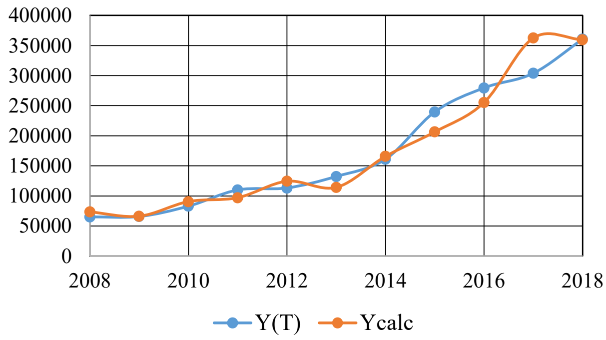

Figure 1. Results of the approximation of the Cobb-Douglas production function for gross value added

This means that the increase in gross value added is, firstly, due to an increase in the number of employees ($a_2 > a_1$); secondly, this is possible due to improving the quality characteristics of labour potential ($a_3 > a_1$). This type of economic growth cannot be called labour-saving; according to Solow, the transition to a model of the production function with scientific and technological progress requires qualitative changes in production processes, improving the efficiency of labour resources and productivity.

Thus, the most significant in the economic growth of agricultural production are quantitative and qualitative indicators of labour potential: the number of employed persons (L) and the integral coefficient of intellectual assets (I), while the capital factor is less influential. This reveals the need to update the issue of priority of development of labour potential of the agricultural sector.

Aggregate influence of factors $(a_1 + a_2 + a_3 + a_4)$ exceeds $1: (a_1 + a_2 + a_3 + a_4) = 1,72 > 1$. This indicates the positive strength of their influence; the resulting production function describes the growing economy (Pshenychnykova, 2017) within the endogenous model of growth. The economic development of agriculture mainly has the characteristics of a large-scale economy: at the current level of science and technology, it is advantageous to expand production for increasing output.

Similarly, there is conducted a study of the Cobb-Douglas production function, which considers the gross output of agriculture Ukraine a performance indicator ($Y(T)$ is the gross output of agriculture, in constant prices of 2010) (Table 3).

After performing the calculations using the method of least squares, the desired Cobb-Douglas production function takes the following form:

$$Y = 341K^{0,08353}L^{1,70970}I^{0,32224}E^{-0,98789} \quad (8)$$

The multiple correlation coefficient is R=0.892, the standard approximation error is 0.107. Fisher's F-criterion calculated is 9.26 – this is greater than Fisher's F-criterion tabular (99% confidence, reliability), which is 8.45. This gives a 99% probability that the found Cobb-Douglas production function (8) corresponds to the initial data of the problem. Therefore, the constructed production function has satisfactory statistical characteristics (Table 4). The value of the multiple correlation coefficient indicates that the variation in the volume of gross output by 89.2% depends on the fluctuations of the factors included in the equation and depends by 10.8% on the factors that are not taken into account. Coefficient of determination R^2 has a satisfactory value (0.796), the variance of the output $Y(T)$ is due to the regression of the selected levers of influence (K, L, I, E) by 79.6 %.

Based on the actual values of gross output and their calculated values, a graphical model of the results of the Cobb-Douglas production function approximation is obtained (Figure 2). In addition to the multiple correlation coefficient, the high degree of accuracy of the regression equation is evidenced by a slight deviation of the calculated values from the actual ones.

Thus, in equation (8) the elasticity coefficients a_2 = 1.70970 and a4 = -0.98789 reflect the influence of factors on performance. Because of a_2 far exceeds 1, the main role in the growth of agricultural production is played by the number of the employed persons. In the case of an increase in the number of employees in agriculture by 1%, an increase in gross output of agriculture by 1.70970% should be expected. The elasticity coefficient a_4 is negative; therefore, the quantity and quality of labour are influenced by environmental factors, namely – pollutant emissions deteriorate the quality of life of the rural population and have a negative impact on crop yields. The sum $(a_1 + a_2 + a_3 + a_4) = 1,13 > 1$ shows the increasing effect of the economies of scale (value $f(x_i)$ increases more than value x_i), the growth of production outpaces the increase in cost factors, with the expansion

Table 3
Statistics for calculations of the production function ($Y(T)$ is the gross output)

T, year	$Y(T)$, mln UAH	$K(T)$, mln UAH	$L(T)$, thous persons	$I(T)$	$E(T)$, thous t	y_1=ln$Y$	x_1=ln$K$	x_2=ln$L$	x_3=ln$I$	x_4=ln$E$
2008	101451	16682	3322.1	0.5399	7210.3	11.5	9.7	8.1	-0.6	8.9
2009	96274	9295	3152.2	0.5120	6442.9	11.5	9.1	8.1	-0.7	8.8
2010	90792	11311	3115.6	0.6479	6678.0	11.4	9.3	8.0	-0.4	8.8
2011	117111	17981	3410.3	0.5566	6877.3	11.7	9.8	8.1	-0.6	8.8
2012	110072	18564	3506.7	0.6072	6821.1	11.6	9.8	8.2	-0.5	8.8
2013	133683	18175	3389	0.5956	6719.8	11.8	9.8	8.1	-0.5	8.8
2014	139058	18388	3091.4	0.5793	5346.2	11.8	9.8	8.0	-0.5	8.6
2015	131919	29310	2870.6	0.5031	4521.3	11.8	10.3	8.0	-0.7	8.4
2016	145119	49660	2866.5	0.5093	4498.1	11.9	10.8	8.0	-0.7	8.4
2017	140535	63401	2860.7	0.4632	3879.1	11.9	11.1	8.0	-0.8	8.3
2018	158307	65059	2937.6	0.4363	3866.7	12.0	11.1	8.0	-0.8	8.3

Table 4
Regression analysis parameters for $Y(T)$ (gross output)

Multiple correlation coefficient R	0.892
Coefficient of determination R^2	0.796
Standard approximation error	0.107
Fisher's F-criterion calculated F_p	9.26
Fisher's F-criterion tabular $F_т$	8.45
Number of observations	11

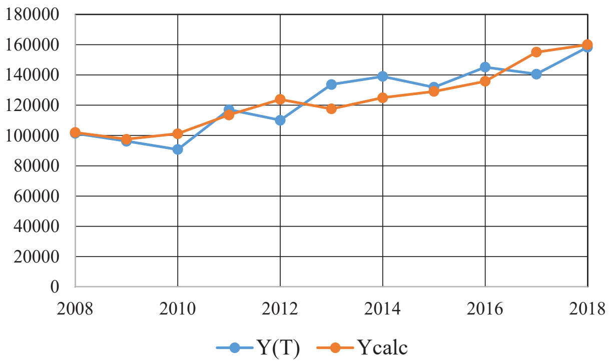

Figure 2. Results of the approximation of the Cobb-Douglas production function for gross output

of production, the average cost of resources per unit of output decreases.

The significant deviation of the elasticity coefficients (8) from 1 can be explained by the fact that other factors, such as political, social and administrative, can have an impact on the situational variable.

4.2. The geometric interpretation of the model obtained

The production functions obtained can be represented by the isoquant curve, which demonstrates different combinations of factors of production function (capital, labour, intellectual assets, environmental factor) in a particular state of technological development, i.e., it illustrates the elasticity of factor substitution, the intensity of various factors in the production process. The resulting output indicator *Y* (gross output of agriculture) and the value of levers of economic growth (*K, L, I, E*), for example, at the level of 2015, are recorded for the analysis of the production function (8). The equation of the balance of fixed capital (*K*) and labour (*L*) at fixed values of other factors (*I, E*) for the production function (8) has the following form:

$$K = \left(\frac{Y}{a_0 + L^{a_2} + I^{a_3} + E^{a_4}}\right)^{\frac{1}{a_1}} \quad (9)$$

The isoquant that meets these conditions is shown in Figure 3. The curve indicates the substitution by capital (*K*) within certain limits of labour (*L*) and vice versa. The slope of the tangent to the isoquant (isocost), plotted at the point of the optimal ratio of capital and labour (Yankovyi, 2018, p. 374), gives evidence of the capital-intensive technical progress – the technological choice is shifted to capital as a more productive factor.

There is the equation of isoquant at fixed values of fixed capital (K) and pollutant emissions (*E*):

$$L = \left(\frac{Y}{a_0 + K^{a_1} + I^{a_3} + E^{a_4}}\right)^{\frac{1}{a_2}} \quad (10)$$

Figure 4 shows the curve of the balance of labour (*L*) and the integral coefficient of intellectual assets (*I*). The shape of the isoquant indicates a perfect substitution of

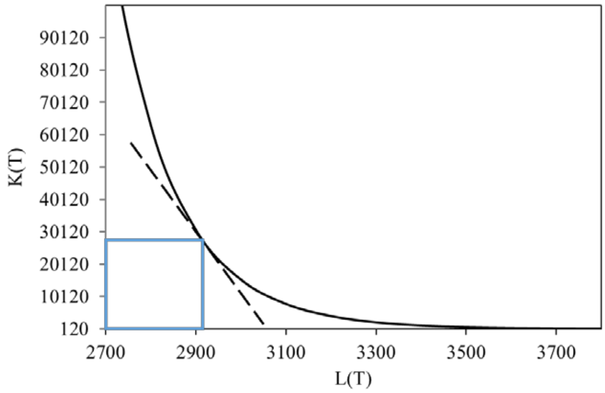

Figure 3. Balance of fixed capital (*K*) and labour (*L*) at fixed values of factors (*I, E*)

the production function *L* and *I* (insufficient amount of labour potential can be substituted by higher indicators of education, qualifications, abilities of workers), constructed tangent determines the qualitative indicators of labour potential (*I*) a more productive factor in technical progress. The isoquant described by equation (9) is shown in Figure 5 also confirms the advantage of qualitative characteristics of human capital over material resources: insufficient amount of fixed capital can be partially offset by the growth of intellectual assets. The shapes of the isoquants in Figures 4 and 5 are close to linear isoquants. This demonstrates the perfect substitution of the factors of labour (*L*) and capital (*K*) with the factor *I* and vice versa. This also confirms the importance of intellectual assets in production.

The equation of isoquant at fixed values of fixed capital (*K*) and the integral coefficient of intellectual assets (*I*) is described by formula (10). Figure 6 shows the curve of the balance of labour (*L*) and pollutant emissions (*E*), which reflects zero probability of substituting these two factors with each other. The shape of the balance curve of the capital (*K*) and pollutant emissions (*E*) built on equation (9) also confirms the impossibility of substitution (Figure 7).

Therefore, the isoquant variations shown in Figures 6 and 7 reflect the impossibility of combining

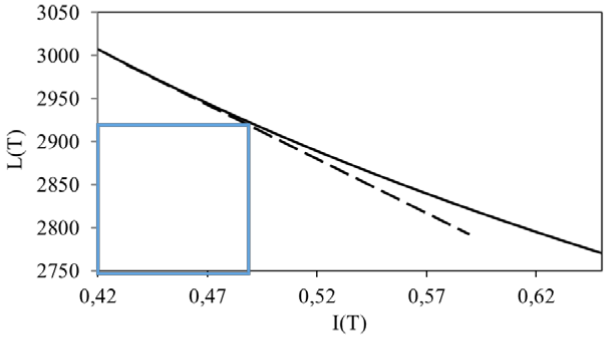

Figure 4. Balance of labour (*L*) and the integral coefficient of intellectual assets (*I*) at fixed values of factors (*K, E*)

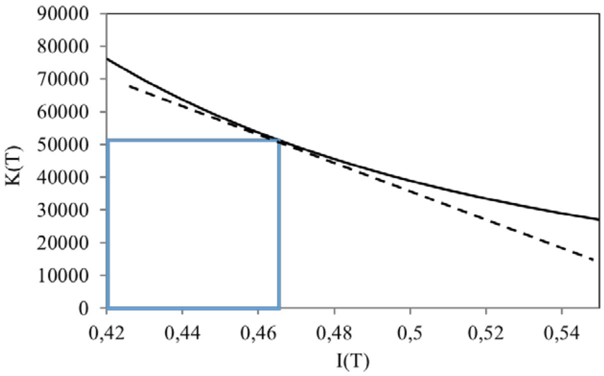

Figure 5. Balance of labour (*K*) and the integral coefficient of intellectual assets (*I*) at fixed values of factors (*L, E*)

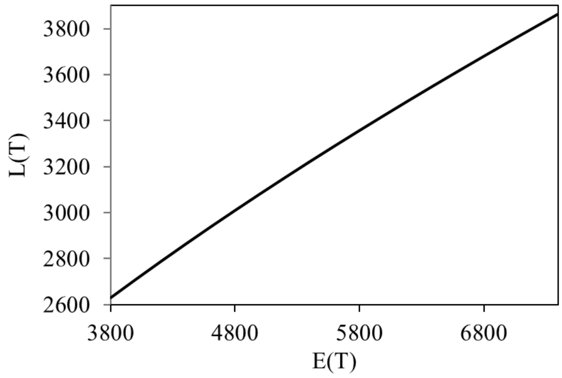

Figure 6. Balance of labour (*L*) and pollutant emissions (*E*) at fixed values of factors (*K, I*)

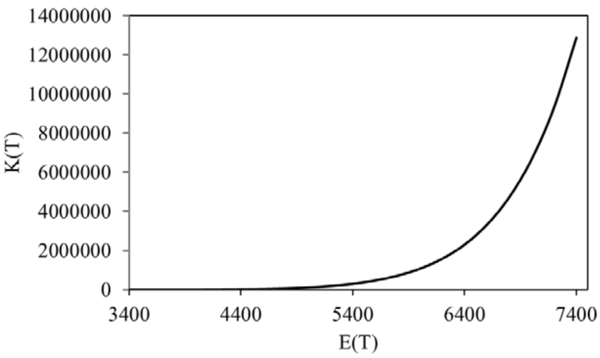

Figure 7. Balance of labour (*K*) and pollutant emissions (*E*) at fixed values of factors (*L, I*)

factors of production with the factor "pollutant emission (*E*)", we believe that the environmental factor makes a significant negative contribution and must be taken into account in the model of economic growth described by the production function.

Since the four-factor Cobb-Douglas production function (8) is used for analysis, it is expedient to consider isoquants in the form of 3D surface (balance of three factors with one fixed factor) for a more detailed assessment of its adequacy.

Balance function of fixed assets (*K*), labour (*L*) and the integral coefficient of fixed assets (*I*) at a fixed value of pollutant emissions (*E*) takes the form of the equation (9). The isoquant that meets these conditions is shown in Figure. The isoquant surface indicates the importance of the factors *L* and *I*.

Equation of the balance of fixed capital (*K*), pollutant emissions (*E*) and the integral coefficient of intellectual assets (*I*) at the fixed value of employees (*L*) is described by formula (9), and is represented in Figure 9 as a surface. The shape of it shows a significant negative impact of increasing pollutant emissions (*E*) and the positive effect of the growth of the integral coefficient of intellectual assets (*I*).

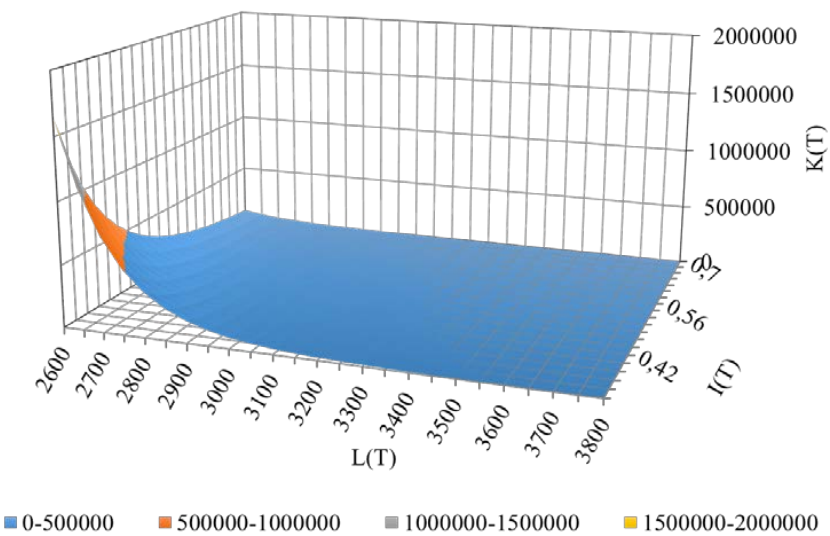

Figure 8. Balance of the fixed assets (*K*), labour (*L*) and the integral coefficient of intellectual assets (*I*) at fixed values of pollutant emissions (*E*)

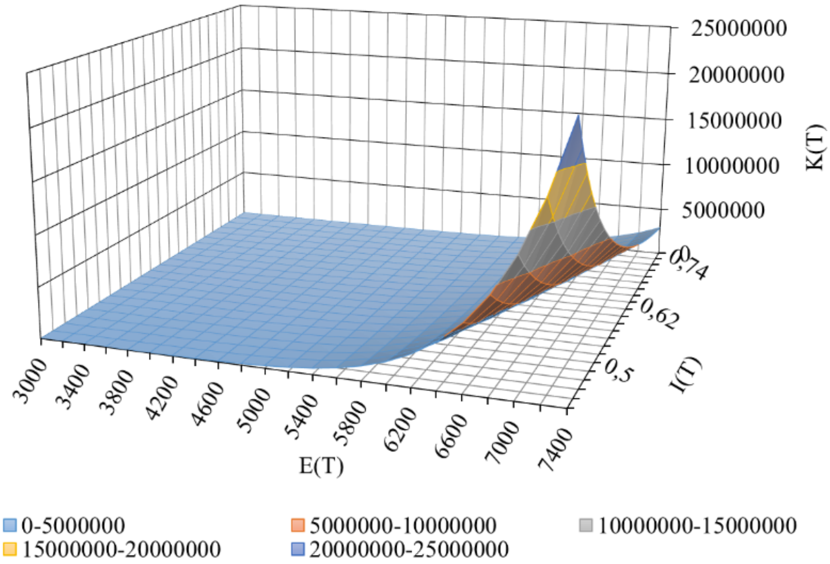

Figure 9. Balance of the fixed assets (K), pollutant emissions (E) and the integral coefficient of intellectual assets (I) at a fixed value of the employees (L)

Figure 10 shows the surface of the balance of fixed capital (K), labour (L) and pollutant emissions (E) at fixed values of the integral coefficient of intellectual assets (I) described by the equation (9).

Comparative analysis of the parameters of production functions for gross value added (7) and gross output (8) (Table 5) indicates a more efficient use of labour potential for processing agricultural raw materials and the creation of finished products, where technical progress (a_0) and quality indicators of human capital (a_3) have much more influence. Thus, the coefficients of elasticity are functions of factors that include the production function. This is shown in the studies of agricultural economics by Artyukh (2016) and Litvin (2017). We also agree with Shumska's (2007, p. 123) conclusions about the sensitivity of the coefficients of the production function to the political and institutional processes that take place in different periods of time. Ukraine is on the path to an efficiency driven economy that depends on key competitiveness factors: institutions, infrastructure, macroeconomic stability, health care and primary education (Vasylieva, 2018); these factors also affect the values of elasticity of coefficients.

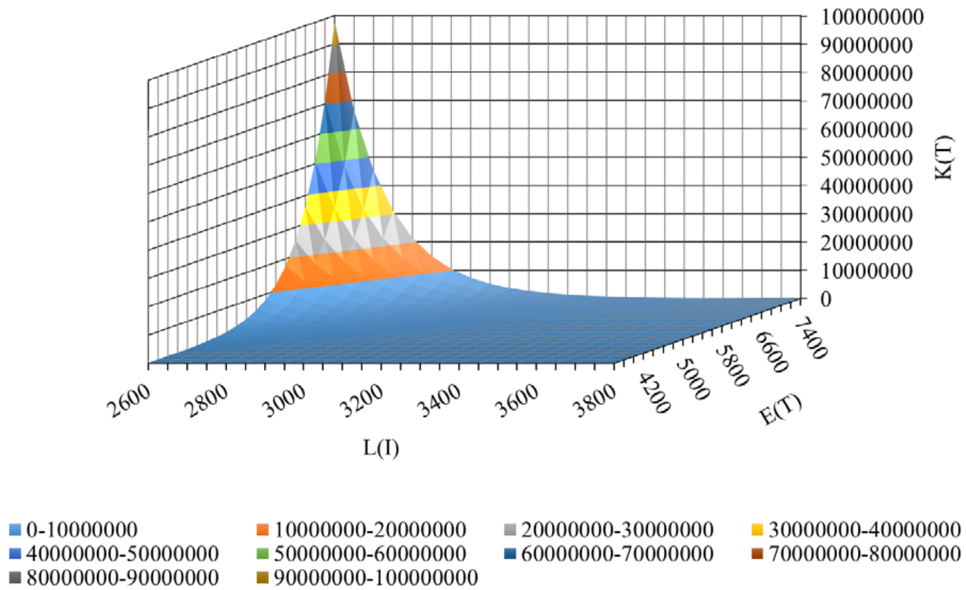

Figure 10. Balance of the fixed assets (K), labout (L) and pollutant emissions (E) at a fixed value of the integral coefficient of intellectual assets (I)

Table 5
Results of modelling the production function

parameters	$Y(T)$ gross value added	$Y(T)$ gross output
a_0	422388	341
a_1	0.34474	0.08353
a_2	2.63344	1.70970
a_3	1.60806	0.32224
a_4	-2.86638	-0.98789
$(a_1 + a_2 + a_3 + a_4)$	1.72	1.13

Using the Cobb-Douglas production function, econometric analysis with eco-socio-economic factors has shown that economic growth in agriculture is associated, firstly, with improved quantitative and qualitative characteristics of labour potential, and secondly, with growing capital investment and reducing pollutant emissions.

5. Conclusion

Economic growth of agricultural production in Ukraine (gross output) is labour-intensive, not capital-intensive, because $(a_2>a_1)$. This significantly depends on the quantitative indicators of the labour potential of rural areas (a_2), which are gradually declining. This is due to negative demographic trends, which, in turn, has resulted in the degradation of rural areas, reduced employment and income.

The share of labour contribution to output is higher than the share of capital. This is justified by the presence of a significant private sector in agricultural production. Households mainly use manual labour, there are no opportunities to attract investment in technical and technological modernization of production; access to state support is limited due to low production volumes per farm. The prospects for economic growth of agricultural production are not to increase the number of resources, but to improve their quality. It is advisable to implement state support measures aimed at increasing the resource capacity of agricultural producers: subsidies for technical upgrades, investment loans for new capacity, reimbursement of capital expenditures for modernization of production, compensation for investment in land reclamation system, implementation of scientific and technical policy in the agricultural sector. To ensure sustainable growth of agricultural production, it is necessary to introduce innovative developments, resource-saving technologies, increase the use of intellectual capital (Potapov, 2020).

Efficient use of labour potential is the basis for economic growth in other sectors of the economy, reducing social tensions, ensuring food independence and security. Modelling how the resource factors act on output using the method of construction and calculation of parameters of the production function allows to predict the sustainable development of agricultural production under quantitative and qualitative changes in the use of labour and capital, as well as environmental factors.

In our opinion, the obtained results on the growing economies of scale give grounds to speak about the optimistic prediction of increasing the resource potential of agricultural production due to the growth of quantitative and qualitative indicators of labour potential, the prospects of which have been widened under decentralization and creation of new economic agents in rural areas.

It would be also beneficial to carry out research to factors of sustainable development of the agricultural sector using other econometric methods.

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