The object of this study was the process of digitalization of the economy and society of the European Union. The task of researching the impact of digitalization on the economic growth of the European Union has been solved. The relevance of the chosen topic is due to the complexity of digital transformation processes taking place in the world economy and the economy of the European Union, in particular, the need to assess their directions and intensity. Four approaches to modeling the impact of digitalization on economic growth based on the neoclassical production function were proposed. The structure of the model was chosen, which makes it possible to evaluate the influence of various factors of digitalization on the key parameters of economic growth. A regression multivariate model for assessing the impact of digitalization on the economic growth of the European Union has been developed. To this end, a sequence of stages was performed: formation of the information base, grouping of digitalization factors, as well as their selection based on correlation analysis. With the help of regression analysis, the parameters of the production function were expressed through digitalization indicators. At the same time, due to the limitation of input data, the Elastic Net Regression method was used. This made it possible to ensure the quality of the new model, namely, to remove low-impact parameters, reduce the multicollinearity of factors, make the model statistically significant, and ensure the stability of coefficients to data changes. The resulting model is eleven-factor; it demonstrates a high predictive ability (the coefficient of determination is 0.987). It can be used as an analytical tool for assessing the impact of digitalization on the economic growth of the European Union. Practical use of the model will help governments and businesses make informed decisions about digital transformation policies

Keywords: digital transformation, economic growth, production function, statistical modeling, European Union

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THE IMPACT OF DIGITALIZATION ON THE ECONOMIC GROWTH OF THE EUROPEAN UNION: AN EMPIRICAL STUDY

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1. Introduction

Digital transformation of the economy has become one of the key modern challenges. Digital technologies are changing all domains of economy and social life, from business, production, trade, public administration, culture, health to banking and education. They revolutionize the forms of conducting business, social life, education, communications, and entertainment, opening up new opportunities and creating new challenges. The study of the development trajectory of the digital transformation of the economy makes it possible to identify the digital drivers of economic development. As well as understand its impact on labor productivity, the formation of innovative development, business competitiveness, population employment, the environment, and other important aspects of civilization. This, in turn, can be useful in the development of policies and strategies to promote the digital transformation of the economy, as well as in the process of making informed decisions about investing in digital technologies. One of the results may be an increase in public interest and awareness of the potential possibilities of digital technologies.

The European Union is an ideal place to study the processes of digitization and its impact on economic growth. This economic and political union is one of the largest, most developed, and digitized economies in the world. According to Eurostat [1], in 2023, 22.9 % of European Union enterprises carried out electronic sales, in 2022 these sales accounted for 18 % of the total trade turnover. In 2023, more than 78 % of enterprises had their website, 60.9 % of enterprises used social networks. One in three businesses in the European Union use enterprise resource planning software, 45.2 % of businesses purchased cloud computing services, and 25.8 % used customer relationship applications. Two-thirds of large enterprises performed data analysis and

less than one in ten enterprises used artificial intelligence technologies. All this shows that the statistical database of the European Union contains a lot of data that can be used to study the impact of digitalization on economic growth. Also, the European Union is a political union, which makes it an ideal training ground for comparative studies between countries on the impact of digitalization on their economies.

The results of such studies are of practical importance because there is a need for empirical studies for a deep understanding of the impact of digitalization and its various aspects on the economic growth of the European Union. The results can become the basis for making informed decisions in the field of policy, stimulation of digital transition, financing, and investments in digital transformation. This will help ensure the sustainable economic development of the European Union, can change the economic landscape and be important for the future of Europe.

This confirms the relevance of the selected research topic of the impact of digitalization on the economic growth of the European Union.

2. Literature review and problem statement

In paper [2], the authors analyze the impact of digitalization on economic growth in the European Union. A linear econometric model of the dependence of gross domestic product per capita on three drivers of digitalization is used to model the impact of digitalization: information and communication technologies, mobile subscribers, Internet users, and fixed broadband subscribers. The authors concluded that digitalization has a positive and significant impact on economic growth. But the limitation of this study is that other factors of the digitalization of the economy and society remained unaccounted for, which may be related to the limited samples of the time series of the digitalization indicators of the European Union.

In work [3], the authors investigate the relationship between digital transformation and economic development, productivity, and employment of the population for a number of countries around the world. The authors used Bayesian linear regression for modeling and obtained a positive relationship between digital transformation and the economic development of the countries of the world. In the modeling process, the authors used the Digital Technology Adoption Index (DAI) as one of the parameters of economic growth. However, the very process of using this index may contain inaccuracies associated with insufficient quality and relevance of data, insufficient consideration of context and institutional factors. Without taking into account the negative consequences and risks of digital transformation, which in turn can lead to wrong conclusions. Thus, the issues of taking into account the impact of the speed of change of the digital landscape and its impact on economic growth remain unresolved.

In [4], the authors set the goal of investigating the impact of information and communication technologies on economic growth. In the study, the method of partial least squares was used to model the impact of the Digital Economy and Society Index on economic growth. The authors concluded that progress in the deployment and use of information and communication technologies contributes to the economic growth of countries. As in the previous study, the use of an integral index imposes a number of limitations on the modeling results, and the assessment of the impact of other factors of digitalization on economic growth remains unresolved.

Paper [5] examines the impact of digitalization of small and medium-sized enterprises on the economic growth of the countries of the European Union. The authors paid attention to the issues of digital maturity of small and medium-sized businesses before the introduction of digital technologies, while the issues of the impact of digitalization on economic development remained unresolved.

Paper [6] analyzes the economic impact of digital technologies in Europe. The authors identified the prerequisites, conditions, and obstacles for the movement of the digital society, as well as the impact of these factors on labor productivity, gross domestic product per capita, and population employment. With the help of econometric models, the authors substantiate the impact of digitalization on the growth of productivity and employment. But in the study, the question of considering a wider range of factors as determinants of economic growth remained unresolved.

Study [7] evaluates the key factors of digitalization in the European Union. In the work, the selection of the most important factors of the digital economy was carried out using the panel regression method. The author pays attention to the infrastructure of the Internet as the main factor in the development of digitalization, while most other non-infrastructural factors remain neglected.

In paper [8], the authors analyzed the context of the relationship between the goals of sustainable development and digitalization. A two-stage methodology for identifying links between information and communication technologies and sustainable development is proposed, which is based on linear regression. The results obtained by the authors demonstrate the connection between factors of digitalization and individual goals of sustainable development. But the issues of identifying the drivers of digitalization and assessing the impact of digitalization factors on the economic growth of the European Union remain unresolved.

Our review of the literature [2–8] allows us to state that it is appropriate and promising to assess the impact of a variety of digitalization factors on the economic growth of the European Union, taking into account objective informational limitations. It can also be argued that among the main reasons that the issues under consideration remain unresolved are the limitations of available data, the inadequacy of methods, the limited scope of research, and the ambiguity of the results and approaches used.

3. The aim and objectives of the study

The purpose of our study is to assess the impact of factors-drivers of digitalization on the economic growth of the European Union, which will make it possible to improve the information and analytical support for monitoring and evaluating the trajectory of the digital transformation of the economy of the European Union.

To implement the goal of the research, the following tasks must be solved:

– to justify the choice of design model for the study of the impact of digitalization on the economic growth of the European Union;

– to build a model for assessing the impact of digitalization on the economic growth of the European Union.

4. The study materials and methods

The object of our research is the process of digitalization of the economy and society of the European Union, the subject is the interrelationships of the factors of this process.

The main hypothesis of the study is the assumption that digitalization has a positive effect on the economic growth of the European Union. This hypothesis is considered through the prism of the neoclassical model of the production function. It is proposed to consider several models, where digitalization can be considered as an external or internal quasi-variable, which has a separate or global impact on capital, labor, and general productivity, which increases the level of aggregate production. It is assumed that digital transformation affects economic growth by increasing labor productivity, increasing the efficiency of capital use, and stimulating technological progress.

The study is based on previous studies [9–14], in which approaches to modeling and forecasting of macroeconomic phenomena and trends have been developed, and include the use of various methods of statistical, correlational, and regression analysis.

The results of the study include an assessment of the impact of digitization factors on economic growth, which can be used to develop recommendations for the development or improvement of the digital transformation strategy of the European Union countries.

The main difficulties of the study are related to the availability of data, their temporal coverage and integrity, as well as the generalized nature of the modeling results. However, the importance of this study lies in its potential ability to provide governments and businesses with a methodological toolkit for assessing the impact of digital transformation on economic growth rates and promoting development through digital innovation.

5. Results of investigating the impact of digitalization on the economic growth of the European Union

5. 1. Justification of the choice of the design of the research model of the impact of digitalization on the economic growth of the European Union

A successful strategy for the digital transformation of the economy depends on a well-thought-out trajectory of its development and stages of implementation. By the trajectory of digital transformation, we shall understand a set of established and substantiated goals, tasks, measures, and their resources necessary for its implementation.

To form and substantiate the trajectory of the digital transformation of the economy, the following important tasks must be solved:

– assessment and forecasting of the potential of digital transformation – study and determination of areas of economic activity that have the greatest potential for the implementation of digital transformation processes;

– study of the dynamics of the digital transformation of the economy, progress and its compliance with the formed strategic goals, objectives, and measures;

– assessment of the level of efficiency of digital transformation and intensity of influence on economic growth.

To solve these problems, it is necessary to form a system of information and analytical support, which will contain models and monitoring methods for assessing the impact of digitalization on economic growth. The development of just such models and methods is an important step for tracking, analyzing, and understanding the impact of digitalization on various sectors of the economy, the economies of countries and international associations as a whole. Modeling the trajectory of digital transformation and studying its impact on society and the economy will allow us to better understand these processes and use the acquired knowledge to support sustainable economic development.

The scheme of the information and analytical system for monitoring and evaluating the trajectory of digital transformation may consist of the following components:

– a database of indicators of the processes of digital transformation of the economy;

– module of analysis and modeling (analysis of trends, modeling of the impact of digital transformation on economic growth, identification of factors, forecasting, etc.);

– data visualization information panels;

– an integrated information system for monitoring the digital transformation of the economy.

This study focuses on two components of the information and analytical monitoring system, namely: the process of finding and collecting data on digital transformation and the process of developing a modeling method for assessing the impact of digitalization on economic growth.

For a better understanding of data sources, generalization of scientific achievements and best practices for assessing the impact of digitalization on economic growth, we shall consider the indices for assessing the level of use of information and communication technologies and digitalization of the economy. Various indices are used to assess the level of digitization of the economy. These indices take into account various indicators from different areas of activity related to the use of digital technologies. In the study, the most well-known indices were considered, their structure was studied, the main characteristics were analyzed, and they were compared with each other. Only those indexes that meet the basic requirements were selected: shared knowledge, authority of the publishing organization, scope, scale of the index. In accordance with the requirements, the following indices were selected (Table 1).

All these indices have common features, but also have differences. First, they are constructed as complex indicators and represent additive models of weighted individual groups of indicators that can be expanded to basic indices. Secondly, all presented indices are unique methodological developments that consider and evaluate various aspects of digitalization of the economy. But they have common features, namely, they evaluate the following common areas of digitalization of the economy: human capital and innovation, infrastructure and technology, digital public services. It is also necessary to highlight a number of limitations. First, different methodologies for assessing and collecting digitalization indicators in different countries do not allow for the formation of a comprehensive integrated indicator that was able to assess the impact of digitalization on the economies of most countries of the world. Studies of the level of digitization according to some indices are aperiodic in nature, which makes proactive analysis and the formation of management actions at various levels impossible. Second, most integral indicators include a large number of basic indicators, which blurs the final evaluation result. Thirdly, these indices do

not take into account the context of institutional qualitative indicators, such as the legal environment, social capital, culture, and education, which can influence the processes of digital transformation. This can lead to ignoring important features of the digital transformation process. Fourth, these indices take into account only the positive changes of digitization in the business environment, while the negative dynamics and risks that digital transformation can cause are ignored. The negative impact of digital transformation can worsen the dynamics of economic development, the social situation of the population, and also increase inequality and polarization in society. Therefore, in order to solve these problems, it is necessary to look for new approaches to assessing the impact of digitalization on the state of economic and social development.

Table 1

Indices for assessing the level of use of information and communication technologies and digitalization of the economy

Index name	Essence
Digital Economy and Society Index (DESI) [15]	Developed by the European Commission, it has been published since 2014 and covers data on 27 member states of the European Union. The index includes 32 different indicators grouped into four generalizing groups: human capital, communication, integration of digital technologies, digital public services. The index model has the form of a sum of equally weighted grouped components, which in turn are additive models of weighted normalized indicators
ICT Development Index (IDI) [16]	Developed and published by the International Telecommunication Union. Measures the degree of development of communication in the world, covers 169 economies of the world. The index calculation methodology was updated in 2023. The index model includes ten indicators grouped into two components: meaningful connection and universal connection
Digital Intelligence Index (DII) [17]	non-annual study prepared by Tufts University. This index evaluates the global digital development and the key factors of digitalization on the country's competitiveness. The index consists of two components: digital evolution indicators, which is a continuation of the digital evolution index (DEI), and digital trust indicators. The assessment of digital evolution is given to 90 countries according to 160 different indicators, which are systematized into the following groups: conditions of supply, conditions of demand, institutional environment, and innovative changes. The evaluation of digital evolution is carried out on new sweeps of the four drivers into thirteen components, which are expanded into thirty-five clusters covering the indicators. Digital trust evaluates 42 world economies based on 197 indicators, which are collapsed into 32 clusters, 14 components and 4 drivers
World Digital Competitiveness Index (WDCI) [18]	Developed by the Center for Global Competitiveness IMD. The index assesses the degree to which 64 countries have implemented digital technologies that contribute to the transformation of government practices, business models, and society as a whole. The index consists of three groups of factors: knowledge, technology, and readiness for the future, they are divided into nine sub-factors, which include 54 criteria
Electronic Government Development Index (EGDI) [19]	A comprehensive indicator demonstrating the state of e-government in UN member states and the ability to participate in the information society. The index is an additive weighted average complex indicator of three dimensions of e-government: the volume and quality of online services, the state of development of the telecommunications infrastructure and internal human resources

One of the most common methods of modeling the economic growth of various economic systems is the use of production functions. The production function is a mathematical expression that demonstrates the influence of various factors of production on the volume of production. In modern practice of modeling, there is a whole arsenal of production functions, among which it is necessary to highlight: linear function, Cobb-Douglas, Allen, Solow, CES function.

In this study, the neoclassical model of the Cobb-Douglas production function [20] was chosen, which is determined by the time series of input data: gross domestic income Y_t, labor resources L_t, total cost of capital K_t:

$$Y_t = AK_t^{\alpha}L, \quad (1)$$

where t=1, 2,... T, T is the length of the time series;

A is a parameter of technological progress.

Moreover, it is assumed that the parameter A can be expressed as a dynamic characteristic A_t, and therefore, there is a relationship:

$$A_t = A\varepsilon_t, \quad (2)$$

where ε_t is the error of the model, which reduces to the ratio of the volumes of the actual gross product Y_t and calculated on the basis of the model $\hat{Y}_t$.

The choice of this function was made in view of a number of its advantages. It is popular and widely used for modeling economic growth for socio-economic systems of various scales. This model is simple and accessible in the process of simulation, analysis, and interpretation of results. Also, the model has a deep theoretical justification, which means it corresponds to the basic principles of neoclassical economic theory. And most importantly, this model is confirmed by empirical studies conducted on the statistical data of various countries. All the above advantages make the model suitable for assessing the impact of digitalization on economic growth.

To build a model and analyze digitalization factors that influence economic growth, it is necessary to choose a way to include these factors in the model. Solving this problem is a subject of debate. Digitization can be considered from the position of four approaches. In the first approach, digitalization can be considered as a factor that directly affects economic development. That is, digitalization encourages the creation of new goods and services that are established in the real sector, change the production process, and stimulate economic growth. In this approach, the digitization parameter (D_t) is added to the model as a separate factor affecting production volumes, the larger the value of this parameter, the greater the production volumes. Accordingly, the digitization parameter (D_t) is an internal quasi-variable, and the neoclassical production function model can be written as:

$$Y_t = AK_t^{\alpha}L_t^{\beta}D_t^{\gamma}. \quad (3)$$

The second approach assumes that digitalization is considered as an external quality factor (D) that can affect the growth of capital or labor productivity. In this case, the model of the neoclassical production function may take the following form:

$$Y_t = A\left(K_t D\right)^{\alpha}\left(L_t D\right)^{\beta}. \quad (4)$$

The digitalization parameter (D) in model (4) can be taken separately for each factor of production (D_K, D_L.) This means that digitalization has an uneven effect on different factors of production. The value of parameter (D) can be calculated by expert evaluation or empirical research. Parameter (D) can take different values, depending on the level of digitalization. For example, if D=1, it means that production is not sensitive to digitalization. If D>1, digitalization increases the efficiency of capital use and labor productivity, which stimulates economic growth. Conversely, if D<1, digitalization negatively affects labor productivity and capital efficiency, reducing returns and reducing output. This representation of the digitalization parameter makes it possible to quantitatively assess its impact on economic growth and compare the impact of digitalization on different countries.

The third approach involves considering digitalization as a complex global process that has an impact through various processes and covers most domains of the economy and society. In this approach, digitalization does not act as a separate factor of production, but can be expressed through the dynamic coefficient of the parameter of technological progress – A_t as an external quasi-variable:

$$A_t = f\left(D_1, D_2, \ldots, D_n\right). \quad (5)$$

In this case, digitalization acts as a stimulator of the creation of new technologies, goods, increasing the productivity of labor and capital, restructuring the structure of the economy. And the model of the neoclassical production function will look like this:

$$Y_t = A\left(D_t\right)K_t^{\alpha}L_t^{\beta}. \quad (6)$$

The fourth approach is a combined combination of the second and third approaches, when the parameters of the model (K_t, L_t) and the dynamic coefficient (A_t) are also quasi-variable:

$$Y_t = A\left(D_t\right)K\left(D_t\right)^{\alpha}K\left(D_t\right)^{\beta}. \quad (7)$$

This approach allows us to assess the impact of digitalization on economic growth in various aspects, taking into account the impact on the return on capital, labor, and the overall efficiency of technology. Model (7) allows one to compare different economies and determine the specific effects of digitalization in each of them.

The choice of the type of model depends on how the process of digitization and its impact on the economy and economic growth are considered. According to the first and second approaches, representing digitalization as a separate variable makes it difficult to express many of its parameters through a single parameter. This is due to the fact that digitization is a complex and multifaceted process that includes many interrelated elements and components. In addition to the presentation of digitalization, an additional factor of production is artificial since it affects all aspects of aggregate production. Also, the first and second approaches make it impossible to use regression analysis to obtain the theoretical value of the digitization parameter (D_t) because it is not possible to obtain its input values.

Unlike the first and second, the third approach considers digitalization as a multifaceted process that affects the increase in the efficiency of the use of production factors, which in turn affects economic growth. One of the limitations of the neoclassical production function is that it takes into account only the factors of capital and labor and does not take into account other external factors. And the expression of factors of digitization through the parameter of total productivity (A_t) makes it possible to take into account the impact of external factors on economic growth. It is more natural to express the factors of digitization through the parameter of total productivity of the factors. Because this parameter is a measure of efficiency and evaluates how effective the country's use of capital and labor is for the production of goods and services. The implementation of digital technologies and their application can affect the increase in the efficiency of the use of capital and labor, which leads to economic growth. It should be noted that the overall productivity cannot depend only on one factor of digital technologies, but also depends on other various factors. Such factors include groups of factors related to data infrastructure, institutional factors, level of digital skills, digital culture, digital integration, digital literacy, digital innovation, and others. Therefore, an important task is to conduct a detailed study on the assessment of the impact of various factors of digitalization on economic growth.

The fourth approach makes it possible to assess the impact of digitalization on all components of economic growth. However, it should be noted that the evaluation of such a model can be difficult from the point of view of obtaining the necessary data, identification of components and multidimensionality. Also, it should be noted that this model is very difficult to interpret, as it can cover a significant number of variables. However, it is the fourth approach that is most appropriate for the purpose of this study.

Studying the impact of digitalization through the neoclassical production function is quite logical and well-founded, as it allows us to assess the potential of digital transformation to increase the rate of economic growth. This makes it possible to quantitatively assess the impact of digitization factors on economic growth rates and predict its impact in the future. Relevant modeling results can be used to develop and improve state policy aimed at the development of the digital economy.

5. 2. Development of a model for assessing the impact of digitalization on the economic growth of the European Union

To obtain the analytical equation of the neoclassical Cobb-Douglas production function for the economy of the European Union, official Eurostat data [21] for the period 1995–2022 were used:

– gross domestic product, million euros (Y_t);

– gross accumulation of capital, million euros (K_t);

– expenses for the payment of wages and social benefits, million euros (L_t).

The choice of a statistical indicator of wage costs instead of an indicator of population employment was necessary to ensure comparability of all indicators in monetary terms and obtain statistically significant modeling results.

The next stage of the research is to replace the object – the economy of the European Union with a neoclassical production function of the type (1). On the basis of successive transformations and stages of regression analysis, the parameters of the model and the following function were obtained:

$$Y_t = 3.2037 K_t^{0.1142} L_t^{0.8784}. \quad (8)$$

Analysis of the statistical properties of the model showed that it is statistically significant (Table 2). The value of the statistical error demonstrates that the estimates of the coefficients are sufficiently accurate. The level of *t*-value and *p*-value show that the coefficients of the model are statistically significant, and the parameters of the model have a significant effect on the dependent variable. *R*-square is 0.997, that is, the model explains 99.7 % of the variance of the dependent variable. The *F*-statistic is very high at 4158, which again confirms that the model is statistically significant and predicts the dependent variable well.

Interpreting the results of the model, we can say that the exponents of the model parameters indicate the elasticity of economic growth. Thus, with an increase in capital or labor by one percent, it will lead to an increase in the gross domestic product by 11.4 % and 87.8 %, respectively. As can be seen, labor resources have a greater influence on the economic growth of the European Union. The sum of powers is less than unity, which indicates the absence of a constant scale of production. Summarizing the statistical properties of the model, we can conclude that it is adequate and can be used for practical research on determining the impact of digitalization on economic growth.

Fig. 1 shows the comparative dynamics of the actual values of the gross domestic product of the European Union and the estimated values obtained on the basis of function (4).

In order to obtain all the time series of the parameters of the neoclassical model of the production function and further study the impact of digitalization on them, it is necessary to express the parameter of the aggregate productivity of factors (A_t)). This parameter can be expressed on the basis of the ratio of the input (gross output) to the weighted product of the inputs of the production function (capital and labor):

$$A_t = \frac{Y_t}{K_t^{\alpha} L_t^{\beta}}. \quad (9)$$

The next stage, which is aimed at assessing the impact of digitalization on the economy and society of the European Union, is the creation of a statistical database that will contain information on various aspects of the digitalization of this economic and political regional association. Data sets on the digital economy and digital society of the European Union were created for the purpose of the study [21–23]. The data sets were divided into seven groups: e-commerce, Internet use, international trade in ICT goods and services, e-government, Internet banking, use of social networks, employment of ICT specialists. Unfortunately, a detailed analysis of the time series showed that individual data sets were too short or had data gaps, which made it impossible to conduct a qualitative study and obtain statistically significant results. This is due to three objective reasons. First, the incompleteness of data for some countries of the European Union is associated with problems in the reliability and confidentiality of this data. Second, separate sets of indicators were generated by aperiodic surveys, which formed asymmetric gaps in the series. Third, this direction in statistical reporting is relatively new and research in this field is just beginning, so the series in the data sets are short. When selecting indicators, gaps in the data were filled with the average values of the extreme actual indicators of the time series.

Table 2

Statistical properties of the obtained model

Model coefficients	Standard error	*t*-value	*p*-value Pr(>|*t*|)
A	0.1647	7.068	2.08e-07
K_t	0.0452	2.527	0.0182
L_t	0.0455	19.304	2e-16

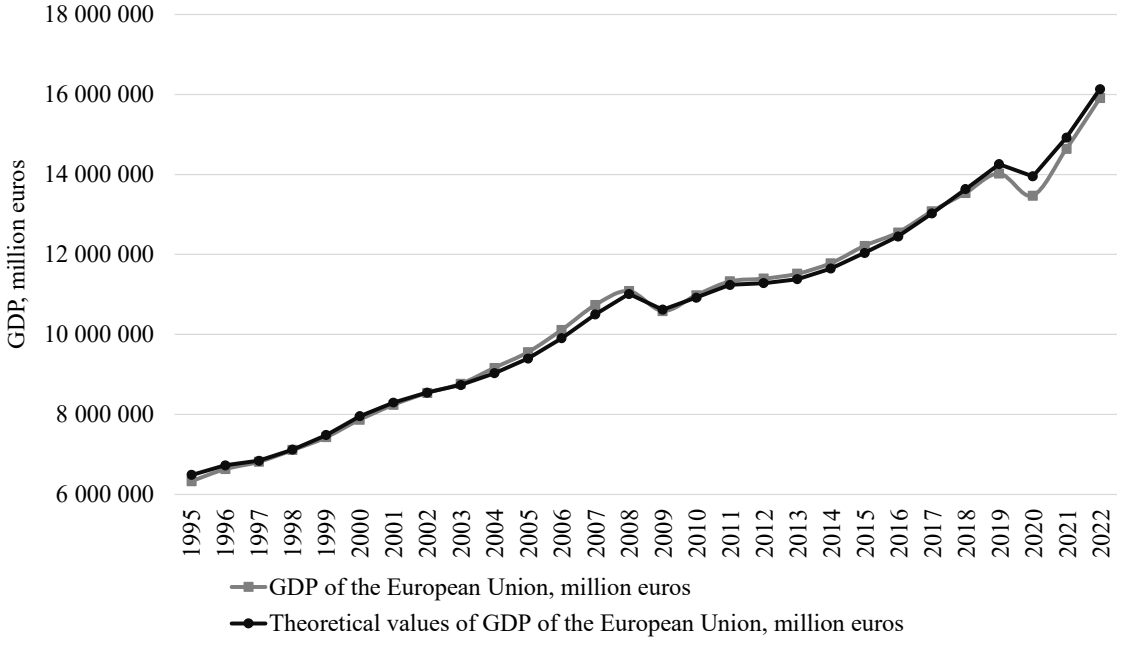

Fig. 1. Comparative dynamics of the actual values of the GDP of the European Union and the estimated values obtained on the basis of the model of the neoclassical production function, million euros

Taking into account the specified limitations, the following groups of indicators and their composition from sets, which are used to analyze the impact of the digital economy of society on the economic development of the European Union, are defined (Table 3).

Table 3

Groups of indicators for analyzing the impact of the digital economy of society on the economic development of the European Union

Indicator	Indicator content
Electronic commerce	Single digital market – promotion of e-commerce for individuals (percentage of individuals) E_c
	The share of turnover of enterprises accounted for by e-commerce (percentage of all types of activity, excluding the financial sector) E_e
	Enterprises that received orders online (percentage of all enterprises) E_o
	Natural persons who use the Internet to sell goods or services (percentage of persons) E_p
	Natural persons who use the Internet to buy goods or services (percentage of persons) E_i
Internet usage	Broadband internet coverage by speed (percentage of households) I_b
	Internet access level – households (percentage of households) I_h
	Persons who regularly use the Internet (at least once a week) (percentage of persons) I_p
	Persons who frequently use the Internet (daily or almost daily) (percentage of persons) I_c
International trade of ICT goods and services	Import of ICT goods and services (million USD) M_T
	Import of electronic data processing and office equipment (million US dollars) M_e
	Import of integrated circuits and electronic components (million USD) M_i
	Import of telecommunication equipment (million USD) M_c
	Export of ICT goods and services (million USD) X_T
	Export of electronic data processing and office equipment (million US dollars) X_e
	Export of integrated circuits and electronic components (million USD) X_i
	Export of telecommunication equipment (million USD) X_c
Electronic governance	Activity of individuals in e-government through websites (percentage of individuals) G_c
Internet banking	Natural persons who use the Internet for Internet banking (percentage of persons) B_c
Use of social networks	Persons who use the Internet to participate in social networks (percentage of persons) S_c
Employment of ICT specialists	Enterprises where ICT specialists work (percentage of enterprises) L_E

To determine the degree and direction of the systemic connection between the indicators of digitalization of the economy and society of the European Union and the parameters of the production function, as well as the selection of these indicators, a correlation analysis was conducted. The purpose of this stage is to determine and select those digitalization indicators that have a strong statistical relationship with the parameters of the production function. If such a connection exists, it will indicate that digitalization affects the productivity of labor, capital, technological development, and, accordingly, economic growth. As part of the correlation analysis, pairwise linear correlation coefficients were calculated, and the level of their statistical significance was determined. The statistical significance of the correlation coefficients was determined using the *t*-test, which depends on the sample size and the value of the correlation coefficient. After calculating the *t*-statistic, its values are compared with the *t*-critical values for the significance level $\alpha=0.05$. Under the condition of the *t*-statistic, more than the *t*-critical correlation coefficient is considered statistically significant, and the digitization indicator can be selected for further research. Table 4 gives the results of the correlation analysis.

Table 4

Indicators of correlation between indicators of digitalization and parameters of the production function

Digitalization indicator	A_t		K_t		L_t		*t*-critical
	r_A	*t*- statistic	r_K	*t*- statistic	r_L	*t*- statistic	
E_c	–0.884	5.336	0.935	7.469	0.963	10.126	2.228
E_e	–0.810	4.374	0.759	3.684	0.826	4.631	2.179
E_o	–0.684	2.963	0.862	5.388	0.910	6.958	2.179
E_p	–0.620	2.497	0.578	2.241	0.679	2.928	2.179
E_i	0.999	24.149	0.952	3.111	0.945	2.900	3.182
I_b	–0.875	5.111	0.948	8.452	0.970	11.213	2.228
I_h	–0.805	4.293	0.868	5.522	0.936	8.421	2.179
I_p	–0.828	4.668	0.908	6.840	0.963	11.279	2.179
I_c	–0.828	4.669	0.915	7.170	0.967	12.060	2.179
M_T	–0.175	0.815	0.876	8.303	0.895	9.218	2.069
M_e	0.262	1.243	–0.125	0.577	–0.069	0.319	2.069
M_i	–0.055	0.254	–0.012	0.053	0.073	0.334	2.069
M_c	0.071	0.326	0.233	1.098	0.369	1.821	2.069
X_T	–0.155	0.717	0.862	7.805	0.902	9.595	2.069
X_e	0.317	1.531	–0.185	0.865	–0.122	0.562	2.069
X_i	–0.065	0.297	0.011	0.050	0.069	0.317	2.069
X_c	0.164	0.763	0.094	0.432	0.228	1.072	2.069
G_c	–0.699	3.529	0.811	4.991	0.934	9.394	2.131
B_c	–0.870	5.576	0.917	7.288	0.969	12.361	2.179
S_c	–0.848	4.527	0.893	5.615	0.926	6.945	2.228
L_E	–0.363	1.170	0.586	2.171	0.551	1.978	2.201

The selection of digitization indicators was implemented based on the algorithm of the following actions:

1. Evaluation of the degree of connection and selection of the indicator, provided that the correlation coefficient is greater than 0.8, which corresponds to a high strength of connection according to the Chaddock scale.

2. Selection of the indicator subject to the fulfillment of the *t*-statistics criterion and, accordingly, its high values.

3. Logical analysis of indicators: determining the nature of the relationship, the importance of the digitization indicator for factors of economic growth, data availability, their completeness and reliability. Logical analysis also made it possible to substantiate the choice of digitization indicators for several parameters of the production function. On the one hand, it makes it possible to obtain a more accurate assessment of the impact of digitalization on economic growth, on the other hand, to exclude duplicate indicators.

Regression analysis was used to express the parameters of the production function through digitalization indicators. But due to the specified limitations imposed by the input

data, the use of traditional regression methods can be ineffective, especially under conditions of short samples and high multicollinearity between factors. All this, in turn, leads to non-statistically significant estimates of the coefficients of the regression model, its weak prognosticity, and the difficulty of interpreting the obtained results. Therefore, Elastic Net Regression was used to build multivariate linear regression models of the dependence of production function parameters on digitalization indicators.

Elastic Net Regression is a synthesized method of regulating and improving the quality of regression models [24, 25]. This method combines two regression models, Ridge and Lasso. The Ridge regression model allows one to solve the problem of multicollinearity between independent variables. And Lasso regression models help focus attention on the most important predictors that significantly affect the dependent variable, making the model more stable, compact, and interpretable. The use of Elastic Net Regression in this study made it possible to solve a number of tasks:

– to remove low-impact parameters from the model, which reduced the risk of overtraining and over-adaptation to the data sample;

– to reduce the multicollinearity of the factors because the group of factors characterizing the digitalization of the economy, which connects them together, was considered in the study. Also, almost all of these factors are increasing, which is explained by the expansion of digitalization in the economy, which also increased multicollinearity;

– to make models of the dependence of production function parameters on digitalization indicators statistically significant. This problem is related to the need to build multivariate models based on a short sample with a small amount of data;

– eliminate the instability of the coefficients and their significant influence on the interpolation results. Elastic Net Regression makes it possible to reduce the size of coefficients, which makes them more resistant to data changes.

According to the results of the regression analysis, the following final multivariate regression models were obtained:

$$A_t = 3.24 + 0.002E_c - 0.005E_e + \\ +0.002I_b + 0.006I_h + \\ +0.004I_c - 0.026B_c + 0.005S_c, \quad (10)$$

$$K_t = 445{,}507 + 10{,}384E_o + 1{,}636I_c + \\ +0.859M_T - 0.733X_T - \\ -30{,}007G_c + 6{,}941.8B_c + 43{,}269S_c, \quad (11)$$

$$L_t = 1{,}946{,}720 + 1.437I_b + 20{,}258I_c + \\ +0.67M_T - 0.67X_T - \\ -18{,}872G_c + 27{,}416B_c + 15{,}263S_c. \quad (12)$$

Analysis of the statistical properties of the models showed that the *R*-square for model (6) is 0.93, for model (7) it is 0.95, and for model (8) it is 0.99, which demonstrates the high predictive ability of the developed models.

According to the obtained neoclassical model of the production function for the European Union (4), as well as the developed models of the dependence of its parameters on the indicators of digitalization of the economy (6) to (8), we shall obtain the following model:

$$Y = \begin{pmatrix} 3.24 + 0.002E_c - 0.005E_e + 0.002I_b + \\ +0.006I_h + 0.004I_c - 0.026B_c + 0.005S_c \end{pmatrix} \times \\ \times \begin{pmatrix} 445507 + 10384E_o + 1636I_c + \\ +0.859M_T - 0.733X_T - 30007G_c + \\ +6941.8B_c + 43269S_c \end{pmatrix}^{0.1142} \times \\ \times \begin{pmatrix} 1946720 + 1.437I_b + 20258I_c + 0.67M_T - \\ -0.67X_T - 18872G_c + 27416B_c + 15263S_c \end{pmatrix}^{0.8784}. \quad (13)$$

The *R*-square for model (9) is 0.987, and the average error of approximation is 1.17 %. These indicators indicate a high predictive ability of the developed model.

It can be seen from the model that in some cases the coefficients of the model parameters have changed their signs compared to the signs of the correlation coefficients. This is due to the multicollinearity between the digitization factors, and Elastic Net Regression, as a regularization method, gives more accurate results than correlation analysis and reduces the effect of multicollinearity on the model and can change the signs of the coefficients.

6. Discussion of results of modeling the impact of digitalization on economic growth

The choice of the design of the model for studying the impact of digitalization on economic growth (7) and its practical implementation (10) to (13), as well as the inclusion of a set of digitalization factors in the model (13) can be explained by the following logical considerations. The inclusion in the model of indicators of the share of e-commerce turnover and enterprises receiving online orders demonstrates that e-commerce allows enterprises to scale and expand their sales markets. It also indicates the degree of adaptation of enterprises to the digital economy and their ability to integrate into the global digital space. This, in turn, increases sales and satisfies customer needs, as well as creates an increase in added value.

The inclusion of indicators of broadband Internet coverage by speed, the share of people who use the Internet frequently, and the level of Internet access of households to the model demonstrates the development of the infrastructure and is a necessary condition for the use of digital services. services. It is also evidence of the involvement of citizens in the digital society and the level of digital literacy.

The inclusion of indicators of import and export of ICT goods and services in the model, on the one hand, reflects the level of demand for digital technologies and services in the countries of the European Union, on the other hand, it reflects the degree of competitiveness of the countries of the European Union. That is, their ability to generate income from the sale of digital technologies, goods, and services.

The next indicator that confirms the digital transformation of the public sector and the expansion of the range of electronic services is the indicator of the activity of individuals in e-government through websites, which is also included in the model. An indicator of the percentage of people who use the Internet for Internet banking was included in the model, which reflects the level of public trust in the digitalization of the financial sector, as well as the level of development of digital skills among the population. The growing popularity of electronic payments leads to the acceleration of the circulation of funds in the economy and stimulates

economic development. The last indicator included in the model was the percentage of people using social networks, this indicator demonstrates the level of digital communication of society and its socialization. Although this indicator indirectly affects economic growth, it has a high predictive value regarding the level of digitization of society and its impact on the economy.

Thus, the proposed approaches to modeling and the model built make it possible to solve the research tasks and successfully achieve its goal. Thanks to the indicated approaches to modeling and the obtained practical result, it becomes possible to fill the gap in knowledge on this topic. Reasonable inclusion of the specified parameters in the model makes it possible to assess the influence of various aspects that reflect the state of development of the digital economy and society of the European Union on its economic growth. The use of this model allows obtaining more accurate and reasonable results and recommendations for the formation of strategies and tactics for further effective digital transformation in the European Union. And the conditions for applying the obtained research results are the availability of current statistical data on the development of the digital economy of the European Union, which are included in the model (13). Therefore, the research results and the developed model can be used as a tool for deepening understanding and decision-making regarding the development of the digital economy and society of the European Union.

The advantages of our research, compared to studies [2, 6–8], are that the developed model includes a wider range of digitalization factors. Also, unlike studies [3, 4], in which the authors suggest measuring digitization through aggregated indices, the model takes into account real processes and removes a number of limitations that were cited above.

The results of modeling the impact of digitalization on the dynamics of the economic development of the European Union allow us to draw the following general conclusions:

1. The increasing degree of digitization of the economy affects the level of efficiency of the use of physical capital and labor and, accordingly, economic growth. This may be due to the fact that with the penetration and spread of digital technologies, the nature of production changes and traditional factors of production become less efficient and productive. It is also necessary to take into account that digital technologies stimulate the creation of new types of production and change the structure of economic activity. The share of sectors that are less dependent on physical capital is increasing. Digital transformation also opens up new opportunities for the development of traditional sectors of the economy, for example, such as agriculture, medicine, education, and others. Intellectual capital, creativity, and innovation become the main levers of development under these conditions, while the need for physical capital decreases.

2. Automation and digitization of production, on the one hand, optimize production and organizational processes, reducing labor needs and increasing productivity, and on the other hand, intensify the processes of using technologies and equipment. This, in turn, leads to faster physical wear and tear on equipment, which in turn leads to higher maintenance costs. In addition, deep digitalization increases costs for personnel training, IT support and constant software updates.

3. Digital transformation increases the impact of globalization on countries' economies. The use of digital technologies makes the global business environment more interconnected, making it easier for companies to do business internationally. Under these conditions, physical capital and labor, which are less mobile resources, become less important, provided that the assets can be transferred to countries with cheaper labor and lower production costs. In addition, digital transformation and globalization are widening the gap in technology development between developed and developing countries.

4. Under the influence of digital technologies, new goods and services are created. Digital technologies change the product structure and the intensity of demand for goods and services, which stimulates the transformation and adaptation of physical capital and labor to changing consumer needs. Also, under these conditions, forms, business models and methods of trade are changing, namely, there is a transition from retail trade to electronic commerce, which does not require significant investments in physical capital. Also, digital technologies internationalize e-commerce, optimize internal processes, make it possible to use new technologies and methods of improving interaction with customers.

5. Digital transformation has an impact on the labor market, changing the requirements for the qualifications and skills of employees, and also leads to an increase in income inequality. Digitization is driving the development of the IT sector with more valuable occupations that have higher wages. Meanwhile, other professions are becoming less in demand. Also, digital transformation forms the growth of business dependence on IT specialists. This leads to an increase in unemployment and a gap in the incomes of the population, which in turn affects the purchasing power, savings, and investments.

6. Under the conditions of digital transformation, there is a transition from capital-intensive to knowledge-intensive production, that is, the role of human and intellectual capital is increasing. Digitization and artificial intelligence can solve many routine tasks, while specialists can focus on solving creative and innovative tasks. Under these conditions, continuity of training, acquisition of new knowledge, skills and adaptation of personnel becomes necessary and important.

7. Digital transformation contributes to the development of related industries involved in the production of digital goods and services. It stimulates the development of online education, online entertainment, 3D printing, telemedicine, social media, streaming services that use digital technologies. Also, digital technologies change the social domain, namely the ways of communication, interaction, affect the quality of life, culture, social structure of society, creativity, self-expression, and self-realization of individuality.

Therefore, the digital transformation has a profound impact on various aspects of the economy and society, including the issue of the efficiency of the use of physical capital, labor, and the dynamics of economic growth. It creates new challenges and opportunities for dynamic development, as well as significant resources and efforts for adaptation.

The limitations of this study include the content and quality of the available data sets, which limit the depth of research into digitalization processes in the European Union. And the main drawback is that the use of the neoclassical production function mostly theorized the study of the processes of economic growth.

It is worth paying attention to the following aspects, which can become the basis for the further development of this research, namely:

– use of the developed modeling method for the member countries of the European Union to study the features of digital development, as well as to determine the digital gap between these countries;

– addition and detailing of the developed model with new parameters of digitalization due to the filling of the data set;

– improvement of the stages of the modeling method in the context of the use of new methods and tools;

– research development in the context of studying cause-and-effect relationships between digitalization parameters and building a hierarchical model with a higher level of detail.

7. Conclusions

1. The models and methods of modeling the impact of digitalization on the economic growth of the European Union have been considered; four approaches to taking digitalization factors into account in models of the neoclassical production function were proposed. The choice of the design of the model, which, unlike the existing ones, makes it possible to determine the impact on key aspects of economic growth, namely capital, labor, and the overall efficiency of technologies, was justified. This allows us to focus on those aspects of digitalization that may have the greatest potential to stimulate economic growth.

2. A model for assessing the impact of digitalization on the economic growth of the European Union has been developed. To form the information base, twenty-one indicators were selected, which were classified into seven relevant groups describing the processes of digitization in the European Union. Correlation analysis was used to select indicators that affect the parameters of economic growth. Tests were conducted to determine the significance of the calculated correlation coefficients, which made it possible to select the key factors of digitalization that affect the parameters of economic growth. Elastic Net Regression was used to build the model, which made it possible to improve the quality of the regression model and include digitalization factors that have short time series and are multicollinear with each other. A feature of our eleven-factor model for assessing the impact of digitalization on the economic growth of the European Union is its high predictive ability (the coefficient of determination is 0.987). The results of our study provide an important contribution to the understanding of the impact of digitalization on economic growth.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The manuscript has related data in the data warehouses: Eurostat [21], Organization for Economic Cooperation and Development [22], World Bank [20].

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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