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IMPACT OF DIGITALISATION ON PRODUCTIVITY GROWTH IN EU MEMBER STATES

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Abstract. Recent economic studies on the relationship between digitalisation and economic growth show some ambiguity in the results due to the use of different methods, measures, country samples and time periods. The *purpose* of this article is to theoretically substantiate, build and econometrically test the model of the impact of digitalisation and other important factors on the growth of total factor productivity in the countries of the European Union for the period of recent years for which data are available. *Methodology*. The regression analysis of panel data with fixed effects was conducted. The regression estimation of the model is done for 27 EU countries and the entire European Union for the available periods 2017–2022. The robustness of the model to the choice of alternative regression methods, heterogeneity, autocorrelation and random effects is also tested. The model is based on the principles of the endogenous growth theory. The author substantiates and models the relationship of productivity growth with digitalisation, exports, imports, use of intellectual property rights, research and development, foreign investment, human capital and institutions; calculates the indicator of total factor productivity (TFP) based on the Cobb-Douglas function; the European Commission's Digital Economy and Society Index (DESI) is chosen as a measure of digitalisation. *Regression results.* It is proved that digitalisation is an important factor in productivity growth in the countries of the EU sample, which has a positive and significant impact on total factor productivity (a 1% increase in the digitalisation index leads to an increase in TFP by about 0.1%). Trade openness (exports and imports) was confirmed to remain a key factor affecting productivity. Income from the use of intellectual property rights has a positive, statistically significant impact on TFP growth, although the magnitude of this impact is rather small compared to the impact of digitalisation and trade. It has been found that the quality of institutions can be important for productivity growth, which is an argument for relevant reforms at the level of the government and local communities. The impact of research and development, foreign direct investment, and human capital on TFP growth is difficult to interpret due to the lack of statistical significance of these parameters, which requires further research.

Key words: economic growth, productivity, total factor productivity, digitalisation, Digital Economy and Societies Index (DESI), European Union, regression analysis.

JEL Classification: O33, O40, O47

1. Introduction

At the current stage of development of the world economy, technologies, including digital technologies, are considered to be a source of productivity growth. A number of economic studies on endogenous growth show that technological components can directly affect the growth of productivity, and then productivity, together with capital and labour, affects the growth of gross output (Lucas, 1988; Keller, 2004; Moskalyk, et al., 2014). In the economic literature, the measure of productivity is total factor productivity (TFP) (Coe et al., 1995). It therefore seems appropriate to examine the direct relationship between digitisation and TFP growth, as opposed to output growth.

The most recent empirical publications in the field of digitalisation show that digital technologies can have a positive impact on productivity through robotics, artificial intelligence, the development of communication networks, digital platforms, etc., leading to

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the modernisation of production, faster data processing, more effective management decisions, savings in transaction costs, etc. Daveri (2003) shows the growth of TFP in the US due to the adoption of information technology. Vu (2011) relates productivity to ICT adoption. According to Dahlman et al. (2016), the digital economy has the potential to increase the productivity of capital and labour. Katz (2017) notes a slowdown in productivity growth in the first decade of the 21st century. Rivares el al. (2019) attest to the growth in productivity due to the development of the digital platform market. Economist van Ark (2016) believes that the new digital economy has not yet shown an improvement in productivity growth in the United States, the United Kingdom and Germany, despite the rapid growth in business spending on ICT, digital capital and services. Amankwah-Amoah et al. (2021) are inclined to believe that while digitalisation can bring new opportunities, the process itself creates significant risks for firms that use traditional approaches and face the opportunism of employers. Furthermore, empirical studies use different measures of digitalisation, ranging from single indicators of the number of fixed or mobile broadband users to various indices, leading to controversial results (Moskalyk et al. 2021). Given the certain ambiguity of the results obtained by researchers due to the use of different methods, measures, samples of countries and time periods, it is important to examine the impact of digitalisation on productivity growth on the basis of a well-founded model, introducing a comprehensive measure of digitalisation, for a sample of a homogeneous group of countries and in recent years of dynamic development of the digital economy.

The purpose of this article is to theoretically justify, build and econometrically test a complex model of the impact of digitalisation and other important factors on total factor productivity growth in a group of European countries for the period of recent years for which data are available. The author develops a model of the relationship between productivity and digitalisation based on the theory of endogenous growth.

2. Model Justification

Coe et al. (1995) presented in detail the methodology for constructing an indicator of total factor productivity according to the Cobb-Douglas equation, relating real GDP to weighted indicators of labour and capital. According to Hulten (2001), TFP can be viewed as an unobservable (residual) quantity in the Cobb-Douglas production function, associated with technological innovation. For empirical purposes, TFP is determined for a specific country and time period (Formula 1):

$$A_{it} = Y_{it} / [K_{it}^{\alpha} \times L_{it}^{1-\alpha}], \qquad (1)$$

where A is total factor productivity, Y is gross output, K is capital, L is labor, i is a country, and t is a time period, a is a coefficient from 0 to 1, which means the value of each of the input factors in gross output.

The studies by Coe et al. (1995), Coe et al. (1997), Bayoumi et al. (1999) empirically confirmed that trade and technology play an important role in TFP growth in both developed and developing countries. Keller (2004) specified the methodology for investigating the impact of trade and technology variables on productivity growth, as well as variables of foreign direct investment, international licensing agreements on intellectual property rights. Another source of productivity growth can be a country's domestic R&D, although this indicator is considered more appropriate for a sample of developed countries, as R&D expenditure is often considered insignificant in most developing countries, assuming their domestic R&D capital is constant (Coe et al., 1997). In this article, the focus is on investigating the relationship between productivity and digitalisation in the European Union, so the variables of R&D and income from the use of intellectual property rights of these countries are introduced.

In addition, human capital is considered in the economic literature to be an important factor in productivity growth because it reflects the quality of a country's labour force, which processes intermediate goods, uses technology and other intellectual inputs obtained through foreign trade and other channels. Falvey et al. (2006) found that countries with higher levels of human capital benefit more from R&D output. A number of economic papers have identified the quality of institutions as an important determinant of economic growth in the world. Rodrik (2004) reports negative growth effects in countries with weak institutions. Dollar et al. (2003) debate the importance of institutions for growth, but lean towards the greater importance of trade. Glaesar et al. (2004) find that human capital is a more important source of growth than institutions (Glaesar et al., 2003, p. 279). To test the hypothesis about the role of human capital and institutions in productivity growth, the relevant indicators were included in the developed model of the impact of digitalisation on productivity growth.

Thus, according to the endogenous growth theory and recent prominent publications, TFP depends mainly on technology, including digital technology. To determine digitalisation, a comprehensive index of digitalisation is introduced – the Digital Economy and Society Index (DESI), developed by the European Commission for all 27 EU member states and the entire European Union, available for 2017–2022 (EU Digital Agenda Data, 2023). This index covers most aspects of digitalisation, is integrated from four sub-indices (including human capital, connectivity, integration of digital technologies, digital public services) and 32 indicators, contains justified weights of these indicators, applies to all spheres such as economy, society and government, and covers the period of COVID-19, during which digitalisation has developed rapidly. Considering the intention of Ukraine to fully integrate into the European Union, as well as the real steps of the Ministry of Digital Transformation of Ukraine in 2021–2022 to join the calculation of this index for Ukraine (EU4DigitalUA 2022), the DESI index of EU member states is particularly relevant for research. Therefore, the DESI index is the best available choice for regression analysis of the impact of digitalisation on economic growth.

3. Model of the Impact of Digitisation on Productivity

To summarise the above theoretical justification, the model of the impact of digitalisation on productivity growth is as follows: the dependent variable is the total factor productivity in logarithms (*lnTFP*), and for comparison, the calculated TFP index, where TFP in 2020 is equal to one (*TFP_ind*). The independent variables are:
– Digitalisation index – Digital Economy and Society Index (DESI), in logarithms ($\ln Digital_{it}$), statistical data source: EU Digital Agenda Data, 2023;
– exports, calculated as the share of exports of goods and services in GDP, in logarithms ($\ln E_{it}$), statistical data source: World Development Indicators, 2023;
– imports, calculated as the share of imports of goods and services in GDP, in logarithms ($\ln I_{it}$), statistical data source: World Development Indicators, 2023;
– payments for the use of intellectual property, receipts, USD current from the balance of payments, in logarithms ($\ln IPR_{it}$), statistical data source: World Development Indicators, 2023;
– human capital, calculated as an indicator of the labour force with higher education (% of the total working-age population with higher education), in logarithms ($\ln HC_{it}$), statistical data source: World Development Indicators, 2023.

Formula 2 illustrates the basic specification of the model.

$$\ln TFP_{it} = a_1 \ln Digital_{it} + a_2 \ln E_{it} + a_3 \ln I_{it} + \\ + a_4 \ln IPR_{it} + a_5 \ln HC_{it} + c_i + u_{it}, \quad (2)$$

where i is a country, t – year, c_i – fixed effect, and u_{it} is an idiosyncratic error.

To form an extended model, the following independent variables were added:
– Foreign direct investment, net inflows (% of GDP), without logarithms, as this indicator contains negative values (Inv_{it}), statistical data source: World Development Indicators, 2023;
– Research and development expenditures as a percentage of GDP in logarithms ($\ln RD_{it}$), statistical data source: World Development Indicators, 2023;
– Quality of institutions according to the Index of Economic Freedom in logarithms ($\ln Ins_{it}$), statistical data source: Heritage Foundation, 2023.

The extended specification of the model is as follows (Formula 3):

$$\ln TFP_{it} = a_1 \ln Digital_{it} + a_2 \ln E_{it} + \\ + a_3 \ln I_{it} + a_4 \ln IPR_{it} + a_5 \ln HC_{it} + \\ + a_6 Inv_{it} + a_7 \ln RD_{it} + a_8 \ln Ins_{it} + c_i + u_{it} \quad (3)$$

where i is a country, t – year, c_i – fixed effect, and u_{it} is an idiosyncratic error.

The method of least squares regression is used to analyse panel data with fixed effects. The fixed effect (c_i) allows to solve the problem of heterogeneity by country in the equation, taking into account certain characteristics of countries such as location, neighbourhood, etc., in order to overcome the problems of heterogeneity between countries in the estimated equation.

Equations (2)-(3) form the causal dependence of TFP on independent variables with fixed factors. It can be assumed that the model proves the causal effect of the digitisation rate on productivity growth, provided that the model is robust. The statistical data for all variables are collected for 2017–2022.

4. Selecting a Performance Variable

Table 1
Measurement of variable productivity: TFP in logarithms (ln*TFP*) or TFP index (*TFP_ind*)

	ln*TFP*	*TFP_ind*
ln*Digital*	0,099*** (4,00)	0,111*** (4,15)
ln*E*	0,775*** (8,94)	0,840*** (8,89)
ln*I*	-0,627*** (8,24)	-0,685*** (8,28)
ln*IPR*	0,018** (2,17)	0,019** (2,11)
ln*HC*	0,195 (0,98)	0,215 (0,99)
Constant	4,941*** (5,38)	-1,373 (1,37)
Prob > F (model)	0,0000	0,0000
The absolute value of the t statistic is given in parentheses.		
Statistically significant with a possible margin of error: * 10%; ** 5%; *** 1%		

Source: developed by the author using Stata, a fixed-effects panel data regression method

First, it is advisable to choose the dependent variable of TFP for the regression model – TFP in logarithms (ln*TFP*) or TFP index (*TFP_ind*). Table 1 shows that the parameters of the indicators are almost the same and statistically significant in both model specifications, although in specification (2), where the dependent variable is the TFP index, the coefficient of the constant loses statistical significance. Therefore, TFP in logarithms (ln*TFP*) was chosen as the dependent variable for further research.

5. Regression Estimation of the Model

The results of the regression estimation of the basic and extended model specifications cover 168 observations (28 countries and 6 years) and are presented in Table 2. It can be confirmed that the digitisation index has a positive and significant impact on labour productivity growth in the countries studied. A 1% increase in the digitalisation index leads to an increase in EU productivity by almost 0.1%. Moreover, the statistical significance of the digitalisation index in the first three specifications of the model is maximum (t-statistics 4.00, 3.93, 3.07), and in the fourth specification of the model with the addition of the institutional index, the statistical significance of the digitalisation index decreases to 1.43. Thus, it is possible to confirm the hypothesis that digitalisation is becoming the main driver of productivity growth.

As for the other systemic productivity factors, exports (ln*E*) have a significant and positive effect on TFP with high statistical significance, while imports (ln*I*) have a negative effect on TFP with high statistical significance. Revenues from intellectual property rights (ln*IPR*) have a positive and statistically significant impact on productivity in all model specifications, although the magnitude of the economic effect is smaller compared to digitisation and trade. The human capital indicator (ln*HC*) can have a positive

Table 2
Evaluation of basic and advanced model specifications

	(1) basic	(2) extended	(3) extended	(4) extended
	ln*TFP*	ln*TFP*	ln*TFP*	ln*TFP*
ln*Digital*	0,099*** (4,00)	0,097*** (3,93)	0,093*** (3,07)	0,040 (1,43)
ln*E*	0,775*** (8,94)	0,776*** (8,93)	0,779*** (8,84)	0,540*** (6,31)
ln*I*	-0,627*** (8,24)	-0,625*** (8,19)	-0,627*** (8,12)	-0,386*** (4,93)
ln*IPR*	0,018** (2,17)	0,018** (2,20)	0,018** (2,15)	0,027*** (3,51)
ln*HC*	0,195 (0,98)	0,206 (1,03)	0,214 (1,05)	0,177 (1,02)
In*v*		0,000 (0,65)	0,000 (0,68)	0,000 (1,56)
ln*RD*			0,010 (0,25)	0,021 (0,56)
ln*Ins*				0,033* (1,95)
Constant	4,941*** (5,38)	4,877*** (5,26)	4,856*** (5,20)	4,876*** (6,11)
Prob > F (model)	0,000	0,000	0,000	0,000
The absolute value of the t statistic is given in parentheses.				
Statistically significant with a possible margin of error: * 10%; ** 5%; *** 1%				

Source: developed by the author using Stata, a fixed-effects panel data regression method and economically significant impact on TFP, but the human capital coefficients do not reach the minimum statistical significance. It is also possible to confirm the positive impact of institutional quality on productivity growth, as predicted by the theoretical concepts of Dollar et al. (2003) and Glezar et al. (2004), although the coefficient of institutional index has a small economic value (0.033) and the minimum acceptable value of statistical significance (with a possible error of 10%). Overall, the results are consistent with economic theory and recent empirical research.

Regression testing did not reveal a statistically significant impact of foreign direct investment and R&D on labour productivity growth. In general, according to Keller (2004), FDI is more closely related to gross output (GDP) than to productivity (TFP), as investment mainly contributes to the creation of production. With regard to research and development, it can be assumed that there may be a time lag between investment in research and development projects and the benefits of these projects, which are not likely to be realised in the same year. These issues need to be studied in detail in the future.

6. Assessment of Model Robustness

It is advisable to apply other regression methods to test the robustness of the model of the impact of digitalisation on productivity growth. The following alternative methods are chosen (Table 3): (1) fixed effects method with Durbin-Watson test, which tests for autocorrelation of the regression model indicators; (2) fixed effects method with autocorrelation of residuals; (3) generalised least squares with random effects and Breusch-Pagan-Lagrange multiplier test, which tests whether random effects are important in panel data analysis.

Table 3 shows that the results of the alternative regression estimation (parameters and statistical significance) of the model indicators remain similar to the results of the main regression method of analysing panel data with fixed effects, which are presented in Tables 1 and 2. Thus, it can be assumed that the model of the impact of digitalisation on labour productivity growth is robust to estimates and acceptable for causal analysis.

7. Conclusions

After analysing the economic literature and empirical studies, a model of productivity growth was established. To measure productivity, the Cobb-Douglas function was applied and the Total Factor Productivity (TFP) indicator was calculated. Independent variables that affect TFP are: digitalisation index as Digital Economy and Society Index (DESI), trade, investment,

Table 3
Robustness test of the model of the impact of digitalisation on productivity

	(1) fixed effects method with the Durbin-Watson test	(2) fixed effects method with autocorrelation of residuals	(3) GLS with random effects and the Breusch-Pagan Lagrangian multiplier test
	ln*TFP*	ln*TFP*	ln*TFP*
ln*Digital*	0,111** (2,40)	0,106*** (2,93)	0,102*** (4,08)
ln*E*	0,836*** (9,95)	0,842*** (9,49)	0,772*** (8,97)
ln*I*	-0,643*** (9,08)	-0,654*** (8,70)	-0,648*** (8,33)
ln*IPR*	0,012 (1,41)	0,012 (1,34)	0,027*** (3,53)
ln*HC*	0,020 (0,10)	0,076 (0,36)	0,174 (0,87)
Constant	5,583*** (11,60)	5,383*** (7,60)	4,919*** (5,32)
Tests	Prob > F = 0,0000 rho_fov:0,98914615 sigma_e:0,03122143 sigma_u:0,29805134 rho_ar:0,50644557	Prob > F = 0,0000 rho_fov:0,98874125 sigma_e:0,03188747 sigma_u:0,29882455 rho_ar:0,28192832	Prob > F = 0,0000 Prob>chi2 =0,0000 chi2(1) = 356,38 Var(u) = 0
Observations	140	140	168
Countries	28	28	28
The absolute value of the t statistic is given in parentheses.			
Statistically significant with a possible margin of error: * 10%; ** 5%; *** 1%			

Source: developed by the author using Stata, a fixed-effects panel data regression method use of intellectual property rights, research and development, human capital and quality of institutions. The regression estimation of the model for the 27 EU countries and the European Union as a whole for 2017–2022 was carried out using a fixed-effects panel data analysis method. The robustness of the model to the choice of alternative regression methods, heterogeneity, autocorrelation and random effects was also checked. The main results of the regression estimation are as follows:

1. It is proved that digitalisation is an important factor in the productivity growth of the countries in the sample of EU countries, having a positive and significant impact on total factor productivity, namely, a 1% increase in the digitalisation index leads to an increase in TFP by about 0.1%.

2. It is confirmed that trade openness (exports and imports) remain key factors affecting productivity. Income from the use of intellectual property rights has a positive, statistically significant impact on TFP growth, although the magnitude of this impact is rather small compared to the impact of digitisation and trade. It was found that the quality of institutions can matter for productivity growth, which is an argument for relevant reforms at the government and local community level.

3. The results of the assessment of the impact of human capital, research and development, and foreign direct investment do not reach the minimum statistical significance, which does not allow to interpret their role in productivity growth. These issues require further research.

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