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ECONOMIC GROWTH MODEL: THE ROLE OF DIGITALIZATION

Most publications justify that digitalization is a source of economic growth, to a greater extent in the countries with higher levels of economic development. However, some papers fail to find empirical evidence supporting this claim, attributing it to digitalization being in its initial stages or to the presence of the digitalization paradox. Economic literature exhibits a degree of ambiguity in its conclusions regarding the role of the digital economy in growth. Researchers employ different measures of digitalization, country and year samples, control variables in regression equation, as well as different regression methods, which can provoke ambiguous effects on the parameters of digital variables. The purpose of the article is to identify the role of digitalization in economic growth by justifying an economic growth model with the digitalization index and providing detailed discussions on our sample of countries over recent years, along with options for regression estimators.

The article utilizes statistical data from the World Bank, European Commission, and Heritage Foundation. Methods such as system analysis, statistical analysis, and the regression estimator of panel data with fixed effects are implemented to identify the role of digitalization in economic growth.

We have designed an economic growth model incorporating the Digital Economy and Society Index (DESI) of EU member states for the years 2017-2022, utilizing available data. The results reveal a positive and significant causal effect of digitization on gross output growth. Specifically, a 1% increase in the digitalization index results in GDP growth of almost 0.2%. Moreover, we observe the important roles of capital, labor, trade, human capital, and intellectual property rights in driving growth, consistent with the theory of endogenous growth.

Proving the importance of digitalization for economic growth can be an argument for policies aimed at promoting digitalization. We suggest further research on the role of digitalization at a more disaggregated level of industries. However, our study does not demonstrate a statistically significant effect of research activity and institutional quality on gross output. We have discussed possible reasons for this and propose further research in these areas.

Keywords: economic growth, digitalization, digital economy, innovations, technologies, regression analysis

JEL classification: *O33, O40, O47*

Більшість публікацій стверджує, що цифровізація є джерелом економічного зростання, більшою мірою в країнах з вищим рівнем економічного розвитку. Однак деякі статті не знаходять емпіричних доказів ролі цифровізації, пояснюючи це тим, що цифровізація знаходиться на початковому етапі або присутністю парадоксу цифровізації. В економічній літературі існує

певна неоднозначність у висновках щодо ролі цифрової економіки в зростанні. Дослідники використовують різні показники цифровізації, вибірки країн і років, контрольні змінні в рівнянні регресії, а також різні методи регресії, які можуть спровокувати неоднозначний вплив на параметри цифрових змінних.

Метою цієї статті є визначити роль цифровізації в економічному зростанні, обґрунтовуючи модель економічного зростання з індексом цифровізації, а також детально обговорюючи вибірку країн за останні роки для аналізу та варіанти регресійних методів. Ля розрахунків використані статистичні дані Світового банку, Європейської Комісії, Heritage Foundation. Застосовані методи системного аналізу, статистичного аналізу та регресійної оцінки панельних даних із фіксованими ефектами для визначення ролі цифровізації в економічному зростанні.

Сформовано модель економічного зростання з індексом цифровізації DESI для країн ЄС 2017-2022 рр., за які є доступні дані. Доведено, що цифровізація має позитивний і значний причинно-наслідковий вплив на зростання валового виробництва. Підвищення індексу цифровізації на 1% зумовлює зростання ВВП майже на 0,2%. Виявлено також значний вплив капіталу, праці, торгівлі, людського капіталу та прав інтелектуальної власності на зростання. Ці результати сумісні з теорією ендогенного зростання.

Доведення важливості цифровізації для економічного зростання може бути аргументом на користь політики підтримки цифровізації. Запропоновано подальше дослідження ролі цифровізації на більш дезагрегованому рівні галузей. Наше дослідження не показує статистично значущого впливу дослідницької діяльності та якості інституцій на валовий випуск. Сформульовано можливі причини цього та напрямки подальших досліджень у цьому напрямку.

Ключові слова: економічне зростання, цифровізація, цифрова економіка, інновації, технології, регресійний аналіз

JEL classification: *O33, O40, O47*

Introduction and review of literature. The role of digitalization in driving economic growth worldwide constitutes a significant topic within economic literature. To study the mechanisms of the influence of digitalization on economic growth, it is important to substantiate the theoretical connections between digitalization and economic growth in order to form a theoretical model for the empirical assessment of such influence. An important challenge of our research is not just to identify regression-correlation relationships between digitalization and growth, but also to determine the causal effect of digitalization on economic growth and the magnitude of the effect in the countries of our sample. The results obtained can serve as a basis for policies aimed at full-fledged and comprehensive digitization of the economy, as well as overcoming possible negative effects and shocks for certain industries, professions and segments of the population.

Economists have been studying the impact of digitalization on economic growth since the 1980s, when computers began to spread. In particular, for the period 1987-1999, the average annual GDP growth in the world was 0.3% due to computerization [1]. With the advent of 3G mobile Internet, scientific research has intensified again. According to a PWC study, global GDP increased by 45% during 2000-2010 due to the spread of 3G Internet [2].

Avotra et al. (2021) argue about a gradual process of digitalization, which can be divided into three waves of technological and innovative changes [3]. We will analyze the effects of the first wave of digitalization on economic growth. Back in the mid-1990s, the Internet boom began which changed the way businesses operate and catalyzed advancements in transaction methods. At that time computers became widely used in business sectors and management. In the first wave of digitalization, computing, broadband and mobile networks played an important role in helping business scale up, allowing traditional sectors of the economy to grow faster. Digital technologies have made it possible to further satisfy additional final demand and thereby stimulate additional production, demand for resources and labor. Atkinson et al. (2009) demonstrated productivity gains as a result of implementing

more efficient business processes supported by ICT, as well as excess inventory marketing and supply chain optimization [4]. Lehr (2006) proved revenue growth due to increased access to new markets and business scaling [5]. Digitalization has also had a positive impact on the structure and deployment of industrial value chains. Firms have been able to attract workers from other regions thanks to the ability to process information and provide services remotely. Abramovsky et al. (2005), on the example of British firms, found that the use of broadband Internet increases the probability of offshore transferring business processes and services by 6-12% in order to optimize costs [6]. Crandall at al. (2007) showed the growth of some types of services, in particular, software development and business process outsourcing [7]. Clark (2008), testing countries in Eastern Europe and Central Asia, found that manufacturing companies with access to broadband Internet generated 6% more foreign sales than other companies [8]. The ability of broadband Internet to increase the market and find the highest possible selling price in open economies is an important advantage for economic growth. In both industry and services, broadband Internet improves export performance by facilitating communication with foreign buyers, improving information about foreign markets, consumers and standards, and ultimately connecting business to consumers, as well as enabling active engagement on business-to-business platforms. Thus, Katz and Callorda (2018) showed that an increase in the digital economy development index by 1% leads to an increase in GDP per capita by 0.13%, and this effect is higher for OECD countries than for developing countries [9]. Hence, the level of development of a country emerges as a crucial factor in reaping the maximum benefits from digitalization. It was also found that ICT has a positive effect on the development of new enterprise ventures. Crandall et al. (2007) estimated that the introduction of a broadband Internet network could yield a multiplier effect of 1.17 on infrastructure investment [7].

At the beginning of the second wave of digitalization, economic growth was supported by the emergence of new digital services and programs [10]. All this became possible due to the intensive spread of Internet technologies and the rapid growth in the number of Internet users, primarily driven by the advent of smartphones supporting Internet communication. The increase in the number of Internet users exerted a significant impact on economic growth and the behavior of firms. Sturgeon (2021) believes that the main characteristic of the digital economy is its liberation of businesses from dependence on geographical location, thereby removing superior location from the list of competitive advantages [11]. However, a new dependence on digital technologies, such as mobile devices, websites, smart contracts, and cloud computing, has emerged. Yun et al. (2020) describes digital transformation as the destruction of traditional business models and industries, wherein digital technologies become a catalyst for changing business strategies [12]. An example of this transformation is the emergence and successful development of e-commerce, which has altered the relationships between consumers and businesses. The primary advantage for consumers is the accessibility of inexpensive goods and services, facilitated by the ability to compare prices with a single click. In 2021, global e-retail sales reached USD 4.9 trillion, with a significant expansion of mobile commerce [13, P. 4]. Sellers received significant savings retail premises rent and personnel costs. China led e-commerce retail sales in 2021, accounting for 43% of total retail sales, followed by the United Kingdom at 35%, South Korea at 28%, the USA at 15%, Japan at 12%, and Germany at 11% [14]. In Latin America, according to Chevalier (2023), the most common e-commerce platform, Mercado Libre, had approximately 148 million active users in 2022 (5.7% more than in 2021) offering their goods online and creating additional employment opportunities [15].

In addition to the initial stimulus, empirical studies confirm a second innovation resulting from the combined adoption of

platforms, broadband Internet, and cloud services. At the same time, the development of local platforms and applications in native languages has become widespread. These local platforms and applications offer numerous advantages, including the strengthening of national culture, the elimination of foreign trade imbalances, the development of local digital infrastructure, and the generation of employment opportunities. The development of local digital content contributes not only to the development of the domestic industry of content and applications, but also to the satisfaction of the needs of the population.

Vu (2011) attests to the significant contribution of the ICT-based digital economy to GDP growth, ranging from 0.1 to 1.0 percentage points with an upward trend after 1995 [16]. Evans et al. (2012) demonstrated that the global commercial aviation industry can save approximately 2 billion US dollars per year due to improved maintenance resulting from Internet utilization [17]. At the same time, economist van Ark (2016) believes that despite the rapid growth of business spending on capital and services in the ICT sector, the new digital economy has not yet brought a noticeable improvement in growth, using the examples of the United States, Great Britain and Germany [18]. Gebauer et al. (2020) point out that companies often face the digitalization paradox, wherein they invest in digitalization but often fail to increase expected profits [19].

In the second decade of the XXI century, a number of studies, including those by Hofman et al. (2016) [20] and Pradhan et al. (2019) [21], have showed that the digital economy can stimulate economic growth in both developed and developing countries. Other economists argue that the digital economy represents a new development model wherein the trajectory of economic growth is changing. According to Pan et al. (2022), digital industries influence changes in the economy structure contribute to increased employment, thus stimulating economic growth [22]. Yu et al. (2022) demonstrate on the example of China that the digital economy plays a significant role in high-quality development primarily through the enhancement of innovation activity and the stimulation of consumer spending [23]. Szeles et al. (2020) [24] report a positive effect of the digitization index on gross output growth.

Digital technologies can have a much wider impact on economic growth; however, due to limitations related to the human factor, this effect may be weakened. The use of the latest technologies may be hindered for various reasons: inconsistency or limitation in the relevant digital skills of employees; incomplete understanding of the advantages offered by digital technologies, and institutional inertia within company management [25]. Overcoming these obstacles could generate additional effects of digitalization on economic growth in the coming years.

The third wave of digitization is characterized by advancements in artificial intelligence, the Internet of Things, robotics, big data analysis, and machine learning. The implementation of these innovations requires large-scale changes in operational processes and organizational structure, as well as employee training (accumulation of intangible capital). The expansion of the third wave of digitalization can yield significant positive effects on economic growth. At the same time, many of these innovations raise fundamental questions about employee resistance, lack of management awareness, and even ethical considerations [10]. These factors may temporarily delay the actual economic impact that the third wave of digitalization will have.

Assuming a mass adoption of the third wave of digitization takes place within a decade, it can be assumed that the economic impact will be significant due to increased efficiency. First, if operating costs are significantly reduced, it is likely that at least some of these savings will be passed on to consumers in the form of lower prices, thereby benefiting them. Second, the third wave of digitalization can reverse the trend towards offshore multinational corporations and fundamentally change global production chains. This could reduce the incentive for

globalization within the automotive value chain, leading to significant changes in the geographic division of labor.

The pandemic caused by the corona virus disease COVID-19 has significantly increased the attention of scientists towards assessing the role of the digitalization in economic development. According to Fang et al. (2022), digital industries have been given a chance to boom by rapidly meeting the new needs of online consumers [26]. A number of scholars suggest that the digital economy plays a positive role in preventing and controlling crisis phenomena, distributing of added value in global value chains, and fostering economic development [27]. Zhang et al (2022) believe that during the COVID-19 pandemic, digital services received a significant share of resources reallocated from traditional industries, thus becoming a powerful engine for accelerated growth [27].

Myovella et al. (2019) examined the relationship between digitalization and economic growth in sub-Saharan Africa and the OECD and found a positive contribution of the Internet to economic growth for both groups of countries. However, they noted that the effect for African countries was smaller compared to OECD countries due to underdeveloped infrastructure in Africa [28]. We agree that digitalization can play a significant role in economic growth, but its impact may vary depending on a country's level of development. Quantitative assessments of the impact of digitization on the economic growth of Ukraine and some other Eastern European countries (except EU member states) are quite limited due to the lack of comprehensive indices of digitization, which poses challenges for further research.

Given the relative novelty of the phenomenon of the digital economy, there are certain discrepancies in the conclusions regarding its effects on growth in the modern economic literature. Additionally, there are discrepancies in methodologies used for empirical assessments, and quantitative studies of the mechanisms through which the digital economy influences economic growth are still limited. Some empirical studies focus on measuring digitalization by indicators such as the number of Internet users, fixed broadband Internet users, and mobile subscribers. These indicators cannot fully capture the broader manifestations of the digital economy. In addition, the results of assessments regarding the impact of digitalization on economic growth are mixed. Authors employ different model specifications to evaluate the impact of digitalization on growth, incorporating different control variables into the regression equation, which can lead to ambiguous effects on the parameters of «digital» variables. Moreover, the problem of endogeneity in the regression equation when assessing the impact of digitalization indicators on growth is obvious, prompting the question of which regression estimators can be used to solve this problem.

Thus, on the basis of the existing literature, we found that the mechanism of the digital economy's influence on economic growth is complex and can yield a positive effect on growth when combined with the development of human capital, investments in research and development, or the incorporation of foreign technological transfers and knowledge. As evidenced by recent empirical studies, the positive effect of digitalization on economic growth is more pronounced in countries with higher levels of economic development. At the same time, the results of many studies remain ambiguous, necessitating further evidence using advanced digitalization indices. Accurate measurement of the digital economy, based on comprehensive indices, is essential for quantifying its impact on growth. In addition, economic growth models should be specified to include all significant indicators that systematically affect growth. Moreover, it is important to analyze endogeneity problems and propose regression methods to address this issue.

The purpose of this article is to investigate the causal effect of the digitization index, along with other important systemic determinants, on economic growth in a broad sample of countries over a period of time, depending on available data. We will

turn to the theory of endogenous growth (the theory of new growth) as well as empirical studies on digitalization and growth. Given the limited empirical evidence supporting the theory of endogenous growth, we aim to identify new empirical justifications for this theory in the context of the impact of digitalization on economic growth.

As we have already justified above, theoretical publications on economic growth reveal complex and diverse connections between technologies, digitalization and growth. Moreover, empirical evidence is mixed. Nevertheless, we believe that digital technologies themselves, along with their active utilization, increasingly contribute to the technological advancement of a country, thereby fostering its economic growth.

According to the economic literature most economists generally agree that digitalization contributes to economic growth through the use of digital technologies and the Internet. This includes business scaling, faster processing of big data, savings on transaction costs, and the use of robotics and artificial intelligence in the production of goods and services. However, recent publications testify to the heterogeneity of empirical results. Numerous empirical studies have been conducted to examine the relationship between digitalization (measured only by broadband or mobile users or digitalization indices) and growth, but they have shown different, often controversial results [10]. In theory, digital technologies have every reason to contribute to economic growth, but it may take time for users to master and apply them in the economy. The heterogeneity of results in empirical papers can be explained by different approaches to country selection, analysis periods, model specifications, regression analysis methods, and endogeneity issues in the estimated equations. Srinivasan and Bhagwati (1999) argue that growth regressions are too simplified and contain too much measurement and specification error to be taken seriously, suggesting instead the use of "detailed country-level analysis" [29]. However, Rodriguez (2007) notes that while the results of regression analysis may be incomplete, they are not to be considered inappropriate [30]. While a positive relationship between digitization and growth may indeed exist, many empirical studies fail to capture it, primarily because the information contained in the data is not sufficiently robust.

An important challenge for our study is to substantiate the reasons for the heterogeneity of results. In our opinion, the first fundamental reason for the mixed empirical evidence on the relationship between digitalization and growth lies in the choice of measure of economic growth. Many empirical works investigating the impact of digitalization and growth use GDP or GDP growth rates as a dependent variable, and show a positive relationship between digitalization and growth in gross output [27]. We implement in our model the dependent variable as GDP in logarithms to standardize the units of measurement, ensure greater stability of the model, and narrow the range of variables to a smaller value, which will reduce the sensitivity of estimates to extreme or atypical observations. In general, logarithmization should be applied to both dependent and independent variables.

A second reason for the mixed results may be the difficulty of measuring digitization. Some studies implement approaches to measuring digitization such as Internet users or some designed digitalization indices. We contend that some of these metrics may contain measurement errors and reflect only some part of digitization. We consider the Digital Economy and Society Index (DESI) developed by the European Commission for all 27 EU member states along with the index for the entire European Union for the period 2017-2022. The DESI index includes various manifestations of digitalization, including indicators of digitalization of business, society and government, making it, in our opinion, the most comprehensive measure of digitization [31]. In addition, the government of Ukraine is working on implementing the DESI index for our country [32], even in times of war. We implement the DESI index to examine the impact of digitalization on gross output growth in our study.

The third reason is that some econometric models do not reliably test causality and endogeneity. In our study, we use econometric methods of panel data analysis with fixed effects to solve these problems. In addition, we test our models for robustness using Durbin-Watson tests to assess autocorrelation in the model, autocorrelation of residuals, and the Breusch and Pagan Lagrange multiplier test to detect the importance of random effects in the model. By establishing the robustness of our model, we can infer a causal effect of digitalization on growth.

The fourth reason pertains to the possible inaccuracy of model specification. According to the economic literature, we believe that various determinants of growth, including trade, foreign direct investment (FDI), research and development, use of intellectual property rights, human capital, and institutions, along with measures of digitalization, have a significant impact on economic growth in a country. Additionally, the growth of gross output is primarily influenced by key inputs such as capital and labor. Some of these factors may not have been included in the regression analysis in some previous studies due to data limitations or other considerations. Rodrik et al. (2004) report negative effects on growth in countries with weak institutions that are unable to respond appropriately [33]. Dollar et al. (2003) debate the importance of institutions for growth but lean towards the greater importance of trade [34, p. 161]. Glaesar et al. (2004) note that "human capital is a more important source of growth than institutions" [35, p. 279]. To test the hypothesis about the role of institutions in economic growth, we include in our model the Index of Economic Freedom, published by the Heritage Foundation [36], as an indicator of the development of institutions in the countries of our sample.

Thus, based on economic theory and recent empirical studies, we construct a model of economic growth. In this model, the dependent variable for the countries in our sample is the annual GDP indicator measured in logarithms. The independent variables include the DESI digitization index, capital, labor force, exports, imports, foreign direct investments, human capital, use of intellectual property rights, internal research and development, and an index of institutional quality.

Data and Methods. We examine the causal relationship between digitalization and economic growth within a group of 28 entities (comprising the 27 EU member states plus the entire European Union) during the period 2017-2022, for which DESI indices are accessible. Panel data analysis employing the fixed effects method is utilized to address issues of country-level heterogeneity.

In econometrics, the regression method of two-stage least squares with instrumental variables (2SLS with IV) has been developed to address the issue of endogeneity resulting from the omission of a time-varying indicator or simultaneity problems. To employ this method, it is necessary, first and foremost, to identify appropriate instrumental variables for the digitization indicator. These instruments should exhibit correlation with the variable of interest (digitalization index) while remaining uncorrelated with the dependent variable (economic growth). According to Keller (2004), finding IV for technology indicators that meet these criteria is extremely difficult or even impossible [37]. Therefore, in our study we reject the 2SLS regression method with IV and focus only on the regression method of panel data with fixed effects (panel data regression with fixed effects) with additional testing our model robustness. We employ logarithmic-linear model specifications: base and extended.

We present the base specification in equation (1), which correlates GDP, constant 2015 US$, in logarithms (ln*GDP*) of the EU member states to the following independent variables:

(1) Digital Economy and Society Index (DESI), in logarithms (ln*DESI*);

(2) capital, measured as gross fixed capital formation in constant 2015 US$, in logarithms (ln*Capital*);

(3) labor force, total, in logarithms, ln*Labor*;

(4) exports, measured as exports of goods and services, % of GDP, in logarithms (ln*EXPORT*);

(5) imports, measured as imports of goods and services, % of GDP, in logarithms (ln*IMPORT*);

(6) foreign direct investment, net inflows, % of GDP, without logarithms, as some values of the indicator are negative and therefore logarithms are not possible (*FDI*);

(7) human capital, measured as labor force with higher education, % of the total population of working age with higher education, in logarithms (ln*HumCap*).

The base specification of the model looks like this:

$$\ln GDP_{it} = a_1 \ln DESI_{it} + a_2 \ln Capital_{it} + a_3 \ln Labor_{it} + a_4 \ln EXPORT_{it} + \\ + a_5 \ln IMPORT_{it} + a_6 FDI_{it} + a_7 \ln HumCap_{it} + c_i + u_{it}, \quad (1)$$

where *i* means countries, *t* means time periods; c_i – unobserved fixed effect (by country); u_{it} – idiosyncratic errors.

The extended model covers a wider list of factors that we have theoretically justified above. Therefore, we include in the analysis the following additional indicators for the countries of our sample:

(1) charges of use of intellectual property, payments, current US dollars from the balance of payments, in logarithms (ln*RoyaltyPay*);

(2) charges of use of intellectual property, receipts, current US dollars from the balance of payments, in logarithms (ln*RoyaltyRec*);

(3) expenditure on research and development as a percentage of GDP, in logarithms (ln*R&D*);

(4) researchers in research and development per million people, in logarithms (ln*Researchers*);

(5) the quality of institutions, measured as the Index of Economic Freedom, in logarithms (ln*IEF*).

DESI statistics were taken from EU Digital Agenda [31], Index of Economic Freedom – from Heritage Foundations [36], all other indicators from – World Development Indicators [38].

The extended specification of the model looks as follows:

$$\ln GDP_{it} = a_1 \ln DESI_{it} + a_2 \ln Capital_{it} + a_3 \ln Labor_{it} + a_4 \ln EXPORT_{it} + a_5 \ln IMPORT_{it} + \\ + a_6 FDI_{it} + a_7 \ln HumCap_{it} + a_8 \ln RoyaltyPay + a_9 \ln RoyaltyRec_{it} + a_{10} \ln R\&D_{it} + \\ + a_{11} \ln Researchers_{it} + a_{12} \ln IEF_{it} + c_i + u_{it} \quad (2)$$

where *i* means countries, *t* means time periods; c_i – unobserved fixed effect (by country); u_{it} – idiosyncratic errors.

The problem of country heterogeneity (c_i) in equations (1)-(2) means that a correlation between the digitization index some country-specific characteristics (location, neighboring countries etc.) is possible. The equations formed entail a causal interpretation, due to the retention of fixed factors in exogenous indicators and ci, an exogenous effect in the digitization index is modelled, affecting the dependent variable of GDP.

Base model results. Our estimation results and main tests of the base model are illustrated in Table 1. It can be proven that the DESI digitization index exhibits a significantly positive causal effect on GDP in the countries within our sample, with sufficient statistical significance. Moreover, across all three of our base regression models, the economic value (0.169, 0.161 and 0.164) and statistical significance (t statistic 6.83, 7.11 and 7.24) of the DESI digitization index remain significant and practically constant. These findings provide compelling evidence in support of the main hypothesis that digitalization is a key determinant of gross output growth. When the DESI digitalization index increases by 1%, the GDP of the EU member states grows by almost 0.2%.

From the estimation results of our three base specifications, we can confirm that traditional inputs such as capital and labor are important drivers of gross output growth for the countries in our sample. An important result is that statistically significant exports have a significantly positive impact on GDP, while imports exhibit a statistically significant negative effect on GDP, consistent with economic theory. Moreover, human capital demonstrates a substantial positive effect on GDP growth (0.327), albeit with statistical significance at the minimum acceptable level of 10%.

Extended model results. The results of the evaluation of the extended model, as well as its main tests, are presented in Table 2.

Table 1

Base model results, panel data regression with fixed effects, least squares method

	(1) base	(2) base	(3) base
	ln*GDP*	ln*GDP*	ln*GDP*
ln*DESI*	0.169***(6.83)	0.161***(7.11)	0.164***(7.24)
ln*Capital*	0.109***(2.65)	0.217***(5.56)	0.221***(5.68)
ln*Labor*	0.587***(4.74)	0.279**(2.56)	0.224**(1.99)
ln*Export*		0.718***(8.07)	0.726***(8.20)
ln*Import*		-0.511***(6.37)	-0.508***(6.37)
FDI			0.000 (0.84)
ln*Hum_Cap*			0.327*(1.77)
Constant	13.902***(6.87)	15.095***(8.94)	14.375***(8.30)
Observations	168	168	168
Countries	28	28	28
R-squared	0.55	0.70	0.71
Prob > F (model)	0.0000	0.0000	0.0000
The absolute value of the t statistic is in parentheses			
* significant at 10%; ** significant at 5%; *** significant at 1%			

Source: estimated by the authors, using the Stata program module - xtreg

Table 2

Extended model results, panel data regression with fixed effects, least squares method

	(1) extended	(2) extended	(3) extended
	ln*GDP*	ln*GDP*	ln*GDP*
ln*DESI*	0.141***(6.22)	0.147***(4.84)	0.048*(1.78)
ln*Capital*	0.212***(5.68)	0.211***(5.62)	0.238***(7.40)
ln*Labor*	0.159 (1.44)	0.160 (1.45)	-0.007 (0.07)
ln*Export*	0.696***(8.17)	0.688***(7.94)	0.474***(6.55)
ln*Import*	-0.489***(6.38)	-0.479***(6.13)	-0.242***(3.54)
FDI	0.000 (1.01)	0.000 (1.15)	0.000**(2.15)
ln*Hum_Cap*	0.410**(2.30)	0.458**(2.50)	0.461***(3.14)
ln*RoyaltyPay*	0.029***(2.63)	0.028**(2.51)	0.014 (1.08)
ln*RoyaltyRec*	0.019***(2.69)	0.017**(2.42)	0.025***(3.87)
ln*R&D*		0.053 (1.13)	-0.014 (0.35)
ln*Reseachers*		-0.066 (1.05)	0.077 (1.48)
ln*IEF*			-0.014 (0.97)
Constant	14.333***(8.56)	14.682***(8.56)	15.912***(10.64)
Observations	168	168	158
Countries	28	28	28
R-squared	0.74	0.74	0.80
Prob > F (model)	0.0000	0.0000	0.0000
The absolute value of the t statistic is in parentheses			
* significant at 10%; ** significant at 5%; *** significant at 1%			

Source: estimated by the authors, using the Stata program module - xtreg

A noteworthy finding is that the use of intellectual property, mainly receipts, in the three extended specifications has a positive effect on GDP growth with high statistical significance. However, the economic impact of this effect is relatively insignificant compared to the effects of digitization index, capital, labor, and trade. At the same time, the parameters of research and development expenditure, the number of researchers, and the index of the institutions quality (Index of Economic Freedom) are statistically insignificant, hindering our ability to interpret their relationship with GDP. The low statistical significance of these indicators can be explained by certain noises in the model, suggesting the potential usefulness of exploring alternative measures for these determinants. In particular, our institutional variables only partially capture the institutions quality, and may also be endogenous and cause the problem of reverse causality between institutional improvement and growth (the scientific debate on these issues is revealed in the papers of Glaesar et al. (2004) [35], Kaufmann et al. (2007) [39]). While we believe it is worthwhile to pursue further research in the future, it's worth noting that our extended model appears to be relatively insensitive to variations in the quality of institutions or their omission.

Model robustness testing. We carry out some alternative and comparative estimations to test the robustness of our base model specification determining the causal relationship between digitalization and GDP growth of 28 EU entities over 6 years. We estimate our model using alternative estimators resistant to autocorrelation and random effects. The results of alternative assessment of models are given in table. 3.

Table 3

Robustness testing of the base model, panel data regression with fixed and random effects with a set of tests

	(1) Regression with Fixed Effects, AR (1) disturbance, Durbin-Watson test	(2) Regression with Fixed Effects, AR (1) disturbance, Autocorrelation of Residuals	(3) GLS with Random Effects, Breusch-Pagan Lagrangian multiplier test
	ln*GDP*	ln*GDP*	ln*GDP*
ln*DESI*	0.070*(1.74)	0.114***(3.81)	0.125***(4.69)
ln*Capital*	0.134***(3.93)	0.133***(3.52)	0.420***(10.75)
ln*Labor*	0.482***(2.83)	0.378**(2.56)	0.606***(12.24)
ln*Export*	0.633***(8.74)	0.656***(8.13)	0.815***(8.38)
ln*Import*	-0.323***(4.64)	-0.368***(4.87)	-0.688***(7.56)
FDI	0.000 (1.62)	0.000 (1.26)	0.000 (0.36)
ln*Hum_Cap*	0.042 (0.24)	0.135 (0.76)	0.100 (0.46)
Constant	13.784***(12.19)	14.913***(9.41)	5.128***(4.40)
Tests:	rho_ar: 0.54231656, sigma_u: 0.85336389, sigma_e: 0.02504015, rho_fov: 0.99913974, Prob > F = 0.0000	rho_ar: 0.27071811, sigma_u: 0.98622014, sigma_e: 0.0261142, rho_fov: 0.99929935, Prob > F = 0.0000	Var(u) = 0 chi2(1) = 322.26, Prob > chi2 = 0.0000, Prob > F = 0.0000
Observations	140	140	168
Countries	28	28	28
The absolute value of the t statistic is in parentheses			
* significant at 10%; ** significant at 5%; *** significant at 1%			

Source: estimated by the authors, using the Stata program module - xtregar, xtreg, xttest0.

As can be seen from Table 3, the parameters and statistical significance of the digitization index and our other determinants of GDP growth remain similar to the regression testing of panel data with fixed effects as presented in Tables 1 and 2. This consistency indicates the robustness of our model, providing further evidence of the positive impact of digitalization on gross output growth and affirming the validity of our model.

Conclusions. The mechanism through which the digital economy influences economic growth is complex, facilitating a positive effect on growth when coupled with advancements in trade, human capital, research and development, utilization of intellectual property rights, and institutional development. As evidenced by recent empirical studies, the positive effect of digitalization on economic growth can be found to a greater extent in countries with a higher level of economic development. At the same time, the results of many studies are ambiguous, underscoring the need for further validation through a robust model of economic growth incorporating a comprehensive index of digitalization.

Based on economic theory and recent empirical research, we develop a model of gross output growth, with GDP serving as the dependent variable for the countries in our sample. The independent variables include the DESI digitization index, capital, labor force, exports, imports, foreign direct investment, human capital, use of intellectual property rights, domestic research and development, and the index of institutions quality.

Our paper examines the causal effect of digitization on gross output growth across a large sample of countries. We incorporate the DESI digitization index into the regression analysis. For a group of 27 EU member states and the entire European Union for the period 2017-2022, we estimate the equation of each country's GDP in relation to its digitization index and other significant systemic factors. These relationships are estimated using regression analysis of panel data with fixed effects, along with robustness testing of our model.

Our main empirical results are:

1. Digitization, which we measure as the DESI index calculated by the European Commission for EU member states, has a positive and economically large causal effect on gross output growth, with high statistical significance. Digitization is a key determinant of economic growth. When the DESI digitization index increases by 1%, the GDP of EU member states increases by almost 0.2%. This conclusion is compatible with the theory of endogenous growth. We can propose further research on the phenomenon of digitalization and its impact on economic growth at a more disaggregated level of industries.

2. to enhance their level of trade openness tend to experience higher GDP growth rates. This conclusion is compatible with the theory of endogenous growth and other empirical works. So, we can empirically prove that trade remains the main determinant affecting the growth of gross output of highly innovative countries of the world.

3. Effective use of intellectual property rights, particularly in the form of income from international license agreements, can have a can positively impact gross output growth. However, the economic effect of this indicator on growth in the countries of our sample is obviously smaller in magnitude compared to the effects of digitization and trade.

4. A higher level of human capital can positively and significantly influence the growth of gross output. This finding aligns with economic theory and contemporary empirical studies.

5. Capital, labor and foreign direct investment have a positive and significant effect on the growth of gross output, which is fully consistent with economic theory.

6. The level of institutional development can potentially impact on GDP growth, but the lack of statistical significance for the institutions parameter in the regression prevents us from asserting this. Our measure of institutions, the Index of Economic Freedom, may not capture all the characteristics of institutional quality relevant to economic growth. Perhaps other measures of institutional quality should be considered, which is the subject of further research.

7. We do not observe a statistically significant impact of R&D on GDP. Despite our attempts to introduce two alternative

measures of domestic R&D, namely R&D expenditures as a percentage of GDP and the number of researchers in R&D fields, statistical significance did not improve. Several explanations may account for the absence of a detectable effect of R&D on economic growth: firstly, our measures of R&D may suffer from measurement errors; secondly, there could be regression noise attributable to our study period coinciding with the COVID-19 pandemic, which imposed significant strains on the economies of the countries in our sample; thirdly, a potential reverse causality between R&D and economic growth may distort our R&D parameter; fourthly, there might be a time lag between spending on research and development and the introduction of developed technology to the market, thus obscuring the effect of R&D on growth within the same year. In our view, the phenomenon of the impact of R&D on economic growth necessitates further research to address these issues.

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ECONOMIC GROWTH MODEL: THE ROLE OF DIGITALIZATION

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Most publications justify that digitalization is a source of economic growth, to a greater extent in the countries with higher levels of economic development. However, some papers fail to find empirical evidence supporting this claim, attributing it to digitalization being in its initial stages or to the presence of the digitalization paradox. Economic literature exhibits a degree of ambiguity in

its conclusions regarding the role of the digital economy in growth. Researchers employ different measures of digitalization, country and year samples, control variables in regression equation, as well as different regression methods, which can provoke ambiguous effects on the parameters of digital variables. The purpose of the article is to identify the role of digitalization in economic growth by justifying an economic growth model with the digitalization index and providing detailed discussions on our sample of countries over recent years, along with options for regression estimators.

The article utilizes statistical data from the World Bank, European Commission, and Heritage Foundation. Methods such as system analysis, statistical analysis, and the regression estimator of panel data with fixed effects are implemented to identify the role of digitalization in economic growth.

We have designed an economic growth model incorporating the Digital Economy and Society Index (DESI) of EU member states for the years 2017-2022, utilizing available data. The results reveal a positive and significant causal effect of digitization on gross output growth. Specifically, a 1% increase in the digitalization index results in GDP growth of almost 0.2%. Moreover, we observe the important roles of capital, labor, trade, human capital, and intellectual property rights in driving growth, consistent with the theory of endogenous growth.

Proving the importance of digitalization for economic growth can be an argument for policies aimed at promoting digitalization. We suggest further research on the role of digitalization at a more disaggregated level of industries. However, our study does not demonstrate a statistically significant effect of research activity and institutional quality on gross output. We have discussed possible reasons for this and propose further research in these areas.

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