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Determinants of ICT Adoption and the Fourth Industrial Revolution in the EU*

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Abstract

Information and communication technology (ICT) is transforming the world and rapidly reshaping both the economy and the society. It is a central driver of the Fourth Industrial Revolution (4IR), a new paradigm of digital transformation, industry, and technological development. Within the European Union (EU), the 4IR has become a strategic priority aimed at reducing the competitive gap with its most important rivals, such as the United States of America and China. This research seeks to increase the knowledge and deepen the understanding of ICT and the 4IR, as well as their drivers. The key objective is to identify the determinants of ICT adoption and the 4IR in the EU during the period 2012-2019. To achieve this, a two-step dynamic panel generalized method of moments (GMM) estimator was used. The main findings indicate that foreign direct investment, institutional framework, economic growth and globalization are all positively and statistically significant associated with ICT adoption and the 4IR. Given that ICT and the 4IR represent crucial engines and strategic priorities of EU and global development, EU policy makers should be focused on the creation of a macroeconomic and political environment that will encourage digital transformation and a faster adoption of ICT.

Keywords: *information and communication technology, the Fourth Industrial Revolution, European Union, generalized method of moments*

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1. Introduction

Information and communication technology (ICT) is a revolutionary technology that leads to rapid technological and economic developments by fostering globalization and international cooperation. It drives the Fourth Industrial Revolution (4IR), a creative destruction process that causes substantial disruptions across all segments of the global economy and society. Roser et al. (2024) state that technological changes, industrial revolutions, and innovations such as ICT have significantly improved living standards and positively affected economic and social development. Philbeck and Davis (2019) note that each industrial revolution represents a technological change that causes significant disruptions and reshapes the society. Horowitz (1964) emphasizes the need to examine various economic and social aspects of industrial developments and their determinants, beginning with the First Industrial Revolution. Wisman and Capehart (2010) refer to Schumpeter and his idea that industrial revolutions represent creative destruction processes that enabled capitalism to become the most effective economic system for increasing living standards and productivity. According to Krapež et al. (2015), the 4IR began in 2011 as a new paradigm aimed at enhancing the competitiveness of Germany and the EU and advancing industrial digitalization.

Pena-Cabrera et al. (2019) note that although the 4IR, driven by ICT, is a major phenomenon that affects all segments of society and transforms it into Society 4.0, it remains understudied, particularly regarding its impacts and drivers. ICT-based technologies spread rapidly, providing significant opportunities for social and economic development and paving the way toward the Fifth Industrial Revolution (5IR), whose key driver is also ICT. Sarfraz et al. (2021) confirm that the 4IR forms the foundation not only for the 5IR, but also for Society 5.0, as both build upon the 4IR technologies. The 5IR is human-centered and more focused on the interdependence between people and machines. The Covid-19 pandemic, which caused the fastest pace of digitalization in human history, was the main driver of transformation from the 4IR to the 5IR. Noble et al. (2022) state that the 5IR focuses on the interaction between humans and machines, as well as on sustainable and inclusive development that benefits multiple stakeholders, including companies, customers, workers and society as a whole. There are certain differences among the 4IR and the 5IR. While the 4IR is focused on technological potential, the 5IR seeks to maximize the potential of people and technology working collaboratively, rather than competitively. Szeszák et al. (2025) argue that the 5IR represents a new technological paradigm in the EU, as the European Commission has identified it as strategic priority. It marks a transformation from a technology-focused to a more human- and sustainability-focused concept. As an evolution of the 4IR, it emphasizes the role of technology in encouraging creativity, promoting ethical behavior and strengthening economic resilience. Laffi and Lenzi (2021) identify ICT as the primary driver of the 4IR, alongside innovation and human capital, and emphasize the need for further research due to a lack of relevant cognitions.

Walsham (2017) explains that ICT remains a new and understudied topic that requires more scientific research, with a particular focus on its impacts on the economy and society and its determinants, given its rapid global diffusion and variety of benefits. The topic also requires an interdisciplinary approach. Duque et al. (2007) support this view, stating that ICT is a crucial globalization and development engine that started to evolve during the Cold War as a scientific and government project, but it spread rapidly throughout the society. Ježić et al. (2022), using panel regression, confirm the importance of ICT in building high-quality human capital, which is a key development engine in high-, middle- and low-income economies.

The research problem addressed in this study concerns the knowledge gap related to understudied topics such as ICT, the 4IR and its determinants. The lack of research on these topics is also confirmed by Walsham (2017) and Pena-Cabrera et al. (2019). The 4IR has been established as a key development strategy of the EU. As confirmed by the European Parliament (2016) and the European Institute of Innovation & Technology (2021), ICT adoption, diffusion and digitalization are the European future and present. The main objective of this research is to identify the main determinants of ICT adoption and the 4IR in the EU during the period 2012-2019.

To achieve this objective, the following research questions were formed:

RQ1: *How is the institutional framework associated with ICT adoption and the 4IR?*

RQ2: *How is globalization associated with ICT adoption and the 4IR?*

RQ3: *How is foreign direct investment (FDI) associated with ICT adoption and the 4IR?*

RQ4: *How is economic growth associated with ICT adoption and the 4IR?*

Hypotheses set in this research are:

H1: *The institutional framework is positively and significantly associated with ICT adoption and the 4IR.*

H2: *Globalization is positively and significantly associated with ICT adoption and the transition toward the 4IR.*

H3*: FDI is positively and significantly associated with ICT adoption and the 4IR.*

H4: *Economic growth is positively and significantly associated with ICT adoption and the 4IR.*

The paper is structured into six sections. The first section provides a brief introduction to the research topic and outlines the research problem, objectives, questions and hypotheses. The second section comprises theoretical background. Methodology is explained in the third section, while the fourth section explains the data and variables used in the model. The results of the model and the discussion are provided in the fifth section. The last, sixth section offers concluding remarks.

2. Literature review

McKinsey (2022) defines the 4IR as a new era in the digitalization of industry and production. It represents a continuation of the previous ICT revolution, driven by ICT-based technologies such as artificial intelligence (AI), blockchain, the Internet of things, big data, smart systems and virtual reality. Chou (2018) describes the 4IR as a major paradigm shift caused by the rapid diffusion of ICT and scientific progress. According to the National Institute for Standards and Technology (2024), ICT is a state-of-the-art widespread technology that encompasses various hardware and software elements, the purpose of which is a faster and a more efficient information collection, storage, exchange and processing.

Previous research, including Castelo-Branco et al. (2022) and Karabegović (2017), identifies ICT and digital infrastructure as the most important indicators and drivers of the 4IR. Other key drivers include knowledge, skills and education level, innovation, managerial practices, and adaptability. Muscio and Ciffolilli (2019) argue that the 4IR remains a highly understudied topic and define it as an innovation in technologies, manufacturing and business operations, characterized by rapid digital transformation and the usage of disruptive technologies and paradigms, such as smart systems. The 4IR is also an EU strategic priority. Its drivers include investments in research and development (R&D), cooperation among private, educational, academic and public sectors, regional collaboration, educational attainment and the share of the workforce employed in the production sector. Broz et al. (2020) find that digital transformation, which is based on ICT and encompasses the 4IR, affects society as a whole and stimulates economic growth, FDI and trade. Milošević et al. (2018) confirm this and state that EU countries differ in the ICT adoption and adjustment to the 4IR, and that economic development and human capital are key drivers of ICT adoption.

Weber and Kaufman (2011) identify multiple economic, technological and social drivers of ICT adoption at the company, industry, national and global levels, including economic activity and growth, living standard, globalization, institutional and legal framework, political environment, innovation capacity, human capital, and technological development. ICT increases productivity and causes significant cultural changes. Chinn and Fairlie (2006) state that institutional quality, such as the initial condition of ICT infrastructure, living standards and human capital, is the most important factor explaining differences in ICT adoption across low-, middle- and high-income economies. Krüger and Rhiel (2016), using principal component analysis on 178 countries (including the EU) in the period 1990-2014, confirm that the main drivers of ICT adoption and the 4IR are living standards, institutional framework, access to electricity and urbanization level. FDI and gross domestic product (GDP) also affect ICT adoption, but their impacts might be questionable.

The OECD (2023) states that FDI plays a crucial role in developing key infrastructure, particularly ICT, in both developed and developing countries. Shahbaz et al. (2022) find that FDI is a significant driver of the 4IR, alongside the institutional framework, financial and banking sector quality, export structure, and living standards, based on a panel of seven countries from 2000 to 2018. Shirazi et al. (2010) note a lack of extensive and systematic research on the effects of FDI on ICT. Using a panel of 17 Asian economies between 1996 and 2005, they found FDI positively affects ICT in the East Asian economies, but negatively in the MENA region. Besides FDI, other important determinants of ICT adoption include GDP growth, human capital, trade liberalization, institutional framework and urbanization. Gholami et al. (2006) confirm a lack of relevant literature that examines correlation among FDI and ICT, especially the impact of FDI on ICT. On a panel of 23 national economies between 1976 and 1999, they found that FDI contributes to better ICT infrastructure and faster adoption, especially in developing countries, and the relationship is bidirectional. Schäfer (2018) argues that the 4IR, driven by R&D and high technologies like ICT, represents a major opportunity for the EU, and that investment activity, particularly FDI, should be a central driver of the 4IR alongside the institutional framework and EU policies.

A crucial problem in the relevant literature is a lack of systematic research on the influence of GDP growth on ICT and the 4IR. Researchers mostly examine the reverse correlation, as confirmed by Broz et al. (2020), or bidirectional causality. Veeramacheneni et al. (2007) argue that the correlation among FDI, ICT and economic growth is an understudied topic and that the examination of this correlation represents an important scientific interest. Using Granger causality tests for 10 Latin American countries in the period 1975-2003, they confirmed that the correlation among FDI, economic growth and ICT differs. In seven out of ten countries there is a strong statistically significant bidirectional causality between ICT adoption and economic growth, while significant effect of economic growth on ICT adoption is found in two observed economies. FDI is confirmed as an important determinant of ICT adoption. Banerjee et al. (2019) also found that there is a bidirectional causality and a strong impact of economic growth on ICT infrastructure and adoption using the Granger causality test on a panel on 107 developed, emerging and transition countries, including the EU, in the period 2008-2017. Koutroumpis (2009) used the macroeconomic production function with a micro-model for ICT on 22 OECD economies between 2002 and 2007. It was found that economic growth and human capital are key drivers of ICT adoption, while investments in R&D are insignificant. Using a panel and the Granger causality test for European countries in the period 1960-2016, Pradhan et al. (2019) confirm an important and bidirectional causality among ICT, economic growth and innovation, although the impact varies depending on other factors, such as the institutional framework and human capital. Economic growth and innovation activity are therefore two important drivers of ICT adoption and the 4IR.

Bakay et al. (2010) identify globalization is an important determinant of ICT adoption. Using a panel of Latin American countries in the period 2002-2008, they find that the determinants of ICT adoption are economic growth, human capital, urbanization, investments in ICT and inequality. Zahid et al. (2018) emphasize the scarcity of quality research examining the importance of economic growth, FDI and globalization for ICT adoption. Using a panel and principal component analysis on BRICS economies between 2000 and 2014, they confirm bidirectional causality among globalization, and ICT adoption and the 4IR, as well as FDI and economic growth. Škare and Riberio Soriano (2021), using a panel of 183 countries, including the EU, confirm globalization as a key factor for ICT adoption and the 4IR. Another important determinant is overall national competitiveness, measured by the Global Competitiveness Index, which includes political, economic, social, cultural and innovation environments. International Monetary Fund (2018) also confirms that globalization and economic growth drive ICT adoption and the 4IR on the global level. Camilla et al. (2013) confirmed on a panel of EU economies in the period 1970-2004 that globalization is a key driver of ICT adoption, technological development and the 4IR, primarily through its drivers, such as FDI and trade. Goldberg et al. (2010) confirm similar findings not only for the EU, but also for all European and Central Asian countries. Sart et al. (2022), using cointegration tests, found that ICT and globalization have positive effects on educational attainment, but also that there is strong bidirectional causality between ICT adoption and globalization in New Europe economies in the period 2000-2018.

Baccianti et al. (2022) find that institutional framework, particularly government effectiveness, and globalization are crucial determinants of ICT adoption and the 4IR in 101 national economies across the world in the period 1996-2019, with a special focus on EU economies. International Telecommunication Union (2021), examining 145 economies in the period 2008-2019, confirms that institutional framework and government effectiveness play key roles in ICT adoption and the 4IR. King et al. (1994) state that institutional quality represents a crucial driver of ICT adoption. Political institutions have the strongest impact because government effectiveness affects ICT through knowledge development, human capital, creation of a macroeconomic framework for ICT adoption, and trade and investment liberalization, while certain top-down policies can have a limited or negative impact on the ICT. Kiessling (2006), using a panel of 82 developed, emerging and transition economies, including the EU, states that institutional framework and government effectiveness positively affect ICT adoption, while another important driver is also the quality of financial and economic institutions. Living standards and human capital similarly exert positive effects on ICT adoption.

3. Methodology and conception of analysis

ICT is a key driver of economic and societal progress. Relevant literature, including Walsham (2017) and Muscio and Ciffolilli (2019), emphasizes that ICT and the 4IR, particularly their determinants, remain understudied, despite their substantial impacts on the economy and society. The EU defines ICT as its strategic priority since it is a key indicator and driver of the 4IR that is set as key EU development and technological strategy to reduce the competitive gap with major global rivals. Although various determinants affect ICT adoption and the 4IR, as mentioned previously, they remain insufficiently explored. Equation 1 presents the dependent and independent variables included in the model.

$$ICT = f(FDI_{i,t};\ inst_{i,t};\ GDPgro_{i,t};\ KOF_{i,t};\ gov_{i,t}) \quad (1)$$

A two-step dynamic panel generalized method of moments (GMM) estimator is used as the methodological approach for this research. As noted by Shahbaz et al. (2022), this method is appropriate for examining correlations among variables such as those analyzed in this paper. Kiviet et al. (2017) confirm that GMM is widely used. It enables the explanation of empirical situations where heterogeneity is not determined and is affected by the regressors in the model. Its advantages include robustness, simplicity, accuracy and suitability for explaining general empirical patterns. Youssef et al. (2014) highlight that GMM improves estimator accuracy and efficiency, while Ahn and Schmidt (1995) confirm its asymptotic efficiency. Syofya (2022) notes that this method is suitable for examining correlations among independent and dependent variables, since it examines dynamic relationships among them and enables the usage of lagged dependent variables. Hansen (1982) and Piper (1982) argue that the usage of this method ensures model stability, accuracy, and asymptotic distribution of normality, making it appropriate for hypothesis testing coefficient estimation. Hsiao (1985; 2020) states that GMM effectively mitigates bias arising from omitted variables and enhances model efficiency by improving accuracy and relevance of results. It also addresses multicollinearity in explaining specific effects of every independent variable in the model. According to Farzana et al. (2024), dynamic panel GMM should be used when the number of units is bigger than the number of time periods. This is the case in the present study (216>8), and the autoregressive nature of the components further supports the use of the dynamic panel approach. Both system GMM and difference GMM are suitable for models with a smaller number of time periods and a higher number of observations and both use the first differences, as confirmed by Bun and Windmeijer (2007). However, Blundell and Bond (1998) show that system GMM generally achieves a higher level of accuracy than difference GMM, particularly for first-difference variables and in the presence of potential biases.

These methodological advantages justify the use of GMM in this research. Since this study examines the topic that is understudied and includes multiple units, the use of a method which is robust and accurate was essential. Due to aiming to produce evidence-based policy recommendations, it is important that the method contributes to explaining situations in general. Furthermore, ICT adoption and the 4IR are impacted by multiple determinants, and since GMM eliminates the effects of biases and omitted variables, this is an additional reason why it was used. The data used in this study are non-stationary and the value of the dependent variable in the current year is determined by its value in the previous year.

This research aims to identify the determinants of ICT adoption and the 4IR in the EU during the period 2012-2019. This period is selected because, as noted by Krapež et al. (2015), the 4IR began in 2011, with its first measurable impacts expected in the following year, which is the first one in the model. According to Noble et al. (2022), 2020 marks the beginning of the 5IR. The model includes 162 observations. Although it cannot confirm bidirectional causality, the focus of the study is on identifying the determinants and drivers of ICT adoption and the 4IR, rather than on assessing the effects of ICT on other indicators.

Equation 2 presents a dynamic model with a single time-changeable lagged variable, where y_{it} represents the dependent variable in period t; y_{it-1} is the dependent variable with one period lag from t; u_i represents particular time-invariant effects and v_{it} represents the error term.

$$y_{it} = \beta y_{it-1} + u_i + v_{it}, \ |\beta| < 1 \tag{2}$$

Individual effects are treated as stochastic. Further significant suppositions related to the invariance of the model are errors v_{it} that are serially uncorrelated. Individual time-invariant effects are mostly related to previous effects of the dependent variable in the model, which indicates the problem of endogeneity. The econometric model used to address this issue is presented in Equation 3.

$$ICT_{i,t} = \beta_0 + \beta_1 FDI_{i,t} + \beta_2 inst_{i,t} + \beta_3 GDPgro_{i,t} + \beta_4 KOF_{i,t} + \beta_5 gov_{i,t} + u_{i,t} + v_{i,t} \tag{3}$$

This chapter has presented and explained the methodology and the initial model used to test the hypotheses. The next section provides a detailed explanation of the dependent and independent variables, such as diagnostics related to model consistency.

4. Empirical data and analysis

This research examines the association of economic growth, institutional framework, FDI and globalization with ICT adoption and the 4IR. The data, variables, and corresponding databases used for the purposes of this research can be found in Table 1. The selection of indicators is based on the relevant literature. Below the table, the rationale for including each variable and the justification for the chosen indicators are explained.

Table 1: Data and variables in the model

Symbol	Variable	Explanation	Database
d_ICT	ICT adoption and the 4IR	ICT infrastructure	World Intellectual Property Organization (WIPO) – Global innovation index (2024)
d_FDI	FDI	FDI inward flow as percentage of global FDI	UNCTAD (2024)
d_inst	Institutional framework	Institutions	World Intellectual Property Organization – Global innovation index (2024)
d_GDPgro	Economic growth	GDP annual growth (%)	World Bank (2024b), World Development Indicators
d_KOF	Globalization	Globalization index	KOF Swiss Economic Institute Globalization Index (2024)
d_gov	Institutional framework	Government effectiveness estimation	World Bank (2024c) – Worldwide Governance Indicators

Source: Author's calculations

The dependent variable in the model is d_ICT, chosen as a proxy for ICT adoption and the 4IR. The values of this indicator range from 0 (minimum) and 100 (maximum). It was set as dependent variable because ICT and the 4IR are understudied topics, as emphasized by Pena-Cabrera et al. (2019) and Walsham (2017). In addition, the main research objective is to identify the determinants of ICT adoption and the 4IR in the EU27, given that the European Parliament (2016) and the European Institute of Innovation & Technology (2021) identify ICT and the 4IR as EU strategic priorities aimed at reducing the gap with major competitors. There are certain reasons why this indicator was used as a proxy not only for ICT adoption but also for the 4IR. It is a very comprehensive indicator that captures all aspects of ICT and its adoption that drive the 4IR: ICT access, usage, online public services and e-participation of citizens. Relevant literature such as Castelo–Branco et al. (2022) and Karabegović (2017) identifies ICT as a key indicator of the 4IR, while McKinsey (2022) notes that the 4IR is built upon ICT-based technologies and represents a continuation of the previous ICT revolution.

Two indicators are used as proxies for the institutional framework: d_inst and d_gov. The d_inst variable measures the quality of the overall institutional environment, including regulatory quality, quality of the business environment, rule of law, and business policies. The values of this indicator range from 0 (minimum) to 100 (maximum). The d_gov variable or government effectiveness estimate measures the opinions of citizens about the civil and the public sector, its independence, quality, and efficiency of government policies and their implementation. The minimum value of this indicator is -2,5, while the maximum is 2,5. These indicators are used due to relevant literature, such as Baccianti et al. (2022) and International Telecommunication Union (2021), where institutional framework is identified as a key driver of ICT adoption and the 4IR. Moreover, the crucial importance of government effectiveness in the creation and implementation of policies for the ICT adoption in certain economies and their successful transition toward the 4IR is also emphasized.

Economic growth is represented by d_GDPgro, measuring annual GDP growth in percentages. FDI is represented by d_FDI, indicating the percentage of inward FDI global flows in a certain country. Globalization is represented by d_KOF, which refers to the KOF Globalization Index, measuring the level of globalization in a certain country and encompassing the degree of political, economic (trade and financial) and social (cultural, interpersonal and information) globalization. The values of the KOF indicator range from 0 (minimum) and 100 (maximum). These three variables share a common rationale for inclusion: as mentioned previously, the correlation between and the impact of these variables on ICT and the 4IR is a subject of scientific debate, as noted by Shirazi et al. (2010). Another very important reason is a lack of relevant literature related to the correlation among and the impact of these three indicators on ICT adoption and the 4IR, as confirmed by Veeramacheneni et al. (2007) and Zahid et al. (2018). In addition, FDI is incorporated because studies such as Glass and Saggi (2008) and Gheribi (2018) identify it as a crucial factor for technology, knowledge and information transfer, which are also the core elements of the 4IR and ICT adoption. GDP growth is used as a proxy for economic growth because the World Bank (2024b) and Callen (2024) identify it as the most widely used indicator of economic growth and prosperity. FDI as a percentage of global flows is used because UNCTAD (2024) identifies it as one of the most used indicators of FDI in certain economy. The KOF Globalization Index is used as a proxy for globalization since it represents the most comprehensive indicator of globalization encompassing its various aspects, such as political, economic and social globalization, as confirmed by relevant literature like Hussain (2022).

Table 2 shows a correlation matrix used to test multicollinearity.

Table 2: Correlation matrix

d_ICT	d_GDPgro	d_inst	d_goveffest	d_KOF	d_FDI	
1.0000	0.0553	-0.1475	0.0686	0.1798	0.1469	d_ICT
	1.0000	-0.0860	0.0837	0.0207	0.3956	d_GDPgro
		1.0000	0.0212	0.0761	-0.0372	d_inst
			1.0000	-0.0321	0.0320	d_goveffest
				1.0000	0.0838	d_KOF
					1.0000	d_FDI

Source: Author's calculations

The results show that there is no multicollinearity, as all coefficients are below the critical threshold of 0.5. Certain unexpected signs appear, such as negative correlations between institutional quality and GDP growth, between globalization and government effectiveness, or between FDI and institutional framework, but their magnitudes are small and close to zero.

The first differences of all variables were used to avoid the problem of non-stationarity, since non-stationary variables can provide misleading results and create the problem of potential spurious correlation. The KPSS test (Kwiatkowski–Phillips–Schmidt–Schin) was used, as it is one of the tests with the highest usage rates, according to Baumohl and Lyosa (2009). Since the period in the model is relatively short (2012-2019), the KPSS test is considered the most suitable because, according to Lee and Schmidt (1996), its explanatory power and accuracy are higher than in other tests, while Arltova and Fedorova (2016) state that it is the most suitable test for shorter time periods and enables higher reliability than other tests. The results of the unit root test can be found in Table 3.

Table 3: Unit root test

Variable	P-value - constant	P-value – with constant and trend
d_ICT	0.5994	0.9785
d_FDI	0.9456	0.9359
d_inst	0.1091	0.1248
d_GDPgro	0.5676	0.6611
d_KOF	0.9252	0.9507
d_gov	0.5123	0.6361

Source: Author's calculations

The null-hypothesis of the KPSS test is that the data is stationary. In first differences, all variables are higher than the critical threshold |p| > 0.05, confirming the null hypothesis and the absence of unit roots.

Based on the theoretical framework and previous tests, the following econometric model was constructed:

$$d\_ICT_{it} = \beta_0 + \beta_1 d_{ICT(-1)_{i(t-1)}} - \beta_2 d_{FDI_{it}} - \beta_3 d\_inst_{it} + \beta_4 d\_GDPgro_{it} +$$

$$+ \beta_5 d\_KOF_{it} + \beta_6 d\_gov_{it} + \sum_{t=2014}^{2018} year_t + u_{it} + v_{it}$$

The model contains one dependent variable and five independent variables whose associations with the dependent variable are tested. The next section presents the results of the model, along with robustness check and diagnostic tests assessing model consistency.

5. Results and discussion

This section is divided into two subsections. The first subsection presents the results of the empirical analysis examining the determinants of ICT development and the transition toward the 4IR in the EU. The second subsection is a discussion of the findings.

5.1. Results

This subsection presents and interprets the results of the dynamic panel GMM estimator, used to test the hypotheses and determine the association between FDI, GDP growth, institutional framework and globalization with ICT adoption and the 4IR. The first differences of all variables were taken to avoid the non-stationarity issue.

The results of the model can be found in Table 4, while Table 5 presents model diagnostics.

Table 4: Results of the model

	Coefficient	Std. Error	z	p-value	
d_ICT (-1)	0.0960535	0.00601544	15.97	<0.0001	***
d_GDPgro	0.208947	0.0601555	3.473	0.0005	***
d_inst	0.334130	0.131318	2.544	0.0109	**
d_goveffest	8.57843	2.83578	3.025	0.0025	***
d_KOF	0.857557	0.0557990	15.37	<0.0001	***
d_FDI	0.375674	0.152003	2.471	0.0135	**

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 5: Model diagnostics

Number of instruments	25
Number of observations	162
Test for AR(1) errors: z	-3.78642 [0.0002]
Test for AR(2) errors: z	0.484416 [0.6281]
Sargan over-identification test: Chi-square(19)	22.4839 [0.2608]
Wald (joint) test: Chi-square(6)	2609.59 [0.0000]
Sum squared resid	6875.426
S.E. of regression	6.638768

Source: Author's calculations

The findings confirm that all independent variables are statistically significant. The lagged dependent variable is significant at the level $p<0.01$, while only the d_inst variable, which is one of the proxies for the institutional framework, is significant at the level $p<0.05$. The number of observations usually follows the formula N x (T-2). N represents the number of units – that is, 27 countries – and T the number of time periods – that is, 8 years. Thus, 27 x (8-2) = 162 observations. The dataset originally contained 216 observations but 54 (27 units x 2 years) were lost due to first differences and lagged dependent variable, resulting in 162 usable observations.

The results confirm a positive and statistically significant association of the lagged dependent variable d_ICT(-1). A one-point increase in the ICT infrastructure score in the previous year is associated with a 0.0960535-point increase in the following year. The d_gov variable, one of the proxies for institutional framework that measures government effectiveness, reaches the highest coefficient value related to the association with ICT adoption and the 4IR. A one-point increase in the government effectiveness score is associated with an 8.57843-point increase in the ICT infrastructure score. As for the second institutional variable, d_inst, a one-point increase of its value is associated with a 0.33413-point increase in the ICT infrastructure score. For both indicators, the association is positive and statistically significant. The d_FDI variable, which is taken as a proxy for investment activity, is positively and statistically significant associated with ICT adoption and the 4IR. A 1% increase in the share of global inward FDI flows in one country corresponds to a 0.375674-point increase in the ICT infrastructure score. Economic growth is also positively and significantly associated with ICT adoption and 4IR. A 1% increase in the annual GDP growth is associated with a 0.208947-point increase in the ICT infrastructure score. These findings suggest that after government effectiveness, globalization has the second-highest coefficient value related to the association with ICT adoption and the 4IR. A one-point increase in KOF Globalization Index score is associated with a 0.857557-point increase in the ICT infrastructure score.

Besides the fact that all independent variables and a lagged dependent variable have a positive and statistically significant association with the dependent variable, all variables display expected signs, and the results of the model are in accordance with economic theory.

Model diagnostics confirm the precision and the accuracy of the model. The Arellano-Bond test confirms that there is first-order autocorrelation, but there is no second-order autocorrelation, since the result of the AR2 test is 0.6281, and this value is higher than the critical threshold of 0.5. The results of the Arellano-Bond test reject the hypothesis that there is second-order autocorrelation. The result of the Sargan test is 0.2608, which is higher than the critical threshold of 0.05, confirming the validity of the instruments and the stability of the model. The results of the Wald test confirm sufficient explanatory power of the variables in the model. Together with the KPSS test, these diagnostics confirm that the model is suitable for this research and provides accurate results.

Standard errors (SE) are very small (<2) for all variables, except for government effectiveness, where SE is 2.83578, which is significantly lower than the coefficient value. Furthermore, the p-value for this variable is significant in 99%, while for other variables significance is 95% and 99%. The absence of second-order autocorrelation and the validity of instruments confirmed by the Sargan test further support model robustness. A robust covariance estimator was used and therefore, standard error values are acceptable.

To check the robustness of the results, as shown in Appendix 1, besides testing multi-collinearity, several additional models were created, and in each one, one independent variable from the original model was excluded. Across all models, the effects of the remaining independent variables on the dependent variable remained positive and significant. Coefficient magnitudes changed slightly, but there were no big differences. Government effectiveness consistently showed the highest coefficient value, ranging from 5.31 to 9.49 (compared to 8.57 in the main model). Significance levels varied between 1% and 5%, except for FDI (when institutional variables were omitted) and institutional quality (when GDP growth was omitted), where significance was 10%. A second robustness check, which can be found in Appendix 2, related to adding one by one variable in the model based on theoretical findings. The aim of this was to test the sensitivity of coefficients. Government effectiveness was the first tested variable, since it is represented as a crucial determinant of ICT development, followed by institutional quality, globalization and FDI. The d_inst variable was insignificant in the model where two institutional variables and globalization were included and showed 10% significance when GDP growth was excluded. In all other cases, independent variables were significant at the level of 1%. Coefficients for all variables remained positive, with a higher sensitivity observed for government effectiveness, which was expected given its strong association with ICT. For all other variables, coefficients variation remained below 1.

In models where only one variable was excluded, no second-order autocorrelation was detected, since AR2 was higher than the critical threshold of 0.5, except for the model excluding globalization, where the AR2 was 0.4731. The Sargan test results were higher than the critical threshold of 0.05, confirming instrument validity and model stability. The results of the Wald test confirmed sufficient explanatory power of the variables in the model.

5.2. Discussion

The most important findings in this research concern the identification of the determinants of ICT adoption and the 4IR, a topic which remains understudied according to relevant literature, such as Walsham (2017) and Muscio and Ciffolilli (2019). This study contributes to the scientific discussion by providing new insights into the topic consistent with the literature reviewed in the introduction and literature review sections. The results confirm a positive and significant impact of GDP growth, FDI, institutional framework and globalization level on ICT adoption and the 4IR within the EU. These findings align with existing research. The International Telecommunication Union (2021) and King et al. (1994) emphasize institutional framework, particularly government effectiveness, as a key precondition for ICT adoption and the 4IR, a point further reinforced by Baccianti et al. (2022) for the EU context. Regarding other determinants, such as globalization, economic growth and FDI, the literature remains limited, and their impact on ICT and the 4IR is still a subject of scientific discussion, as noted by Veeramacheneni et al. (2007). Nevertheless, the findings of this research are in accordance with the relevant literature, such as Pradhan et al. (2019), Banerjee et al. (2019), Gholami et al. (2006), Škare and Riberio Soriano (2021) and Camilla et al. (2013).

This research contributes to economic theory by addressing the research gap concerning the impact of economic growth, FDI and globalization on ICT adoption and the 4IR – an area recognized as scientifically important, which is confirmed by Zahid et al. (2018), Broz et al. (2020) Veeramacheneni et al. (2007). A more detailed overview of the scientific contributions is provided in the conclusion.

The results of this research provide a foundation for practical contributions, particularly in the development of policy guidelines. For the EU, the development of a high-quality institutional framework adjusted to the digital age is essential, enabling government effectiveness in the creation and implementation of policies related to ICT adoption and the 4IR. EU policy makers should consider redirecting public priorities on ICT, and, crucially, ensuring the consistent implementation of policies that support ICT adoption and the 4IR to encourage competitiveness on country and company level. Institutions have to ensure the rule of law and create a regulatory framework that will foster market competition. Governments should create public policies that support ICT adoption and the 4IR, thereby enabling reindustrialization. Since institutional quality also comprises elements of business regulations, EU institutions and national authorities must create a macroeconomic environment that encourages private-sector initiatives in the transition toward the 4IR and ICT development. As the 4IR is closely tied to reindustrialization and the manufacturing sector (predominantly privately owned), EU regulations should aim to reduce business barriers and enhance market competition. Businesses should become active stakeholders in shaping an institutional framework adjusted to the needs and requests of the 4IR. Through professional associations, such as Economic Chambers, they can engage in public discussions on institutional reforms and contribute to improving government effectiveness. Public policy measures should therefore strengthen not only public institutions, but also companies in the EU market and the overall investment environment. Since firms are most familiar with the practical effects of regulations, they should communicate challenges to policy makers, who can then make informed decisions.

Further economic and political liberalization and globalization should remain priorities for EU policy makers. Although globalization currently faces certain challenges, Boretos (2009) explains that global relations have historically fluctuated due to wars, crises, pandemics and protectionism, yet the process has never ended. Papanikos (2024; 2025) and the KOF Swiss Economic Institute (2024) confirm, based on historical trajectories and the first presidency of Donald Trump, that despite periods of deglobalization, globalization will continue due to the substantial benefits it provides. They explain that globalization trends have changed over time due to an increasing or decreasing level of globalization. New geopolitical relations may lead to protectionist measures, such as tariffs, being imposed on the EU by the US government. Such developments could motivate the EU to foster cooperation with different trade partners worldwide and enhance bilateral cooperation in all fields. It is important that the EU continues expanding its network of free trade agreements (FTAs), such as that with Mercosur started in December 2024, which created a market of 800 million people (European Comission, 2024). EU is the world's largest single market and an attractive investment and trade destination. Despite potential protectionist measures imposed by the US administration, the EU should seek to redefine its political and economic relations with the US, since they are major trading partners and allies, and especially because the USA has reached its peak of globalization during the first presidency of Donald Trump. As Papanikos (2025) argues, globalization is a natural and ongoing process and it is impossible to end it. Although the USA and the EU are major trade partners, they have not yet signed an FTA. Strengthening globalization and redefining trade relations with the US, potentially through an FTA, could reduce tariffs, eliminate trade barriers, and increase business dynamism and competition within the EU market. Expanding and updating FTAs would lead to faster integration into global trade and investment flows, increasing FDI inflows into the EU. FDI represents one of the most powerful channels for transferring and diffusing technology, knowledge, and information, contributing to further ICT adoption and the 4IR. Such an economic environment would stimulate economic activity, foster GDP growth and further advance ICT adoption and the transition toward the 4IR. Since companies and businesses are expected to become active stakeholders in adjusting the institutional framework, they have to be ready to adapt to challenges and solutions in the new global environment. In addition to the FTA with Mercosur, the new FTA in India, described by the European Comission (2026) as EU's largest trade agreement, creates a market of two billion consumers, with tariffs on 96.6% of EU products removed or decreased. Companies should therefore adjust their business strategies to the evolving global market to fully benefit from these opportunities and enhance their competitiveness.

6. Conclusion

The aim of this research was to identify the determinants of ICT adoption and the 4IR in the EU. The main motivation was to contribute to scientific discussion and economic theory by examining relatively new and understudied topics – ICT and the 4IR – and providing evidence-based policy guidelines. A comprehensive literature review established the theoretical foundation for selecting the independent variables and confirmed the research gap outlined in the problem statement. The tested hypotheses were supported by the econometric model, whose results represent the central findings of this study. These results highlight the importance of FDI, economic growth, institutional framework and globalization for ICT adoption and the 4IR, with institutional framework representing a crucial determinant with the biggest and the most significant impact.

The results of the econometric model, combined with the comprehensive literature review, form the basis for both the theoretical and practical contributions of this research. The most important theoretical contribution of this paper is the identification of the drivers of ICT adoption and the 4IR, thereby expanding existing knowledge and offering new insights into these topics. The study also contributes to the scientific discussion on the correlation among FDI, economic growth and globalization with ICT adoption and the 4IR. An additional contribution stems from the observed sample, the EU, which has positioned the 4IR as a crucial development strategy for increasing competitiveness level, while setting ICT adoption as a key strategic priority. This study fills the gap in economic science by offering new insights into relevant economic, societal and practical challenges associated with ICT adoption and the 4IR, as well as their links to economic growth, FDI and globalization. The practical contributions, particularly the policy guidelines, are discussed in detail in the discussion section.

Despite its contributions, this research faces certain limitations. One major limitation is the scarcity of comprehensive studies on ICT and the 4IR, as well as their correlation with determinants such as FDI, GDP growth, and globalization. This gap served as the main motivation for the study, as its findings provide new knowledge related to economic science and make this research relevant. Another limitation concerns the indicators. Although multiple indicators of ICT adoption and the 4IR exist, the study uses the ICT infrastructure from the World Intellectual Property Organization (2024) Global Innovation Index Database because it is comprehensive and because it encompasses different aspects of ICT. While other drivers and determinants of ICT adoption exist, the use of system GMM helps mitigate omitted-variable bias and ensures the robustness and validity of the results through diagnostic testing. A further limitation is the exclusion of the UK due to Brexit, as the policy guidelines are focused on the period after Brexit. Although Brexit was voted on during the observed period (in 2016), it took effect in 2020, while the final year in the model is 2019.

Further research could include other variables like human capital quality, investments in R&D and education, quality of education system, index of economic freedom, trade openness, environmental indicators, and population, and examine their correlations with ICT adoption and the 4IR. Another area for further research is using a sample of different groups of countries, as the 4IR is a global challenge, and comparing the EU with its main competitors. Further research could also explore the broader social and economic impacts of ICT and the 4IR.

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References

Ahn, S. C., & Schmidt, P. (1995). Efficient estimation of models for dynamic panel data. *Journal of Econometrics*, *68*(1), 5–27. https://doi.org/10.1016/0304-4076(94)01641-C

Arltová, M., & Fedorová, D. (2016). Selection of unit root test on the basis of time series length and value of AR(1) parameter. *Statistika*, *96*(3), 47–64. https://doaj.org/article/ca92920816ef46e0b9e874642271805e

Baccianti, C., Labhard, V., & Lehtimäki, J. (2022). *Digitalisation, institutions and governance, and diffusion: Mechanisms and evidence* (Working Paper Series No. 2675). European Central Bank. https://doi.org/10.2866/944440

Bakay, A., Collins, E. O., & Nacasius, U. U. (2010). Factors explaining ICT diffusion: Case study of selected Latin American countries. *The International Journal on Advances in ICT for Emerging Regions*, *3*(2), 25–33. https://icter.sljol.info/articles/10.4038/icter.v3i2.2846

Banerjee, A., Rappoport, P. N., & Alleman, J. (2020). A cross-country analysis of ICT diffusion, economic growth, and global competitiveness. In: J. Alleman, P. Rappoport, M. Hamoudia (Eds.), *Applied Economics in the Digital Era (pp. 63–102)*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-40601-1_3

Baumohl, E., & Lyocsa, S. (2009). Stationarity of time series and the problem of spurious regression. *MPRA* Paper No. 27926. https://mpra.ub.uni-muenchen.de/27926/1/Stationarity_of_time_series_and_the_problem_of_spurious_regression.pdf

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, *87*(1), 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8

Boretos, G. P. (2009). The future of the global economy. *Technological Forecasting and Social Change, 76*(3), 316–326. https://doi.org/10.1016/j.techfore.2008.06.003

Broz, T., Buturac, G., & Parežanin, M. (2020). Digital transformation and economic cooperation: The case of Western Balkan countries. *Zbornik radova Ekonomskog fakulteta u Rijeci: časopis za ekonomsku teoriju i praksu/Proceedings of Rijeka Faculty of Economics: Journal of Economics and Business*, 38(2), 697–722. https://doi.org/10.18045/zbefri.2020.2.697

Bun, M. J. G. & Windmeijer, F. (2007). The weak instrument problem of the system GMM estimator in dynamic panel data models. *University of Bristol Economics Working Paper* No. 07/595. http://dx.doi.org/10.2139/ssrn.976398

Callen, T. (2024). IMF: Gross domestic product: An economy's all. https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/gross-domestic-product-GDP

Camilla, M., Serlenga, L., & Shin, Y. (2013). Globalisation and technological convergence in the EU. *Journal of Productivity Analysis*, *40*(1), 15-29. https://doi.org/10.1007/s11123-012-0308-9

Castelo-Branco, I., Oliveira, T., Simões-Coelho, P., Portugal, J., & Filipe, I. (2022). Measuring the Fourth Industrial Revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain. *Computers in Industry*, *138*(4), 103639. https://doi.org/10.1016/j.compind.2022.103639

Chinn, M. D., & Fairlie, R. W. (2006). The determinants of the global digital divide: a cross-country analysis of computer and internet penetration. *Oxford Economic Papers*, *59*(1), 16–44. https://doi.org/10.1093/oep/gpl024

Chou, S. Y. (2018). The Fourth Industrial Revolution: Digital fusion with Internet of things. *Journal of International Affairs*, *72*(1), 107–120. https://www.jstor.org/stable/26588346

Duque, R., Collins, M., Abbate, J., Azambuja, C. C., & Snaprud, M. (2007). History of ICT. In: W. Shrum, K. R. Benson, W.E. Bijker, K. Brunnstein (*Eds.*), *Past, Present and Future of Research in the Information Society (pp. 33–45)*. Springer, Boston, MA. https://doi.org/10.1007/978-0-387-47650-6_3

European Commission. (2024). *Trade and Economic Security*. https://commission.europa.eu/about/departments-and-executive-agencies/trade-and-economic-security_en

European Commission. (2026). *Factsheet - EU-India Free Trade Agreement: Main benefits*. https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/india/eu-india-agreements/factsheet-eu-india-free-trade-agreement-main-benefits_en

European Institute of Innovation & Technology. (2021). *Digital Transformation of European Industry; A Policy Perspective*. https://www.eit.europa.eu/library/digital-transformation-european-industry-policy-perspective-full-report

European Parliament. (2016). *Industry 4.0*. https://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf

Farzana, A., Samsudin, S., & Hasan, J. (2024). Drivers of economic growth: a dynamic short panel data analysis using system GMM. *Discover Sustainability, 5*(1), 393. https://doi.org/10.1007/s43621-024-00612-9

Gheribi, E. & Voytovych, N. (2018). Prospects of foreign direct investments in technology transfer. *Economic and Environmental Studies*, *18*(2), 551–576. http://dx.doi.org/10.25167/ees.2018.46.5

Gholami, R., Tom Lee, S. Y., & Heshmati, A. (2006). The causal relationship between information and communication technology and foreign direct investment. *The World Economy*, *29*(1), 43–62. http://dx.doi.org/10.1111/j.1467-9701.2006.00757.x

Glass, J. A., & Saggi, K. (2008). The role of foreign direct investment in international technology transfer. In. A. K. Dutt & J. Ros *(Eds.)*, *International Hand-*

book of Development Economics. Edward Elgar Publishing. https://www.elgaronline.com/display/9781845423278.00058.xml

Goldberg, I., Branstetter, L., Goddard, J. G., & Kuriakose, S. (2010). *Globalization and technology absorption: The role of trade, FDI, and cross-border knowledge flows*. World Bank. https://openknowledge.worldbank.org/server/api/core/bitstreams/d8621cdc-ad90-5d4c-b601-4f69c03685d3/content

Hansen, L. P. (1982). Large sample properties of generalized method of moments estimators. *Econometrica*, *50*(4), 1029–1054. https://doi.org/10.2307/1912775

Horowitz, I. L. (1964). Sociological and ideological conceptions of industrial development. *American Journal of Economics and Sociology*, *23*(4), 351–374. https://doi.org/10.1111/j.1536-7150.1964.tb00968.x

Hsiao, C. (1985). Benefits and limitations of panel data. *Econometric Reviews*, *4*(1), 121–174. https://doi.org/10.1080/07474938508800078

Hsiao, C. (2020). Analysis of Panel Data. (3rd Edition) Cambridge, UK, Cambridge University Press. https://doi.org/10.1017/CBO9781139839327

Hussain, M. R. (2022). Measuring the impact of globalization on countries using composite indexes. *Cross-Cultural Management Journal*, *24*(2), 121–142.

International Monetary Fund. (2018). World Economic Outlook 2018. https://www.imf.org/en/publications/weo/issues/2018/09/24/world-economic-outlook-october-2018

International Telecommunication Union. (2021). *The impact of policies, regulation, and institutions on the ICT sector performance*. https://www.itu.int/dms_pub/itu-d/opb/pref/D-PREF-EF.ICT_SECT_PERF-2021-PDF-E.pdf

Ježić, Z., Zaninović, P. A., & Škulić, R. (2022). How does the ICT affect human development? Evidence from developing vs. developed countries. *Zbornik radova Ekonomskog fakulteta u Rijeci: časopis za ekonomsku teoriju i praksu/Proceedings of Rijeka Faculty of Economics: Journal of Economics and Business*, *40*(1), 9–27. https://doi.org/10.18045/zbefri.2022.1.9

Karabegović, I. (2017). Digital technology as the key factor in the Fourth Industrial Revolution - Industry 4.0. *International Journal of Engineering and Advanced Research Technology*, *3*(3), 17–22.

Kiessling, J. (2006). Institutions and ICT technology adoption. Research Papers in Economics 2006:7. Department of Economics, Stockholm University. https://umu.diva-portal.org/smash/record.jsf?pid=diva2%3A212118&dswid=-6541

King, J. L., Gurbaxani, V., Kraemer, K. L., McFarlan, F. W., Raman, K. S., & Yap, C. S. (1994). Institutional factors in information technology innovation. *Information Systems Research*, *5*(2), 139–169. https://doi.org/10.1287/isre.5.2.139

Kiviet, J., Pleus, M., & Poldermans, R. (2017). Accuracy and efficiency of various GMM inference techniques in dynamic micro panel data models. *Econometrics*, *5*(1), Article 14. https://doi.org/10.3390/econometrics5010014

KOF Swiss Economic Institute. (2024). *KOF Globalisation Index* [Data set]. ETH Zurich. https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html

Koutroumpis, P. (2009). The economic impact of broadband on growth: A simultaneous approach. *Telecommunications Policy*, *33*(9), 471–485. https://doi.org/10.1016/j.telpol.2009.07.004

Krapež, A., Meško, M., & Roblek, V. (2015). A complex view of Industry 4.0. *Sage Open*, 6(2), 1–11. https://doi.org/10.1177/2158244016653987

Krüger, J. J., & Rhiel, M. (2016). Determinants of ICT infrastructure: A cross-country statistical analysis. *Darmstadt Discussion Papers in Economics*, 228. https://www.econstor.eu/handle/10419/147296

Laffi, M., & Lenzi, C. (2021). The antecedents of 4.0 technologies: an analysis of European patent data. *Economics of Innovation and New Technology*, *32(*3), 1–18. https://doi.org/10.1080/10438599.2021.1937617

Lee, D., & Schmidt, P. (1996). On the power of the KPSS test of stationarity against fractionally-integrated alternatives. *Journal of Econometrics*, *73*(1), 285–302. https://doi.org/10.1016/0304-4076(95)01741-0

McKinsey & Company. (2022, August 17). *What are Industry 4.0, the Fourth Industrial Revolution, and 4IR?* https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-are-industry-4-0-the-fourth-industrial-revolution-and-4ir

Milošević, N., Dobrota, M., & Barjaktarović Rakočević, S. (2018). Digital economy in Europe: Evaluation of countries' performances. *Zbornik radova Ekonomskog fakulteta u Rijeci: časopis za ekonomsku teoriju i praksu/Proceedings of Rijeka Faculty of Economics: Journal of Economics and Business*, *36*(2), 861–880. http://dx.doi.org/10.18045/zbefri.2018.2.861

Muscio, A., & Ciffolilli, A. (2019). What drives the capacity to integrate Industry 4.0 technologies? Evidence from European R&D projects. *Economics of Innovation and New Technology*, *9*(2), 1–15. https://doi.org/10.1080/10438599.2019.1597413

National Institute of Standards and Technology. (n.d.). Information and communications technology (ICT). In *CSRC glossary*. Retrieved June 8, 2026, from https://csrc.nist.gov/glossary/term/information_and_communications_technology

Noble, S. M., Mende, M., Grewal, D., & Parasuraman, A. (2022). The Fifth Industrial Revolution: how harmonious human–machine collaboration is triggering a retail and service [r]evolution. *Journal of Retailing, 98*(2), 199–208. https://doi.org/10.1016/j.jretai.2022.04.003

OECD. (2023). FDI in critical infrastructure. https://www.oecd.org/investment/FDI-critical-infrastructure.pdf

Papanikos, G. T. (2025). The Trump effect on globalization: If the first time was a farce, would the second be a tragedy? *Athens Journal of Business & Economics*, *12*(1), 9–32. https://doi.org/10.30958/ajbe.12-1-1

Pena-Cabrera, M., Lomas, V., & Lefranc, G. (2019). Fourth Industrial Revolution and its impact on society. In *Proceedings of the 2019 IEEE CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON)* (pp. 1–6). IEEE. https://doi.org/10.1109/CHILECON47746.2019.8988083

Philbeck, T., & Davis, N. (2019). The Fourth Industrial Revolution: shaping a new era. *Journal of International Affairs*, *72*(1), 17–22. https://www.jstor.org/stable/26588339

Piper, A. (2014). The benefits, challenges and insights of a dynamic panel assessment of life satisfaction. *MPRA Paper* No. 59556. https://mpra.ub.uni-muenchen.de/59556/1/MPRA_paper_59556.pdf

Pradhan, R. P., Arvin, M. B., Nair, M., Bennet, E. S., & Hall, J. H. (2019). The information revolution, innovation diffusion and economic growth: an examination of causal links in European countries. *Quality & Quantity*, *53*(1), 1529–1563. https://doi.org/10.1007/s11135-018-0826-2

Roser, M., Ritchie, H., & Mathieu, E. (2024). *Technological change*. Our World in Data. https://ourworldindata.org/technological-change

Sarfraz, Z., Sarfraz, A., Iftikar, H. M., & Akhund, R. (2021). Is COVID-19 pushing us to the Fifth Industrial Revolution (Society 5.0)? *Pakistan Journal of Medical Sciences*, *37*(2), 591–594. https://doi.org/10.12669/pjms.37.2.3387

Sart, G., Bayar, Y., Corpădean, A. G., & Gavriletea, M. D. (2022). Impact of ICT and globalization on educational attainment: Evidence from the new EU member states. *Sustainability*, *14*(5), 3039. https://doi.org/10.3390/su14053039

Schäfer, M. (2018). The Fourth Industrial Revolution: How the EU can lead it. *European View*, *17*(1), 5–12. https://doi.org/10.1177/1781685818762890

Shahbaz, M., Gyamfi, B. A., Festus, V. B., & Agozie, D. Q. (2022). Toward the Fourth Industrial Revolution among E7 economies: Assessment of the combined impact of institutional quality, bank funding and foreign direct investment. *Evaluation Review*, *46*(6), 779–803. https://doi.org/10.1177/0193841x221112547

Shirazi, F., Gholami, R., & Higón, D. A. (2010). Do foreign direct investment (FDI) and trade openness explain the disparity in ICT diffusion between Asia-Pacific and the Islamic Middle Eastern countries? *Journal of Global Information Management*, *18*(3), 59–81. http://dx.doi.org/10.4018/jgim.2010070103

Škare, M., & Riberio-Soriano, D. (2021). How globalization is changing digital technology adoption: An international perspective. *Journal of Innovation & Knowledge*, *6*(4), 222–233. https://doi.org/10.1016/j.jik.2021.04.001

Syofya, H. (2022). Modeling analysis of economic growth in Asia with a dynamic panel approach generalized method of moment (GMM). *International Journal* *of Entrepreneurship and Business Development*, *5*(4), 716–725. http://dx.doi.org/10.29138/ijebd.v5i4.1900

Szeszák, B. M., Gergely Kerékjártó, I., Soltész, L., & Galambos, P. (2025). Review on the Fifth Industrial Revolution. *Journal of Physics: Conference Series, 3142*(1), 2001. https://iopscience.iop.org/article/10.1088/1742-6596/3142/1/012001/pdf

United Nations Conference on Trade and Development [UNCTAD]. (n.d.). *UNCTADstat data centre*. Retrieved June 8, 2026, from https://unctadstat.unctad.org/datacentre/

Veeramacheneni, B., Ekanayake, E. M., & Vogel, R. (2007). Information technology and economic growth: a causal analysis. *Southwestern Economic Review*, *34*(1), 75–88.

Walsham, G. (2017). ICT4D research: reflections on history and future agenda. *Information Technology for Development*, *23*(1), 18–41. https://doi.org/10.1080/02681102.2016.1246406

Weber, D. M., & Kauffman, R. J. (2011). What drives global ICT adoption? Analysis and research directions. *Electronic Commerce Research and Applications*, *10*(6), 683–701. https://doi.org/10.1016/j.elerap.2011.01.001

Wisman, J. D., & Capehart, K. W. (2010). Creative destruction, economic insecurity, stress, and epidemic obesity. *American Journal of Economics and Sociology*, *69*(3), 936–982. http://dx.doi.org/10.1111/j.1536-7150.2010.00728.x

World Bank. (2024a). Economy Overview. https://www.worldbank.org/en/publication/global-economic-prospects

World Bank. (2024b). World Development Indicators. https://databank.worldbank.org/source/world-development-indicators

World Bank. (2024c). Worldwide Governance Indicators. https://databank.worldbank.org/source/world-development-indicators

World Intellectual Property Organization. (2024). *Global Innovation Index 2024*. https://www.wipo.int/global_innovation_index/en/

Youssef, A. H., El-sheikh, A. A., & Abonazel, M. R. (2014). New GMM estimators for dynamic panel data models. *International Journal of Innovative Research in Science, Engineering and Technology*, *3*(10), 16414–16425. http://dx.doi.org/10.15680/IJIRSET.2014.0310003

Determinante razvoja informacijsko-komunikacijske tehnologije i tranzicije prema četvrtoj industrijskoj revoluciji u Europskoj uniji

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Sažetak

Informacijsko-komunikacijska tehnologija (IKT) mijenja svijet i rapidno preoblikuje društvene i ekonomske paradigme. Ona je ključni pokretač četvrte industrijske revolucije (4IR) koja predstavlja novu paradigmu u digitalnoj transformaciji, industriji i tehnološkom razvoju. Unutar Europske unije (EU), 4IR postala je strateški prioritet usmjeren na smanjenje razvojnog jaz u odnosu na njezine najvažnije konkurente, kao što su Sjedinjene Američke Države i Kina. Ovo istraživanje nastoji povećati znanja i produbiti razumijevanje IKT-a i 4IR-a, kao i njihovih pokretača. Glavni je cilj ovog rada utvrditi determinante razvoja IKT-a i 4IR-a u EU u razdoblju između 2012. i 2019. godine. Za postizanje tog cilja korišten je dinamički panel procjena generalizirane metode momenata (eng. GMM) u dva koraka. Ključni rezultati pokazuju da su izravna strana ulaganja, institucionalni okvir, ekonomski rast i globalizacija pozitivno i statistički značajno povezani s razvojem IKT-a i tranzicijom prema 4IR-u. Budući da IKT i 4IR predstavljaju ključne pokretače i strateške prioritete razvoja na EU i globalnoj razini, nositelji javnih politika u EU trebali bi se usmjeriti na stvaranje makroekonomskog i političkog okruženja koje će poticati digitalnu transformaciju i brže širenje IKT tehnologije.

Ključne riječi: *informacijsko-komunikacijska tehnologija, četvrta industrijska revolucija, Europska unija, generalizirana metoda momenata*

JEL klasifikacija: *O30, O10, F63, L52*

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Appendix

Appendix 1: Robustness checks

Table 6: Results of original model

	Coefficient	Std. Error	z	p-value	
d_ICT (-1)	0.0960535	0.00601544	15.97	<0.0001	***
d_GDPgro	0.208947	0.0601555	3.473	0.0005	***
d_inst	0.334130	0.131318	2.544	0.0109	**
d_goveffest	8.57843	2.83578	3.025	0.0025	***
d_KOF	0.857557	0.0557990	15.37	<0.0001	***
d_FDI	0.375674	0.152003	2.471	0.0135	**

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 7: Model diagnostic

Number of instruments	25
Number of observations	162
Test for AR(1) errors: z	-3.78642 [0.0002]
Test for AR(2) errors: z	0.484416 [0.6281]
Sargan over-identification test: Chi-square(19)	22.4839 [0.2608]
Wald (joint) test: Chi-square(6)	2609.59 [0.0000]
Sum squared resid	6875.426
S.E. of regression	6.638768

Source: Author's calculations

Table 8: Robustness check 1: without institutional variables

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0617702	0.0164452	3.756	0.0002	***
d_GDPgro	0.244925	0.0465294	5.264	<0.0001	***
d_KOFGlobaliza~	0.779534	0.0797528	9.774	<0.0001	***
d_FDIgloflow	0.245441	0.131553	1.866	0.0621	*

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors

Source: Author's calculations

Table 9: Robustness check 1 – Model diagnostic

Number of instruments	23
Number of observations	162
Test for AR(1) errors: z	-3.92765 [0.0001]
Test for AR(2) errors: z	0.274982 [0.7833]
Sargan over-identification test: Chi-square(19)	23.0095 [0.2369]
Wald (joint) test: Chi-square(6)	493.643 [0.0000]
Sum squared resid	6863.455
S.E. of regression	6.590871

Source: Author's calculations

Table 10: Robustness check 2 – Excluded variable: institutions

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0882318	0.00991590	8.898	<0.0001	***
d_GDPgro	0.206787	0.0516327	4.005	<0.0001	***
d_KOFGlobaliza~	0.876467	0.0726448	12.07	<0.0001	***
d_FDIgloflow	0.288463	0.135339	2.131	0.0331	**
d_goveffest	8.52675	2.55014	3.344	0.0008	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 11: Robustness check 2 – Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.84452 [0.0001]
Test for AR(2) errors: z	0.574333 [0.5657]
Sargan over-identification test: Chi-square(19)	23.8759 [0.2010]
Wald (joint) test: Chi-square(6)	671.781 [0.0000]
Sum squared resid	6849.211
S.E. of regression	6.604964

Source: Author's calculations

Table 12: Robustness check 3: Excluded variable: government effectiveness

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0681707	0.0130563	5.221	<0.0001	***
d_GDPgro	0.229574	0.0545010	4.212	<0.0001	***
d_KOFGlobaliza~	0.746567	0.0632193	11.81	<0.0001	***
d_FDIgloflow	0.342602	0.134871	2.540	0.0111	**
d_inst	0.454053	0.145043	3.130	0.0017	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 13: Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.81871 [0.0001]
Test for AR(2) errors: z	0.114319 [0.9090]
Sargan over-identification test: Chi-square(19)	20.4415 [0.3685]
Wald (joint) test: Chi-square(6)	1075.73 [0.0000]
Sum squared resid	6935.696
S.E. of regression	6.646534

Source: Author's calculations

Table 14: Robustness check 4: Excluded globalization variable

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0454805	0.00668416	6.804	<0.0001	***
d_GDPgro	0.195120	0.0577587	3.378	0.0007	***
d_FDIgloflow	0.389039	0.122779	3.169	0.0015	***
d_inst	0.481386	0.151266	3.182	0.0015	***
d_goveffest	5.31556	0.975822	5.447	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 15: Robustness check 4: Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.80383 [0.0001]
Test for AR(2) errors: z	0.717461 [0.4731]
Sargan over-identification test: Chi-square(19)	21.9402 [0.2872]
Wald (joint) test: Chi-square(6)	215.315 [0.0000]
Sum squared resid	7325.886
S.E. of regression	6.830937

Source: Author's calculations

Table 16: Robustness check 5: Excluded FDI variable

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0928388	0.00859438	10.80	<0.0001	***
d_GDPgro	0.325509	0.0304441	10.69	<0.0001	***
d_inst	0.349498	0.149786	2.333	0.0196	***
d_goveffest	8.56867	3.03534	2.823	0.0048	***
d_KOFGlobaliza~	0.885442	0.0499963	17.71	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 17: Robustness check 5 - Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.81347 [0.0001]
Test for AR(2) errors: z	0.199614 [0.8418]
Sargan over-identification test: Chi-square(19)	22.0112 [0.2837]
Wald (joint) test: Chi-square(6)	5671.27 [0.0000]
Sum squared resid	6911.872
S.E. of regression	6.635108

Source: Author's calculations

Table 18: Robustness check 6: Excluded GDP growth variable

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0835745	0.00729621	11.45	<0.0001	***
d_inst	0.312665	0.181635	1.721	0.0852	*
d_goveffest	9.49894	2.45144	3.875	0.0001	***
d_KOFGlobaliza~	0.836041	0.0523850	15.96	<0.0001	***
d_FDIgloflow	0.524715	0.111396	4.710	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 19: Robustness check 6 - Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.852 [0.0001]
Test for AR(2) errors: z	0.767744 [0.4426]
Sargan over-identification test: Chi-square(19)	23.3042 [0.2242]
Wald (joint) test: Chi-square(6)	1785.7 [0.0000]
Sum squared resid	6996.155
S.E. of regression	6.675440

Source: Author's calculations

Appendix 2: Building the Model

Table 20: ICT – government effectiveness

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.00939026	0.00622203	1.509	0.1312	
d_goveffest	5.10440	1.81816	2.807	0.0050	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 21: Model diagnostics ICT – government effectiveness

Number of instruments	21
Number of observations	162
Test for AR(1) errors: z	-4.00802 [0.0001]
Test for AR(2) errors: z	1.18982 [0.2341]
Sargan over-identification test: Chi-square(19)	23.7916 [0.2043]
Wald (joint) test: Chi-square(6)	7.95532 [0.0187]
Sum squared resid	7530.141
S.E. of regression	6.860275

Source: Author's calculations

Table 22: ICT – institutional variables

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0218745	0.0111433	1.963	0.0496	**
d_goveffest	6.13868	1.96222	3.128	0.0018	***
d_inst	0.377055	0.114696	3.287	0.0010	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 23: Model diagnostics ICT – institutional variables

Number of instruments	22
Number of observations	162
Test for AR(1) errors: z	-3.96219 [0.0001]
Test for AR(2) errors: z	1.0836 [0.2785]
Sargan over-identification test: Chi-square(19)	22.0565 [0.2815]
Wald (joint) test: Chi-square(6)	19.4696 [0.0002]
Sum squared resid	7575.251
S.E. of regression	6.902397

Source: Author's calculations

Table 24: ICT – institutional variables and globalization

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0625349	0.0117203	5.336	<0.0001	***
d_goveffest	9.18431	2.65545	3.459	0.0005	***
d_inst	0.175773	0.178549	0.9844	0.3249	
d_KOFGlobaliza~	0.900114	0.0409300	21.99	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 25: Model diagnostics ICT – institutional variables and globalization

Number of instruments	23
Number of observations	162
Test for AR(1) errors: z	-3.91629 [0.0001]
Test for AR(2) errors: z	0.708426 [0.4787]
Sargan over-identification test: Chi-square(19)	23.8207 [0.2031]
Wald (joint) test: Chi-square(6)	2271.55 [0.0000]
Sum squared resid	7105.092
S.E. of regression	6.705888

Source: Author's calculations

Table 26: ICT – institutional variables, globalization and FDI

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0835745	0.00729621	11.45	<0.0001	***
d_goveffest	9.49894	2.45144	3.875	0.0001	***
d_inst	0.312665	0.181635	1.721	0.0852	*
d_KOFGlobaliza~	0.836041	0.0523850	15.96	<0.0001	***
d_FDIgloflow	0.524715	0.111396	4.710	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 27: Diagnostic tests ICT – institutional variables, globalization and FDI

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.852 [0.0001]
Test for AR(2) errors: z	0.767744 [0.4426]
Sargan over-identification test: Chi-square(19)	23.3042 [0.2242]
Wald (joint) test: Chi-square(6)	1785.7 [0.0000]
Sum squared resid	6996.155
S.E. of regression	6.675440

Source: Author's calculations