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Digital Progression and Economic Growth: Analyzing the Impact of ICT Advancements on the GDP of European Union Countries

Anastasios I. Magoutas [1,2], Maria Chaideftou [1], Dimitra Skandali [2] and Panos T. Chountalas [1,3,*]

[1] School of Social Sciences, Hellenic Open University, 26335 Patras, Greece; amagoutas@ba.uoa.gr (A.I.M.); maria.chaideftou@gmail.com (M.C.)
[2] Department of Business Administration, National and Kapodistrian University of Athens, 10559 Athens, Greece; dskandali@ba.uoa.gr
[3] Department of Business Administration, University of Piraeus, 18534 Piraeus, Greece
* Correspondence: pchountalas@unipi.gr

Abstract: This research thoroughly examines the dynamic relationship between the European Union's economic growth and rapid advancements in Information and Communication Technology (ICT). Specifically, it assesses how certain ICT indicators are associated with significant economic growth. Utilizing an extensive dataset from the Digital Economy and Society Index 2022 (DESI), the Statistical Office of the European Union (EUROSTAT), and the Organisation for Economic Co-operation and Development (OECD), this study encompasses data from all 27 European Union member states. Employing structural equation modelling, our analysis illustrates the positive correlation between ICT development and the Gross Domestic Product (GDP) index. Our findings highlight the critical role of swiftly evolving technological landscapes, emphasizing the growing influence of new Artificial Intelligence (AI) technologies in business sectors. Furthermore, this study showcases the need to enhance human capital and expedite the growth of e-government technologies. These advancements are pivotal in strengthening the infrastructure supporting citizens and public enterprises across European countries, thereby contributing to their economic vitality.

Keywords: economic growth; gross domestic product; information and communication technology; digital technology integration; artificial intelligence; e-government technologies; European Union

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1. Introduction

Over the past two decades, Information and Communication Technology (ICT) has experienced remarkable growth (Lucky 2004; Cave et al. 2006). Its expansion has significantly transformed Europe's digital infrastructure and has shaped the economic landscape through advancements such as enhanced mobile broadband coverage and the accelerated spread of high-speed internet. The pervasive impact of digitalization has revolutionized numerous facets of daily life, including government services, education, online commerce, and diverse business transactions (Kiss and Páger 2023). These changes are evident in the evolving modalities of business operations, workplace dynamics, educational methods, social interactions, and the exchanges between citizens, businesses, and governmental entities (de Clercq et al. 2023).

The consistent and rapid growth of the ICT sector justifies a thorough examination of its impact on the economic growth of European Union countries. This area has attracted considerable attention from researchers who have explored the influence of ICT expansion on economic development at a national level. Notably, Rai et al. (2019) and Makridakis (2017) have delved into the effects of ICT technologies on economic growth. Kumar et al. (2016) offered a detailed analysis of how ICT investment enhances overall productivity in macroeconomic variables. They employed an extended Solow (1956) model, the Autoregressive Distributed Lag (ARDL) bounds testing approach to cointegration, and Granger causality tests to confirm their findings. Understanding the relationship between

ICT growth and economic development within the European Union becomes increasingly important because new virtual environments, such as the metaverse, are currently in their infancy, according to Dwivedi et al. (2022). Therefore, identifying the necessary conditions for technology to exert a positive influence on economic dynamics is imperative. This will not only clarify the role of ICT in shaping economic trajectories but also inform strategic investments and policy decisions in the digital sector.

This study's innovative contribution lies in its integration of three distinct global databases: the Digital Economy and Society Index (DESI), the Statistical Office of the European Union (EUROSTAT), and the Organisation for Economic Co-operation and Development (OECD). Using Structural Equation Modelling (SEM) analysis, the research explores the potential links between ICT development and economic growth within the EU member states. Panel data serve as the foundation of analysis, and it enables a thorough examination of how various ICT dimensions affect important economic indicators at different levels. More specifically, this study examines the impact of ICT on the Gross Domestic Product (GDP) per capita (GDPM_CUER), in terms of millions of euros, and the GDP per capita (GDPM_CUSD), in millions of US dollars, compared against employment rates. This research also employs the Partial Least Squares (PLS) technique to synthesize data from multiple sources. This approach allows for a more comprehensive understanding of the relationship between ICT growth indicators and economic metrics, marking a significant contribution in the field of economic and technological research.

This study is structured as follows. It begins with an introduction, setting the stage for the subsequent in-depth review of relevant literature. The presentation of the conceptual model and a thorough analysis of the hypotheses follow. The research methodology is described in detail, followed by the empirical analysis of the available data. This study concludes with a presentation and discussion of the results, leading to the final section where conclusions are drawn.

2. Literature Review

The relationship between ICT and economic growth has been extensively explored through a multitude of economic theories and research studies (Vu 2011; Mattalia 2013; Kumar et al. 2023; Albiman and Sulong 2017). Tracing the evolution of this discourse, the Solow (1956) and Swan (1956) model, first suggests that ICT growth is a significant contributor to GDP growth through its contribution to increased productivity. Central to the Solow–Swan model is the assumption that consistent capital and labor units are employed within the economic framework, implying that identical capital and labor inputs should yield consistent outcomes over time. Consequently, any observed increases in productivity not justified by increases in capital and labor are attributed to the exogenous influence of ICT development and investment. The model highlights the transformative role of ICT in driving economic efficiency and growth and provides a robust and fundamental theoretical framework to help in the understanding of the intersection of technology and economics.

Vu (2011) presents a compelling theoretical and empirical analysis of the correlation between ICT growth and economic growth. He suggests that ICT penetration boosts economic growth by fostering knowledge exchange and innovation, enhancing resource efficiency for households and enterprises, reducing production costs, spurring demand, and stimulating investment. Particular emphasis is placed on internet penetration as a key driver of economic expansion. Vu suggests that prioritizing investments in infrastructure, as well as interventions in advancing education and training, which prepare individuals for the digital era and promote internet use in business and government sectors, will help countries realize economic growth benefits. Expanding on this perspective, Mattalia (2013) provides an in-depth examination of the role of technological change and revolution in economic growth. He introduces a model that segments the economy into four distinct sectors: final goods, equipment, intermediate goods, and research and development (R&D). Through this framework, Mattalia analyzes the impact and spillover effects of what he terms "ICT-driven growth episodes". His findings reveal that increased productivity across these sectors not only propels ICT growth but also leaves a lasting, long-term impact on the economy. This study underlines the profound influence of ICT growth on sectoral productivity and its cascading effect on overall economic development.

Albiman and Sulong (2017) provide an insightful analysis of the impact of ICT penetration on Sub-Saharan African (SSA) economies, concluding that middle-income countries experience a more pronounced effect compared to low- or high-income counterparts. Their model clearly demonstrates the positive and linear influence of internet penetration on the economic growth of lower-middle-income countries, underlining the importance of fixed telephone line infrastructure. Building on this, Njoh (2018) employs a Solow–Swan-based theoretical framework to investigate the relationship between ICT and economic development in Africa. His findings highlight a positive correlation between these variables, reinforcing the notion that ICT is a driver of economic progress in the region. Bahrini and Qaffas (2019) extend the analysis to the Middle East, North Africa (MENA), and SSA regions, using a panel Generalized Method of Moments (GMM) growth model. Their study confirms the superior performance of MENA countries in terms of internet usage and broadband adoption compared to SSA countries, illustrating the varying levels of ICT impact across different regions. Kurniawati (2022) delves into the relationship between ICT and economic growth in high- and middle-income Asian nations. Employing panel cointegration and estimation methodologies, she addresses concerns of endogeneity and cross-sectional dependence. Her findings indicate that high internet penetration significantly fosters economic development in high-income Asian countries.

Recent studies have made significant strides in unpacking the complexities of the modern Solow paradox. Capello et al. (2022) provide a methodical and empirical analysis of the seemingly incongruous relationship between the widespread adoption of ICT and labor productivity growth in various regions. Their research demonstrates that the adoption of new technologies generally enhances productivity in the industries where they are integrated. Complementing this, Kaygisiz (2022) adopts the input-oriented Charnes Cooper and Rhodes (CCR-O) Model to ascertain digital intensity levels. This approach enables the evaluation of countries' digital transformation performance, offering a comprehensive indicator of their progress in the digital domain. Further contributing to this field, Cornet et al. (2023) explore the interplay between the Digital Entrepreneurship Indicator (DEI) and the location quotient of small ICT firms. Employing geographically weighted regression, their study highlights a positive correlation between these factors.

Jemala (2022) supports the idea that there is a significant shift in Asian countries' focus towards technological innovation, moving away from traditional reliance on Europe and North America. His hypothesis is centered around the increased attention to three non-patent forms of technology protection: industrial designs, trademarks, and utility models. This suggests a strategic redirection in the protection and commercialization of technological innovations in Asia. Conversely, Ibrahimi and Fetai (2022) conduct a detailed investigation into the impact of ICT on GDP growth in Western Balkan countries over the period 2000–2019. Their methodology encompasses a variety of econometric techniques, including pooled Ordinary Least Squares (OLS), fixed effects, random effects, and the Hausman Taylor model augmented with instrumental variables. This comprehensive approach provides a robust analysis of the economic implications of ICT in this region. Meanwhile, Pan et al. (2022) employ the Competitive Advantage Theory to examine the effects of internet convergence on the competitive advantage of manufacturing businesses at different stages. Using a unique dataset of hand-collected patent data from Chinese manufacturing firms listed between 2005 and 2018, Pan, Bai, and Ren's findings reveal a nuanced impact: while technology and market convergence enhance the competitive edge of manufacturing enterprises, business convergence appears to have a diminishing effect. This study contributes valuable insights into the strategic importance of convergence in technology and markets for manufacturing competitiveness in the evolving digital landscape.

3. Conceptual Model and Hypothesis Analysis

This research builds upon prior studies to identify the key ICT factors influencing economic growth (EG), as measured by the GDPM_CUER and GDPM_CUSD. Consequently, our central hypothesis suggests a direct and positive correlation between the evolution of ICT and EG in EU member states. Thus, we state that: H1. ICT has a positive and significant impact on GDP.

According to Eurostat (2022), the Digital Economy and Society Index (DESI) has extensively documented the growth of ICT in EU member states. Eurostat's methodology encompasses a comprehensive array of indicators, systematically tracking the progress of the ICT sector across four primary dimensions: Connectivity, Integration of Digital Technology, Human Capital, and e-government. The detailed methodological approach DESI follows, including the full list of indicators and their definition and measurement, is included in the link provided in Appendix A. In this section, we present these subcategories of ICT development and some key findings about each, as detailed in Table 1. This approach ensures a thorough understanding of the various facets of ICT growth and their potential impact on the economic landscape of the European Union.

Table 1. ICT subcategories and indicators from DESI being examined: initial model *.

Construct	Subcategory I	Subcategory II	Indicators	Abbreviations
ICT	Connectivity	Broadband price	Broadband price index	BPI
		Fixed broadband coverage	Fixed very high capacity network coverage	VHCN
		Fixed broadband set up	At least 100 Mbps fixed BB take-up	AL
	Integration of Digital Technology	Digital technologies for business	Electronic information sharing	EIS
			Cloud	CL
			Artificial intelligence	AI
			e-invoices	EINV
		e-commerce	SMEs selling online	SMO
			e-commerce turnover	EC
			Selling online cross-border	SOC
	Human Capital	Internet user skills	At least basic digital content creation skills	DCS
		Advanced skills	Female ICT specialists	FS
			Enterprises providing ICT training	EPT
			ICT graduates	GR
	e-government	-	e-government users	EGU
		-	Digital public services for citizens	DP

* Note: The underlined variables were used at the subsequent stage. Source: Authors' edit using DESI's categories.

3.1. Connectivity

The connectivity dimension primarily assesses the availability of infrastructure, measuring both mobile and landline coverage and uptake. The EU-27 region is generally regarded as a mature market in terms of connectivity. However, disparities persist, particularly in coverage between urban and rural areas. In evaluating connectivity across nations, Denmark emerges as the top performer, closely followed by the Netherlands, Spain, Germany, France, and Ireland. On the other end of the spectrum, Belgium and Estonia occupy the lower ranks, with Poland and Croatia not far behind. This study focuses on three key indicators to measure connectivity: the Broadband Price Index (BPI), Fixed Very High Capacity Network (VHCN) coverage, and the uptake of fixed broadband services with speeds of at least 100 Mbps (AL). These metrics provide a comprehensive view of the connectivity of the EU-27 region and enable an in-depth analysis of the capabilities of its infrastructure and its digital readiness.

3.2. Integration of Digital Technology

The integration of digital technology is a crucial measure used to assess the performance of businesses, regardless of size. The adoption of digital technologies enhances business efficiency and productivity, improves services and products, and expands market reach. The European Union has set ambitious goals, aiming for 90% of small and medium enterprises (SMEs) to have achieved basic digital integration by 2030, reflecting the critical importance of digital technology in contemporary business practices. To thoroughly analyze this subcategory of ICT integration, our study uses seven distinct indicators. These include Electronic Information Sharing (EIS), Cloud Computing (CL), the application of Artificial Intelligence (AI) in business, the use of Electronic Invoices (EINV), the proportion of SMEs engaging in online sales (SMO), e-commerce turnover (EC), and cross-border online sales (SOC). Each of these indicators offers a unique perspective on the extent to which digital technologies are being incorporated into business operations and provides a multifaceted view of digital integration in the EU's business sector. This comprehensive approach allows for a detailed understanding of how digital technology integration is shaping the business landscape in the European Union.

3.3. Human Capital

The Human Capital dimension measures the existence and level (basic or advanced) of digital skills EU member states. Despite widespread internet access, with at least 85% of households connected and 87% of Europeans engaging with the internet regularly (ranging from weekly to daily usage), only 54% of the population possesses at least basic digital skills, as reported by Eurostat (2021). This disparity highlights the significance of not only ensuring access to the internet, but also equipping individuals with the necessary skills to effectively use digital technologies. This is a critical factor in monitoring and fostering the growth of the ICT sector. In assessing Human Capital, our study incorporates four specific indicators: the proportion of individuals with at least basic digital skills in internet usage (DCS), the percentage of female ICT specialists (FS), the prevalence of advanced skills in enterprises providing ICT training (EPT), and the number of ICT graduates (GR). These indicators collectively provide a comprehensive picture of the digital competencies within the EU, highlighting areas of strength and opportunities for improvement in digital literacy and specialization. This holistic approach is essential for understanding the role of human capital in the development of the ICT sector in the European Union.

3.4. e-Government

The provision and accessibility of e-government services have experienced a significant increase, a trend further accelerated by the COVID-19 pandemic. During this period, digital interactions became not only the norm but often the sole means of executing certain tasks, as outlined by Rodríguez-Núñez et al. (2023). The European Union has set an ambitious goal: ensuring that 100% of key public services for businesses and citizens are available online by 2030. According to Eurostat (2021), the current average for online public services availability in the EU stands at 67.3%. However, there are vast differences in the rate of availability of e-government services between member states. Estonia and Finland are at the forefront, very close to the 100% mark. On the other hand, Greece and Romania face substantial challenges, with only about 40% of their services currently available online. In assessing the impact of e-government, our study focuses on two key indicators: the use of e-government services (EGU) and the availability of Digital Public Services (DP). These indicators allow us to evaluate the effectiveness and reach of e-government initiatives across the EU and offer insights into the current state of digital governance and its effect on the public and private sectors within the European Union.

Having identified the indicators that represent ICT growth in EU member states, we proceed with selecting the most suitable measure to represent economic growth as compared against employment rates. In our model, we have used Gross Domestic Product GDP as a proxy for economic growth, and, more specifically, we use three sets of variables: Gross Domestic Product, GDP current per head vs. Employment in Millions of Euros, GDP current per head vs. Employment in Millions of US Dollars, and GDP constant per head vs. Employment in Millions of US Dollars.

Table 2 presents the list of indicators used to measure the impact of ICT on the economic growth of the 27 EU member states.

Table 2. Variables measuring EG: initial model *.

Construct	**Subcategory I**	**Indicators**	**Abbreviations**
Economic Growth (EG)	Gross Domestic Product	GDP current per head vs. Employment in Millions of Euros	GDPM_CUER
		GDP current per head vs. Employment in Millions of US Dollars	GDPM_CUSD
		GDP constant per head vs. Employment in Millions of US Dollars	GDPM_COUSD

* Note: The underlined variables were used at the subsequent stage. Source: Authors' edit using EUROSTAT's and OECD'S databases.

4. Methodology

This study aims to demonstrate the relationship between ICT and economic growth within the context of the European Union. Recognizing the pivotal role a country's economic level plays in this relationship, as per the research performed by Mayer et al. (2020), our research focuses on 16 distinct metrics across the EU's 27 member states, spanning from 2017 to 2022. These metrics are selected to reflect key areas of ICT development and their subsequent impact on GDP growth.

The Structural Equation Modelling (SEM) method, which is supported by Fernández-Portillo et al. (2020), is used to test our main hypothesis, which is that ICT has a positive and enhancing effect on economic progress. This approach facilitates a detailed analysis of the causal links between ICT and economic growth (Chin 1998).

Data for this analysis were sourced from official, licensed databases of the Digital Economy and Society Index (DESI), the Statistical Office of the European Union (EUROSTAT), and the Organisation for Economic Co-operation and Development (OECD). These sources provide robust data to assess the relationship between various ICT indicators and GDP metrics, specifically: GDP per capita versus employment in millions of euros (GDPM_CUER), GDP per capita versus employment in millions of US dollars (GDPM_CUSD), and GDP per capita at constant prices versus employment in millions of US dollars (GDPM_COUSD), for the period 2017–2022. The datasets used are available via the links provided in Appendix A.

To predict latent variables, the analysis was executed using SmartPLS software version 4.0.9.2, leveraging the estimation capabilities of the ordinary least squares method as per Henseler et al. (2015). This advanced statistical tool enables a precise and reliable examination of the interdependencies and influences within our dataset, ensuring the integrity and accuracy of our findings.

5. Results

5.1. Assessment of the Measurement Model

The initial step in our analysis involves a comprehensive evaluation of the measurement model, focusing on assessing its reliability and validity. Figure 1 illustrates the conceptual map of the model.

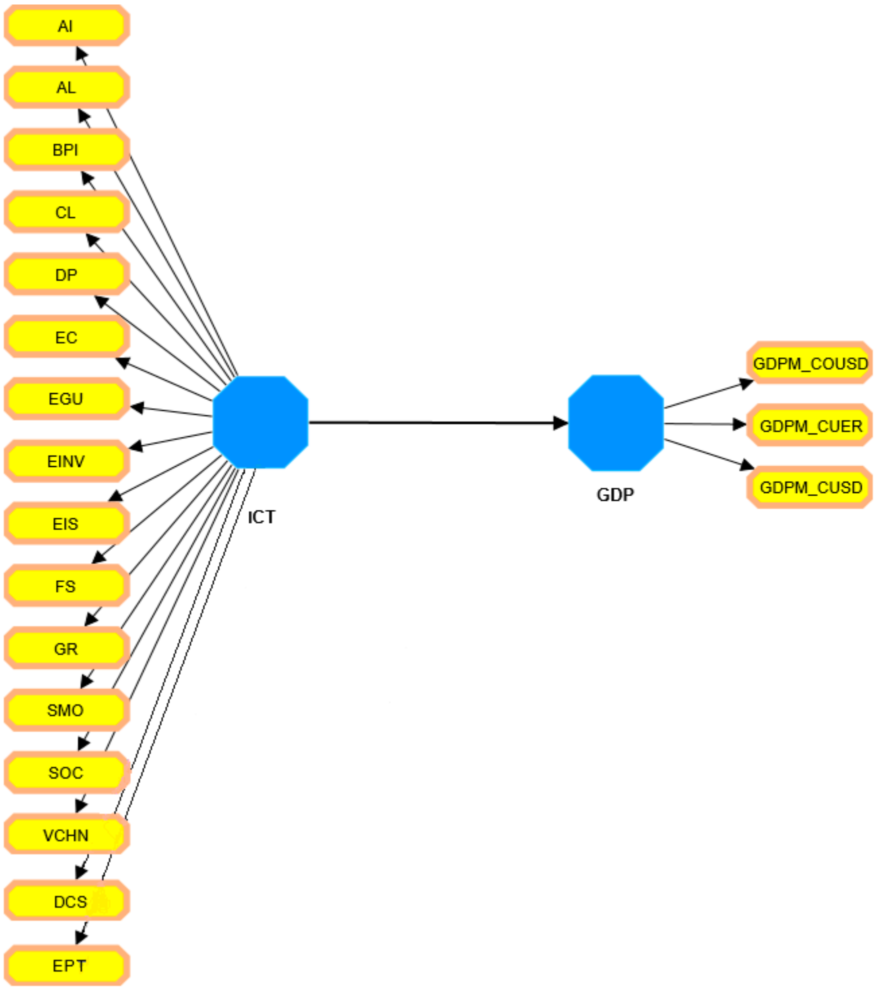

Figure 1. Initial model in the first stage. Source: Authors' edit.

For the reliability analysis, we examined both composite reliability and Cronbach's alpha values, as the data set includes results from surveys conducted by Eurostat. Please refer to Appendix A for a link to DESI's methodological note for more information. In our study, these values stand at 0.91 and 0.876, respectively, thereby satisfying the established theoretical criteria set by Gefen et al. (2000). This indicates a high level of internal consistency within our constructs, ensuring the reliability of our measurement model. Additionally, to establish convergent validity, we analyzed the outer loadings of each construct. The values obtained were as follows: AI = 0.758, DCS = 0.891, DP = 0.760, EGU = 0.844, and EPT = 0.834. These figures meet the standards for convergent validity as outlined by Bagozzi and Yi (1988), confirming that our model's constructs are adequately measured by their respective indicators. In the final part of this analysis, we addressed the Average Variance Extracted (AVE). Our calculation yielded an AVE of 0.671, which surpasses the threshold of 0.5. This result signifies that there are no issues related to convergent validity in our study, as detailed in Table 3. This comprehensive assessment of the measurement model ensures its robustness and appropriateness for further analysis.

Table 3. Reliability and validity analysis.

Construct	Items	Loading >0.704	Alpha >0.7	CR >0.7	AVE >0.5
ICT	AI	0.758	0.876	0.91	0.671
	DCS	0.891			
	DP	0.760			
	EGU	0.844			
	EPT	0.834			
GDP	GDPM_CUER	0.996	0.992	0.996	0.992
	GDPM_CUSD	0.996			

Note: The deleted items from the model due to low factor loadings are BPI, VCHN, AL, EIS, CL, EINV, SMO, EC, SOC, FS, GR, and GDPM_COUSD. Source: Authors' edit.

In our study, we also assessed the discriminant validity as per Fornell and Larcker's (1981) criteria. This involved confirming that the square root of the Average Variance Extracted (AVE) for each construct—GDP at 0.996 and ICT at 0.819—exceeds all corresponding inter-construct correlations. The details of this analysis are presented in Table 4.

Table 4. Discriminant validity analysis.

Constructs	1	2
1. Gross Domestic Product	**0.996**	
2. Information and Communication Technology	0.361	**0.819**

Note: Values on the diagonal (bold) represent the square root of the average variance extracted, while the off diagonals are correlations. Source: Authors' edit.

Following this validity assessment, we refined our measurement model by removing any indicators that did not adhere to the established quality standards outlined by Hair et al. (2021). This process of selection and elimination ensured that our measurement model only included indicators that met the highest criteria of analytical vigor. The revised measurement model presented in Figure 2, reflects these adjustments and the resulting streamlined structure. This step is critical in enhancing the model's precision and reliability, ensuring that the subsequent analysis is based on the most robust and valid constructs.

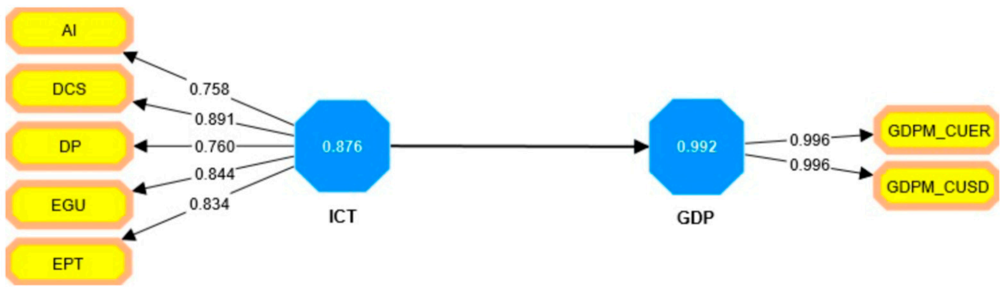

Figure 2. Graphical representation of assessment of measurement model. Source: Authors' edit.

In summary, we have taken all the necessary steps to ensure our measurement model is robust. We have eliminated indicators with low factor loadings ensuring we include the indicators that are present closest to the dataset's mean, therefore the most relevant. We have also ensured each construct is unrelated to the others, therefore reaffirming the model's validity. We present the result of these actions in Tables 3 and 4 and a graphical representation of our final model is in Figure 2 above.

5.2. Structural Model

5.2.1. Hypothesis Testing

For the hypothesis testing phase of our structural model, we employed the bootstrapping method, utilizing a sample size of 5000 as recommended by Ringle et al. (2015) to ensure robust hypothesis results. This approach provides a more accurate estimation of the standard errors and strengthens the reliability of our findings. Table 5 presents the detailed results concerning the direct effect of ICT on GDP and, hence, on EG. This table outlines the crucial importance of ICT's impact on the economy.

Table 5. Hypothesis testing direct effect.

Hypothesis	Direct Relationships	Std. Beta	Std. Error	T Values	P Values
H1	ICT → GDP	0.361	0.183	1.977	*

Note: Indicates significant paths: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS = not significant. Source: Authors' edit.

According to Hypothesis 1, a positive direct effect between ICT growth and GDP exists. The analysis revealed a path coefficient (β) of 0.361 and t-statistics of 1.977, indicating a statistically significant positive relationship between ICT growth and GDP growth. Therefore, based on this evidence, Hypothesis 1 is accepted, as illustrated in Figure 3. This acceptance highlights the crucial role of ICT in fostering economic growth, as reflected in GDP increases. Evidently, the large sample size, the strict bootstrapping method, and the clear presentation of the results presented in Table 5 and Figure 3 all support the validity and strength of our findings in relation to the proposed hypothesis.

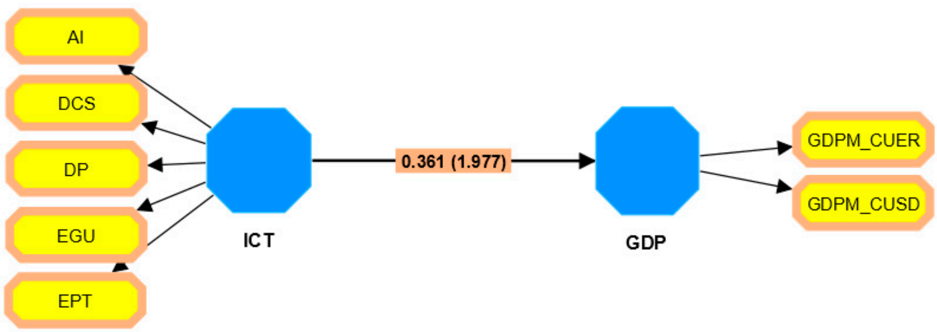

Figure 3. Graphical representation of the structural model. Source: Authors' edit.

We proceeded with hypothesis testing and have clearly demonstrated a direct positive effect between ICT and GDP growth, as confirmed by beta values and t statistics, therefore confirming our hypothesis. A graphical representation of our findings is presented in Figure 3, above.

5.2.2. Quality Criteria

We also used quality criteria to verify the suitability of our model and the validity of the results as presented above.

R-square, F-square, and Q-square values are shown in Table 6.

Table 6. R^2, F^2 and Q^2.

Latent Variables	R^2	R^{2Adj}	Q^2	F^2
GDP	0.131	0.096	0.078	
ICT → GDP				0.150

Source: Authors' edit.

Figure 4 provides a visual depiction of both R-square (R^2) and effect size (F^2) values, which are key metrics in evaluating the explanatory power and impact of our model. The R-square value of 0.131, while representing a small effect, is significant in the context of our study. It indicates the proportion of variance in an endogenous construct that is explained by its predictor constructs, as outlined by Hair et al. (2021). This value is crucial in assessing the strength and relevance of the model in explaining the relationship between the constructs. Furthermore, the effect size (F^2) in this study is calculated at 0.150, which, according to Cohen (2013), signifies medium effects exerted by the exogenous latent variable on the endogenous construct. This measure is instrumental in understanding the practical significance of the exogenous variables within our model.

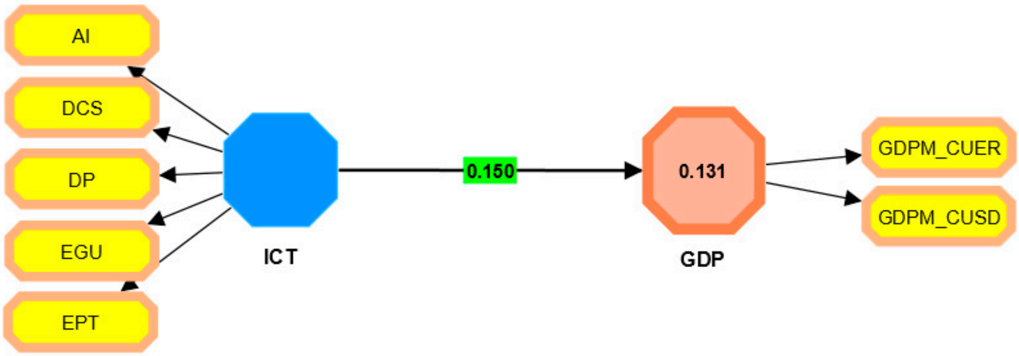

Figure 4. Graphical representation of R^2 and F^2. Source: Authors' edit.

Additionally, the Q-square (Q^2) value at 0.078, indicates a small but meaningful effect for the latent constructs within our model. This value also confirms the model's predictive relevance, as suggested by Chin (1998), given that Q^2 is above zero. The positive value of Q^2 underlines the model's ability to predict endogenous constructs with a degree of accuracy. The graphical illustration of the Q^2 values in Figure 5 provides a clear visual representation of the model's predictive power. This visualization aids in the interpretation and understanding of the model's predictive relevance, enhancing the overall understanding of this study's findings.

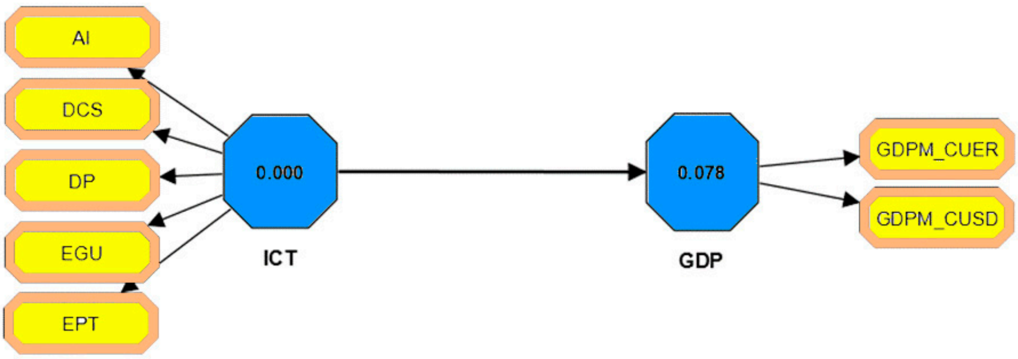

Figure 5. Graphical representation of Q^2. Source: Authors' edit.

The results of our analysis confirm Hypothesis 1 (H1) and demonstrate that ICT growth has a direct and positive influence on GDP growth. This hypothesis has been validated with a statistical significance exceeding the 95% confidence level, and it is further reinforced by the confidence interval test and the path coefficient analysis. Five of the ICT indicators we have examined in our model emerge as critical factors that GDP growth, and therefore economic development, in the 27 EU member states. Human Capital emerges as the most influential indicator in the model and, in particular, the indicator measuring at least basic Internet User Skills (DCS = 0.891) has the highest score. This is followed in second place by e-government usage, as measured by E-Government Users (EGU =

0.844). These indicators are followed by another Human Capital indicator in Advanced Skills of Enterprises in providing ICT training (EPT = 0.834), and the critical contribution of e-government in offering Digital Public Services (DP = 0.760). The fifth significant indicator which measures the Integration of Digital Technology, for the first time, highlights the role the adoption Artificial Intelligence (AI = 0.758) plays in enhancing the GDP index. These insights collectively confirm the multidimensional impact of ICT, and, in particular, Human Capital and e-government services, in fostering economic growth within the European Union, and they highlight the strategic importance of these factors in the region's economic development.

6. Discussion

The analysis of this study prominently positions the Human Capital factor as a key driver of ICT growth. This is echoed in the works of Pradhan et al. (2018), as well as Bahrini and Qaffas (2019), who emphasize the critical importance of ensuring that internet users possess at least basic Internet User Skills. This finding also reveals a broader implication: the indispensable role of education in fostering these necessary digital competencies. To effectively equip individuals with fundamental internet skills, there is an urgent need to develop a comprehensive educational framework. Such a framework should not only aim to promote digital literacy but also provide essential knowledge and skills for the use of technological tools and media. This will ensure that individuals can effectively navigate and benefit from the digital landscape. In the realm of advanced research, Herrera et al. (2023) employ machine learning algorithms to obtain insights into the intersection of ICT, education, and income distribution in Brazil. Their findings highlight the transformative potential of education in the digital era. Furthermore, Billon et al. (2009) observe that, in countries with high ICT adoption levels, education is a key factor shaping digitalization patterns, influencing GDP, and forging a multidirectional relationship between these variables. As we progress into an increasingly digitalized world, the importance of education and training becomes ever more paramount. Both education and training are not only beneficial but essential to the continued growth and integration of ICT in various sectors. The need for strategic focus on educational initiatives that can keep pace with and enhance the ongoing evolution of ICT emerges as more important than ever.

This study's findings also bring to the forefront the role of advanced skills in enterprises providing ICT training, significantly contributing to the European Union's economic prosperity. This observation extends the earlier findings about the crucial role of the Human Capital and the importance of at least basic internet user skills. Such skills are crucial for consumers, and, in certain contexts, notably in Sub-Saharan African (SSA) countries, the presence of basic ICT skills, including internet user skills, has been identified as a mitigating factor against poverty's severity and intensity, particularly when combined with targeted financial development actions (Ofori et al. 2021). In contrast, countries with mature ICT infrastructures, such as the top-performing OECD nations included in our study—Denmark, Iceland, and South Korea—have implemented strategies to promote and facilitate the use of ICT, which have resulted in increased levels of economic growth (Ali et al. 2020). This contrast highlights a divergence in ICT skill requirements based on the country's stage of ICT development.

In the European business context, however, basic ICT skills or internet user skills are not sufficient to foster economic growth. In the contrary, more advanced skills are needed. Ala-Mutka (2011) suggests that there is a need to obtain more sophisticated abilities and expertise, particularly in areas such as interaction and cooperation, information management, problem-solving, learning, and meaningful engagement. This advanced skill set is crucial in leveraging ICT for economic growth and innovation and underlines the need to invest in the continual evolution of skills along with the advancing technological landscape.

Inextricably linked to the preceding indicators, e-government users and digital public services for citizens are fundamentally intertwined with economic growth. These elements are mutually dependent, and the availability of digital services does not guarantee their effective use. Essential to the use of e-government services is the population's proficiency in basic internet skills. Van Deursen and van Dijk (2009) conducted a comprehensive analysis of digital skills among Dutch internet and e-government service users. Their findings reveal that the population's digital skill level significantly influences not only the usage of these services but also the accessibility, comprehension, and utilization of information available on the internet. They advocate for the implementation of policies aimed at enhancing government websites and digital services, as well as the digital competencies of e-government service users. Hyytinen et al. (2022) note an increase in e-government users, attributing this trend to the strategic involvement of policymakers and the application of what they term 'informational and social impact nudges'. This observation suggests that targeted governmental policies play a significant role in the increase ion e-government users and their impact on economic growth. Furthermore, Panagiotopoulos et al. (2023) emphasize the need for coordinated efforts to improve the provision of e-government services. They argue that enhancing these services' effectiveness and efficiency requires a transformation in their strategic management and operational models, which, in turn, would contribute to a better understanding of their positive impact on economies. Zoroja (2015) argues that governments that create an inclusive and transparent environment, particularly by offering e-government services, are likely to stimulate economic growth. This aligns with multiple studies that have explored the correlation between digitalization and the economic growth of businesses.

Artificial Intelligence (AI) has been, for the first time, identified in this study as a significant driver of economic growth in the 27 EU member states, particularly in the context of the Integration of Digital Technology in Business. Makridakis (2017) already predicted a substantial expansion of AI, along with its anticipated impacts on various industries and sectors. Brodny and Tutak (2022) highlight the varied levels of AI adoption across different EU-27 enterprises, correlating them with each country's position in the Digital Economy and Society Index's digitalization rankings. In their research, Pallathadka et al. (2023) explore the applications of AI in enhancing business performance and customer interactions, particularly in e-commerce, business management, and the finance sectors. Their findings suggest that AI contributes to sales growth, profit maximization, and sales forecasting, thereby influencing the economic performance of enterprises and, by extension, the GDP. Rai et al. (2019) explore the integration of AI with business operations, including hybrid models that combine AI and human intervention. Similarly, sector-specific research by Petrescu et al. (2022) investigates AI's role in Business to Business (B2B) marketing, incorporating perspectives from both academia and industry practitioners. Kulkov (2021) further examines AI's transformative impact in the pharmaceutical industry, noting that its application varies based on company size and specific needs. He observes that smaller firms benefit from AI in research and development, while larger entities leverage AI to enhance sales, marketing, and manufacturing processes, directly contributing to profit generation and operational efficiency. The use of AI also raises ethical considerations across various fields, including healthcare (Kumar et al. 2023), education (Chiu et al. 2023), and business education and skills development (Sollosy and McInerney 2022). These ethical dimensions highlight the need for further research to trace and assess the impact of AI adoption in business practices, its effectiveness, and its indirect influence on economic growth more accurately. Such comprehensive research will aid the understanding of and allow us to maximize AI's potential benefits while addressing its challenges and ethical implications.

This study's findings also yield an unexpected observation: the impact of connectivity, particularly the role of broadband, which is extensively explored and recognized in the works of Pradhan et al. (2018) for the Group of 20 (G20) countries, as well as by Bahrini and Qaffas (2019) for the MENA and SSA regions, is absent in our refined measurement model. This discrepancy can be attributed to the varying influences of mobile band and mobile network integration in different economic contexts. Research, including Kumar et al. (2016), indicates that these factors have a more pronounced impact on GDP in emerging and low-income countries. Conversely, as Edquist et al. (2018) suggest, their effect is more muted in developed economies. The absence of connectivity indicators in our model suggests that EU countries, generally, have already achieved a high degree of ICT infrastructure integration, despite some differences between rural and urban areas, as de Clercq et al. (2023) observed. Such a scenario indicates a more advanced stage of digital development in the EU, where the incremental impact of further connectivity improvements on GDP might be less pronounced compared to less-developed regions.

The outcomes of this research demonstrate a clear connection between the development of ICT and GDP growth, corroborating findings from prior studies, notably those conducted by Ishnazarov et al. (2021) and Chen et al. (2023). Ishnazarov et al. (2021) provide an in-depth analysis of the interplay between ICT and economic growth within the digital economy, highlighting innovation as a key driver of growth across diverse nations and regions. Their comprehensive study, which examined data spanning over 170 countries from 1990 to 2019, concluded that the ICT index has a considerable impact on GDP growth. This finding reinforces the transformative role of ICT in shaping economic trajectories on a global scale. Chen et al. (2023) delves into the concept of Digital Financial Inclusion (DFI-ICT), highlighting how ICT strategies can be leveraged to promote sustainable long-term growth and economic stability. This approach emphasizes the strategic use of digital technologies to enhance financial inclusion, thereby facilitating broader economic development.

7. Conclusions

This study explores the ICT sector's development and its relation to economic growth. This study follows a unique approach, as it integrates three comprehensive global datasets (DESI, EUROSTAT, and OECD) in its analytical model. This study uses Structural Equation Modelling analysis from year 2017 to year 2022, aiming to demonstrate the positive correlation between ICT and economic growth in 27 EU member states.

The ICT sector's growth has undeniably influenced key sectors in European economies, such as research, education, and business, fundamentally transforming social interactions and the dynamics between enterprises, governments, and the broader market for products and services. Our findings reveal that the primary factors connecting ICT development to GDP growth are Human Capital, e-government, and the Integration of Digital Technology.

These findings are in line with studies such as García-Muñiz et al. (2022), who demonstrate that the critical factors that influence economic growth include individuals with basic internet skills, users of e-government services, and professionals with advanced skills acquired through firm-sponsored training. The crucial role of education in acquiring digital skills emerges as a result. Furthermore, enhancing basic digital literacy, by integrating training initiatives to maximize the use of digital tools and media, should be the foundation of public policies that aim to stimulate economies. Indeed, advanced skills are needed and used by enterprises, and this is another deciding factor affecting economic development.

It is also not unexpected that, in regions where the corporate adoption of the internet and e-commerce is widespread and well-established, these factors also serve as key drivers of economic growth (Tsachtsiris et al. 2022). The business environment and the underlying framework in which companies operate have a considerable influence on economic growth, as demonstrated by a shift in online and remote services due to the COVID-19 pandemic and recorded in Eurostat's DESI year-on-year results. These services have become instrumental in the business sector's adaptation and evolution in the current digitally driven era. Moreover, the significant impact of e-government users on national economic trajectories suggests that policymakers and political leaders should prioritize and amplify investments in ICT and education.

Last, but not least, this study highlights the increasingly important role that AI technologies play in their application to business practices therefore indirectly driving economic growth. AI's rapid expansion fundamentally alters corporate dynamics and places the human–robot interaction at the forefront of current and future considerations (Savarese et al. 2016). Going forward, it is critical that we increase our understanding of the evolving relationship between humans and AI, both in current business contexts and in anticipation of future developments, as well as across sectors such as service provision and education.

This study therefore builds on the work of Fernández-Portillo et al. (2020) and brings to the surface ICT indicators which have been considered previously and continue to be very important (i.e., basic internet skills), along with others which are gaining prominence (i.e., advanced skills), while previously instrumental indicators, such as broadband connectivity and the use of the internet, are no longer detected as statistically important. It also highlights the emerging importance and role of indicators that have not been detected/or have not been measured before (i.e., AI technologies).

As demonstrated in both studies, it is evident that Human Capital is the differentiating factor when we explore the relationship between ICT and GDP growth. Basic internet skills are the pre-requisite for both consumers and employees in all areas of business as more and more aspects of the EU countries' economic lives and business transactions are digitalized.

However, we now also have clear indications that basic skills are not enough to navigate an increasingly digitalized landscape. On the supply side of services and goods, more digitalized services should be offered to citizens and businesses, while more advanced skills are also increasingly needed by employees for businesses, and therefore for European economies, to grow. On the demand side, consumers and citizens increasingly demand access to digital services due to their speed and efficiency benefits, but also face a more complex landscape that they need to be equipped and supported to navigate. The role of education and well-designed and thought-out economic policies that encourage and integrate advanced ICT skills training has become apparent, now more than ever.

In an era of rapid technological advancement, the transformative and increasingly more visible role of machine-generated outputs in aid of efficiency in the production process and in various sectors can also not be denied. More research is needed to further explore the numerous facets of ICT sector development on economic growth, particularly focusing on the complex interplay between technology, human capital, and economic outcomes. Such research is not only pertinent but necessary to fully grasp the intricate dynamics at play and to inform policy- and decision-making processes that will shape the future economic landscape of the EU and beyond.

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Appendix A

Table A1. Indexes and data sources.

INDEXES	Links
DESI	
Entire dataset including all indicators for DESI 2022	https://digital-decade-desi.digital-strategy.ec.europa.eu/api/v1/chart-groups/desi-2022/facts/, accessed on 27 February 2023
List of DESI 2022 indicators	https://digital-decade-desi.digital-strategy.ec.europa.eu/datasets/desi-2022/indicators accessed on 27 February 2023
DESI 2022 Methodological note	https://ec.europa.eu/newsroom/dae/redirection/document/88557 accessed on 27 February 2023
OECD	
GDPM-COUSD	https://www.oecd-ilibrary.org/economics/data/aggregate-national-accounts/gross-domestic-product_data-00001-en accessed on 27 April 2023 Data set available on this link with results filtered based on requirements. Dataset available for download.
GDPM-CUER	https://www.oecd-ilibrary.org/economics/data/aggregate-national-accounts/gross-domestic-product_data-00001-en accessed on 27 April 2023 Data set available on this link with results filtered based on requirements. Dataset available for download.
GDPM-CUSD	https://www.oecd-ilibrary.org/economics/data/aggregate-national-accounts/gross-domestic-product_data-00001-en accessed on 27 April 2023 Data set available on this link with results filtered based on requirements. Dataset available for download.
Eurostat	
Real GDP per capita	https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/table?lang=en accessed on 27 April 2023
Labour Force Survey	https://ec.europa.eu/eurostat/databrowser/view/TIPSLM16/default/table Employment vs GDP accessed on 27 April 2023

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