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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

THE IMPACT OF INFORMATION AND COMMUNICATION TECHNOLOGIES ON ECONOMIC GROWTH: THE CASE OF SELECTED EUROPEAN COUNTRIES*

Tamerlan MASHADİHASANLİ** 
Haluk ZÜLFİKAR*** 

Abstract

This paper investigates the impact of information and communication technologies on economic growth in 35 selected European countries during 2001-2021. With rapid advancements in information and communication technologies, understanding its influence on economic growth becomes imperative for policymakers and researchers alike. Utilizing a comprehensive dataset, this study employs rigorous econometric techniques to analyze the relationship between information and communication technologies indicators and economic growth indicators by applying system generalized method of moments method. According to the Levin–Lin–Chu unit root test, all variables are stationary at the I (0) level except TEL which is stationary at the I (1) level. According to the results of the two-step system generalized method of moments estimator, lagged GDP, telephone lines, mobile use, and internet usage positively affected GDP, although consumer price index, trade and final consumption expenditure affected negatively. In terms of significance of the effects, the effect of lagged GDP, consumer price index, final consumption expenditure and mobile use was significant, whereas the effect of trade, telephone lines and internet usage were not significant. The Arellano-Bond test showed that there is no autocorrelation, and according to the Sargan and Hansen tests results, the instrumental variables are appropriate and consistent in the model and the model has no speciation errors. From the results it can be concluded that information and communication technologies positively affected economic growth in 35 selected European countries. These findings strongly confirm the theoretical assumption that information and communication technologies are now a critical strategic aspect in assuring economic development and high long-term growth.

Keywords: ICT, Economic Growth, Panel Data Analysis, GMM, European countries
JEL Classification: O11, O20, O33, O40

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** Istanbul University, Department of Economics, E-mail: tamerlan.mashadihasanli@ogr.iu.edu.tr, ORCID: 0000-0002-8186-8420

*** Istanbul University, Department of Economics, E-mail: zulfikar@istanbul.edu.tr, ORCID: 0000-0002-9712-5373

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1. Introduction

Rapid advances in information and communication technologies (ICT) have transformed economies and societies around the world. In European countries, ICT has emerged as an important driver of economic growth, innovation, and competitiveness. Increasing integration and dependence on digital technologies has reshaped industries, increased productivity, and opened new avenues for socio-economic development. As a result, understanding the relationship between ICT and economic growth in European countries has become a critical issue for policymakers, researchers, and stakeholders.

This paper aims to investigate the effect of information and communication technologies on economic growth in 35 selected European countries during 2001-2021. By analyzing this relationship, we seek to shed light on the potential benefits and implications of ICT adoption for sustained economic development within the European countries' context. Understanding how ICT influences economic growth is essential for developing successful policies and strategies that leverage digital technologies to foster prosperity, innovation, and competitiveness.

Previous studies have examined the impact of ICT on economic growth, highlighting its role as a catalyst for productivity improvements and innovation. However, the specific context of the European countries necessitates a comprehensive examination of this relationship within the region. The European countries, with its diverse economic structures, varying levels of ICT adoption, and distinct policy frameworks, presents a unique environment to explore the nuances and dynamics of the ICT-economic growth nexus.

To achieve our research objectives, we have developed a comprehensive dataset including a set of ICT and economic growth indicators for 35 European countries. Using a system GMM approach, we aim to identify empirical evidence on the relationship between ICT and economic growth. The analysis considers key ICT indicators such as fixed telephone lines, mobile subscriptions, and internet users, alongside relevant economic growth indicators, such as gross domestic product (GDP).

This study's findings are expected to add to the existing research by offering useful insights on the role of ICT in promoting economic growth in European countries. Furthermore, the empirical information gathered will educate policymakers, stakeholders, and researchers on the potential benefits, challenges, and policy implications of ICT adoption for long-term economic development. Policymakers may design focused plans and programs that utilize the transformative power of ICT to boost productivity, build innovation ecosystems, and promote inclusive growth by understanding the specific dynamics inside the European countries' context.

In the following parts, we will describe the methodology used, discuss the empirical analysis and results, interpret the findings, and finish with policy implications and future research avenues. We hope that by conducting this extensive analysis, we will contribute to a better understanding of the complicated relationship between information and communication technologies and economic growth in European countries, providing insights that can drive evidence-based decision-making in the digital era.

2. Literature Review

The relationship between ICT and economic growth has been an important research topic in the growth literature for the last 20 years. It is observed that the first studies on this subject have been conducted in developed countries since the mid-1990s, when the aforementioned technologies emerged. However, as economic activities gained a global dimension and started to find widespread use in national and international activities, the effects of ICTs, whose economic efficiency increased in developing countries, started to be investigated in developing countries since the beginning of the 2000s. The general finding of these studies, which benefited from data and panel data approaches, is that ICTs make a positive contribution to growth in developed and developing countries, although their direction and size differ according to the period of study, the econometric analysis method applied and the level of development of the countries under consideration.

Haldar et al. (2023) examined the effect of ICT on economic growth for 16 emerging economies between 2000 and 2018. According to the findings, internet-use, which is one of ICT components, increases economic growth significantly in the lower and middle-income quantiles of the emerging economies. Colecchia and Schreyer (2002) studied the effect of information and communication technology capital accumulation on economic growth in 9 OECD member countries (Australia, France, Germany, Canada, France, Italy, Japan, USA, and England) for the period 1980-2000 with the growth accounting approach. They found that the investments made in these technologies make a positive contribution to economic growth, and this contribution varies between 0.2% and 0.5% annually depending on the disparities in the economic systems of the countries studied.

By using a panel of 123 countries – 45 high-income countries, 58 middle-income countries, and 20 low-income countries from the period 2002 to 2017, Appiah-Otoo and Song (2021) investigated the possible effect of ICT on economic growth. The findings show that ICT increases economic growth in these countries. Pohjola (2002) investigated the impact of ICT investments on economic growth for 39 developed and developing countries. According to the results of the regression analysis covering the 1980-1995 period, it was concluded that when developed and developing nations were analyzed jointly, ICT investments had a considerable effect on economic growth in developed countries but not in developing countries.

Kurniawati (2022) investigated the causal association between ICT and economic growth in high – and middle-income Asian countries utilizing data from 25 Asian countries from 2000 to 2018. According to the findings, rising Internet penetration has resulted in good and significant economic development in high-income Asian countries. In addition, middle-income countries are beginning to realize the benefits of ICT Internet. The findings showed that increasing telephone line and mobile phone penetration can increase economic growth in middle-income Asian countries. In his study on the Turkish economy, Dağdelen (2002) investigated the contribution of the use and production of information and communication technologies to economic growth.

According to the EKK analysis performed using annual time series data, although it is quite weak, information and communication technologies positively affect growth in Turkiye.

In their research, Brodny and Tutak (2022) found that an increase in ICT leads economic growth to increase in EU-27 countries. From 2001 to 2012, the causal linkages between information and communication technology (ICT) infrastructure and economic growth in Asian countries were studied. It was concluded that these variables have been determined to be cointegrated with various short and long-term causal linkages between ICT infrastructure and economic growth, financial development and economic growth, and ICT infrastructure and financial development (Pradhan et al., 2015). Usman et al. (2021) analyzed the effects of ICT on economic growth by using the data from 1990 to 2018 and found that overall, ICT considerably and favorably helps to India's economic growth.

Cheng et al. (2021) investigated the relationship between ICT and economic growth using panel data from 72 countries from 2000 to 2015 and the GMM method. They discovered that in middle and low-income countries, mobile growth increases economic growth while increasing Internet or secure Internet servers does not. Daveri (2003) in his study investigating the effect of ICT expenditures on economic growth in G-7 countries between 1990 and 2000, stated that the contribution of ICT to economic growth in countries other than the USA is extremely low.

By using data from 2001 to 2017, Sinha and Sengupta (2022) found that ICT has positive and significant effects on economic growth in Asia-Pacific Developing Countries. Pazarlıoğlu and Gürler (2007) estimated the relationship between telecommunication investments and economic growth in European Union (EU) core countries, member states and candidate countries by using fixed effects panel data method. When the results of the analysis applied using the annual panel data for the period 1990-2004 are examined, it is observed that the effect of telecommunication infrastructure investments on GDP, which is used as an economic growth indicator, is positive. Accordingly, a 1% increase in investments increases the growth by 0.33% in the countries covered.

Konak (2020:238) investigated the relationship between ICT exports and economic growth for 7 selected countries. According to the results of the panel data analysis created with the annual data of the 2000-2015 period, it has been concluded that ICT exports in the mentioned countries have a positive effect on economic growth. In their research, Pradhan et al. (2021) stated that in the long term, strong economic growth contributes significantly to ICT infrastructure development in the Indian states.

Datta and Agarwal (2004) examined the long-term relationship between telecommunication infrastructure investments and economic growth for 22 OECD countries and found that there is a significant and positive relationship between telecommunication infrastructure and GDP. In their study, Ahmad and Satrovic (2023a) analyzed together effect of economic complexity and technological innovation on energy productivity and carbon productivity and investigated how monetary policy moderates this effect in Group of Seven (G7) countries in 1995-2019. The results showed that both economic complexity and technological innovation positively affected

environmental sustainability. In terms of moderating effects, expansionary monetary policy was being used to manifest the positive environmental effects of economic complexity and technological innovation.

The effect of ICT on economic growth and unemployment has been examined in terms of 23 EU countries and Turkey. Data from 1996 to 2016 were used. FGLS Panel Data Analysis method was applied. Findings revealed that ICT has positively affected economic growth in the EU and Turkey, and reduced unemployment to a minimum level between the years investigated (Alper, 2017: 45). By using panel data of 7 OECD countries, Ahmad and Satrovic (2023b) studied fiscal decentralization's role in moderating the impact of economic complexity and government intervention on environmental sustainability in the presence of GDP from 1995 to 2018. Their findings revealed that economic complexity and government intervention decrease energy efficiency and economic growth is the driving factor behind long-term environmental sustainability.

Yousefi (2011) examined the influence of ICT on economic growth in 62 high, upper-middle, low-middle, and low-income countries from 2000 to 2006. Yousefi concluded in his study utilizing panel data analysis that ICT has a vital role in the economic growth of high – and upper-middle-income nations but does not contribute to the economic growth of low – and lower-middle-income countries.

Erdil et al. (2010) evaluated the influence of ICT on growth in 131 underdeveloped countries, including Turkey. According to the results obtained from the econometric analysis using the GMM method, when considered as a production factor such as physical and human capital accumulation and when used with some control variables, these technologies positively affected on economic growth in underdeveloped and developing countries. Based on these results, the researchers drew attention to the importance of continuing the investments made in these technologies. Nejati and Shah (2023) also found that there is a positive relationship between ICT and economic growth.

The joint influences of ICT and financial development on economic growth were examined in 43 developing countries between 2000 and 2014 by using GMM method. It is concluded that ICT positively affects economic growth, but does not financial development (Das et al., 2018: 928). Ahmad and Satrovic (2023c) investigated how fiscal policy instruments are effective in moderating the effect of economic openness on environmental sustainability for G7 countries in 1990–2019 in the presence of technological innovation and they found that technological innovation positively affects environmental sustainability and fiscal policy instruments increase the demand for environmentally friendly products, resulting in a reduction in consumption-based anthropogenic emissions associated with economic openness.

Samimi and Leadary (2010), who stated that ICT affects growth positively through innovation and productivity, analyzed the influence of ICT on economic growth for the period 2001-2006 in 30 developing countries. GDP was taken as the growth indicator and the Digital Opportunity

Index (DOI) was taken as the indicator of technology, and from the analysis using the random effects panel data approach, it was determined that ICT had a statistically significant positive influence on economic growth. Accordingly, a 1% increase in the use of these technologies causes an increase of 0.000792% growth.

Artan et al. (2014) studied the impact of ICT development on economic growth for 17 transition economies with annual data for the period 1994-2011. In the study, in which 3 different models were created and static panel data analysis method was used, the results obtained from all three models showed that the use of telephone and internet positively affected economic growth. In his research. Ramzan et al. (2022) found that ICT causes economic growth to rise in Pakistan. Satrovic et al. (2023) revealed that technological innovation and economic growth decrease the harmful environmental influence of natural resources that causes environmental degradation.

In the study conducted by Kooshki and Ismail (2011), it has been estimated whether ICT effectively influences economic growth in OECD, BRICs, NICs countries from 1990 to 2008. In the analysis using GMM method, it was found that ICT had a positive effect on economic growth. Based on their findings, the researchers concluded that these technologies play an important part in the economic process, and that countries seeking to accelerate their growth should boost their investments in these technologies and at the same time support these investments with complementary investments.

Kılıç et al. (2017) researched the relationship between ICT exports and economic growth for 7 selected countries. According to the results of the panel data analysis created with the annual data of the 2000-2015 period, ICT exports in the mentioned countries positively affect economic growth.

Farhadi and Fooladi (2011) studied the relationship between economic growth and the use of ICT in 159 countries for the period 2000-2009 by applying GMM. According to results, the positive effect of the use of ICT on economic growth varies depending on the income levels of the countries and this positive effect increases as the income level rises. Based on these results, the researchers stated that the technologies have a critical role in growth and therefore, it is necessary for countries aiming at a sustainable and high rate of growth to implement policies that increase the diffusion of these technologies.

3. Material and Method

3.1. Methodology

Information and communication technologies have become essential components of modern economies, dramatically influencing numerous industries and spurring innovation. While there is broad consensus on the relevance of ICT, there is a need for a better understanding of how ICT investments and usage specifically contribute to economic growth in the European context. This paper contends that a thorough examination of the relationship between ICT and economic

growth, using advanced econometric methodologies such as the two-step system Generalized Method of Moments GMM, can yield nuanced insights that go beyond conventional wisdom.

The purpose of this research is to examine the impact of information and communication technologies on economic growth in 35 European countries. The research intends to provide a clear and intuitive knowledge of the relationship between ICT adoption and economic development by adopting a rigorous two-step system GMM technique. We use the System Generalized Method of Moments (GMM) technique, because it successfully addresses endogeneity and allows for efficient estimate in the presence of persistent variables, the System GMM technique is particularly well suited for panel data analysis. This study seeks to produce strong and reliable estimations of the association between ICT and economic growth in the selected European countries by applying the System GMM technique. The use of panel data, in conjunction with a rigorous econometric technique, allows for a thorough analysis that reflects the dynamic nature of the ICT-economic growth nexus. The methodology enables endogeneity control and provides significant insights into the impact of ICT on economic development in Europe.

This study proposes the following main hypothesis:

Hypothesis 1:

Greater adoption and effective use of ICT positively correlate with higher rates of economic growth across the selected 35 European countries.

Hypothesis 1a:

Fixed telephone lines positively affect economic growth in the chosen 35 European countries.

Hypothesis 1b:

Mobile phone usage are positively associated with economic growth in the selected 35 European countries.

Hypothesis 1c:

Increased internet usage is linked to enhanced economic growth across the 35 European countries under examination.

The study predicts that nations with more robust ICT, paired with strategic policies to exploit the potential of ICT, will see faster economic growth than those with lower ICT adoption and use.

The econometric representation of the System GMM estimator model can be expressed as follows:

$$Y_{it} = \alpha + \rho Y_{i,t-1} + \beta X_{it} + \eta_i + \varepsilon_{it}$$

where:

- Y_{it} denotes the dependent variable of interest, such as economic growth statistics, observed for country i at time t.
- α is the intercept term.
- $Y_{i,t-1}$ represents the lagged dependent variable, capturing the persistence in the relationship between ICT and economic growth.
- X_{it} refers to a vector of exogenous variables that include ICT indicators and other control variables that affect economic growth.
- β is the vector of coefficients related to exogenous variables.
- η_i denotes country-specific fixed effects, which account for time-invariant features that influence economic growth but differ between nations.
- ε_{it} represents the error term, which captures the relationship's unobserved components and random disturbances.

The System GMM estimator uses lagged levels as instruments to address endogeneity and other omitted variable biases. The model's orthogonality criteria are used to build the instrumental variables (IV). The first-difference transformation is used to reduce time-invariant country-specific effects and increase parameter estimation efficiency.

The moment conditions produced from the instrumental variables are used to calculate the System GMM estimator. The system of equations is estimated jointly while taking the relationship between the differenced variables and the lagged levels into consideration. This estimation method alleviates worries about endogeneity, accounts for unobserved heterogeneity, and provides accurate parameter values.

There are two steps to the estimating technique. The differenced equations are estimated using the GMM estimator in the first stage. This phase removes the country-specific fixed effects and decreases the possibility of endogeneity issues. In the second stage, the system GMM estimator is used, with lagged levels acting as additional instruments. This stage considers the dynamic nature of the link between ICT and economic growth.

The system GMM estimator gives consistent and efficient estimates of the model's coefficients, taking both differenced variables and delayed levels into account. It resolves endogeneity concerns and contributes to the understanding of the causal relationship between ICT and economic growth in the selected European countries.

This study intends to use the System GMM estimator to accurately estimate the parameters and obtain reliable insights into the impact of ICT on economic growth in the European context, while addressing potential endogeneity issues and controlling for unobserved heterogeneity.

In order to investigate the effect of information and communication technologies on economic growth, we use the following econometric model:

$$\ln GDP_{ti} = \beta_0 + \beta_1 \ln GDP_{ti-1} + \beta_2 \ln ICT_{ti} + \beta_s \ln Z_{ti} + y_i + \eta_i + \varepsilon_{it} \qquad (1)$$

Where $\ln GDP_{ti}$ is the logarithm of GDP per capita; β_0 is a constant term; $\beta_1 \ln GDP_{ti-1}$ is the one period lagged logarithm of GDP per capita. β_1 coefficient is anticipated to be statistically significant in order to validate the dynamic process of this model, that is, the previous GDP per capita may have an impact on current GDP. $\beta_2$displays the estimated parameter of ICT variables, with each proxy estimated in its own equation. The type of proxy employed in the ICT option causes a difference in these calculations, while all other independent variables remain constant. ICT's proxies are presented by the number of fixed telephone lines per 100 inhabitants, the number of mobile phone user per 100 inhabitants and the number of internet user per 100 inhabitants.

β_s donates the estimated parameters of each control variable Z. That is to say it can reflect the value of consumer price index (β_3), trade openness (β_4), and final consumption expenditure (β_5). For this study, five independent variables are defined, including a lag dependent variable, ICT, and three control variables for each equation that will be calculated. As a result, based on neoclassical growth theories and empirical evidence, their coefficient should be positive. And y_i represents time dummies and it is included to prevent any possible cross-individual correlation, η_i donates unobserved particular terms for each country, while ε_{it} donates the error terms that are supposed to be white noise.

The Stata 15 package program was used to estimate the model in this investigation.

3.2. Variables and Data Collection

To conduct our analysis, we have compiled a rich dataset incorporating relevant ICT and economic growth indicators for the selected European countries. The ICT indicators encompass various dimensions of digital technology adoption and infrastructure, such as fixed telephone lines, mobile subscriptions, and internet users. These indicators reflect the extent to which countries have embraced and integrated ICT into their economies.

Additionally, economic growth indicator, which is gross domestic product (GDP), has been incorporated into the dataset. This indicator captures the overall economic performance and provide insights into the relationship between ICT and key economic outcomes. In the study, apart from these variables, different variables were also used according to the chosen method. The variables that were used in the study and summary statistics of each variable are given in Table 1.

The dataset employed in this study is derived from reputable international source, as the World Bank. By utilizing established and reliable data sources, we aim to assure the correctness and consistency of the variables used in the analysis. The time period coveres specified period from

2001 to 2021, allowing for a longitudinal analysis of the relationship between ICT and economic growth. The availability of historical data enables us to capture trends and identify potential shifts in the ICT-economic growth dynamics within the selected European countries.

By utilizing this robust dataset, we aim to provide a comprehensive and rigorous analysis of the influence of ICT on economic growth in the European countries. The dataset's breadth and depth allow for a nuanced exploration of the multifaceted relationship between ICT and economic development, providing valuable insights for policymakers, researchers, and stakeholders interested in leveraging ICT for sustainable economic growth in the Europe.

Table 1: Variables

Variables	*Definition*	*Source*	*Values*	
GDP	GDP per capita	World Bank	Mean	9.90
			SD	1.04
			Min	6.22
			Max	11.80
TEL	Fixed telephone lines (per 100 inhabitants)	World Bank	Mean	3.48
			SD	0.52
			Min	1.31
			Max	4.31
MOB	Mobile phone user (per 100 inhabitants)	World Bank	Mean	4.62
			SD	0.43
			Min	1.52
			Max	5.14
INT	Internet user (per 100 inhabitants	World Bank	Mean	4.00
			SD	0.72
			Min	-1.12
			Max	4.60
CPI	Consumer price index	World Bank	Mean	4.59
			SD	0.21
			Min	3.62
			Max	5.75
TRD	Trade openness	World Bank	Mean	4.60
			SD	0.44
			Min	3.81
			Max	5.96
PCNS	Final consumption expenditure	World Bank	Mean	4.32
			SD	0.14
			Min	3.58
			Max	4.73

Our study' theoretical underpinning is based on the awareness that technical improvements, particularly in the field of ICT, have become powerful drivers of economic progress. Our selection of variables shows careful examination of factors that influence economic growth both directly and indirectly. We establish GDP as the dependent variable, indicating the ultimate measure of

economic performance. Recognizing the temporal structure of economic processes, we include lagged GDP as an endogenous variable that captures the inertia of past economic activity.

We examine the crucial function of fixed telephone lines, mobile phone usage, and internet usage as core components of ICT to develop a logical connection between variables. These explanatory factors indicate how far countries have progressed in adopting information and communication technology, which can boost efficiency, innovation, and market reach. These factors reflect the assumption that a technologically enabled society is ready for increased economic growth through rapid business interactions, information transmission, and digital commerce.

We include critical control variables with our primary variables to account for external influences on economic growth. The Consumer Price Index (CPI) captures inflationary pressures, influencing consumer purchasing power and thus economic performance. Trade and final consumption expenditure variables, respectively, provide insights into external trade dynamics and domestic consumption patterns, both of which play important roles in establishing a country's economic trajectory.

Our study tries to unravel the numerous paths by which ICT, inflation, trade, and consumption interact to form economic growth patterns in the European setting by interlinking these variables within a robust analytical framework. This theoretical foundation not only strengthens our study design, but it also contributes to the scholarly discourse on the complex dynamics that underpin the transformational potential of ICT in promoting socioeconomic advancement.

The analysis in this study focuses on 35 selected European countries, encompassing a diverse range of economies and varying levels of ICT adoption. The countries included in the dataset represent different regions within the Europe, providing a comprehensive coverage of the economic landscape across the continent. This paper aims to investigate the effect of information and communication technologies on economic growth in 35 selected European countries during 2001-2021. The dataset of the study was obtained from the World Bank and the countries involved in the study are shown in Table 2.

Table 2: Countries

Albania	France	Luxembourg	Russian Federation
Austria	Germany	Malta	Slovak Republic
Belgium	Greece	Moldova	Slovenia
Bulgaria	Hungary	Netherlands	Spain
Croatia	Ireland	North Macedonia	Switzerland
Denmark	Iceland	Norway	Sweden
Czechia	Italy	Poland	United Kingdom
Estonia	Lithuania	Portugal	Ukraine
Finland	Latvia	Romania	

4. Findings

The findings of the study, which was conducted on 35 selected European countries that we aim to analyse the effect of ICT on economic growth, were obtained by applying the stationarity test, pooled OLS, fixed and random effects estimators, and finally, two step system GMM estimators.

4.1. Stationarity Condition

Since it is a necessary condition for the series to have stationarity in panel data analysis. As it is known, when working with non-stationary data, test statistics will lose their reliability and spurious regression problems occur between variables. The LLC unit root test was used to determine stationarity of the variables. LLC unit root test results have been shown in Table 3.

Table 3: Levin, Lin, and Chu Unit Root Rest Results

Variables	In level and with intercept	One difference and with intercept	Variable	In level and with intercept	One difference and with intercept
GDP	-11.23*** (.000)	-11.39*** (.000)	TEL	7.64 (1.000)	-2.96** (.001)
CPI	-5.77*** (.000)	-6.30*** (.000)	MOB	-9.47*** (.000)	-7.73*** (.000)
TRD	-5.41*** (.000)	-11.91*** (.000)	INT	-17.87*** (.000)	-14.23*** (.000)
PCNS	-3.04** (.001)	-11.65*** (.000)			
Notes: p-value in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%					

According to the LLC unit root test, all variables are stationary at the (I_0) level except TEL. But when we check one difference for TEL, we see that TEL becomes stationary at the (I_1) level.

4.2. Pooled OLS, Fixed Effect and Random Effect Estimators

After the stationarity test, the pooled OLS, fixed, and random effects estimators were used to estimate the effect of ICT on economic growth. Pooled OLS (Pooled Ordinary Least Squares) is a regression method used in data analysis. This approach is ideal for analyzing panel data amongst different units or groupings. Panel data are data sets that have the same units observed over time. Pooled OLS uses regression analysis and takes all panel data as a single data set. In this approach, the entire data set is put to a single regression model, with no regard for distinctions across units or groups. As a result, discrepancies between units or groups are ignored, and all units are studied collectively. In panel data analysis, it is supposed that one of the ways to include the findings obtained from the changes that occur between the units or the changes that occur over time between the units in the analysis is that the existing change will cause differences in the coefficients in the regression analysis. Fixed-effect models are those that take this shift into consideration. Random effects analysis is used if the data to be analyzed are selected at random or as a sample from the entire universe, whereas fixed effects analysis is used otherwise (Baldemir and Keskiner, 2004: 48). Pooled OLS, Fixed Effect and Random Effect test results have been shown in Table 4.

Table 4: Pooled OLS, Fixed Effect and Random Effect Results

Dependent variable: GDP per capita (GDP)			
Variables	Pooled OLS	Fixed Effect	Random Effect
GDP (-1)	0,9605*** (0,000)	0,8044*** (0,025)	0,9598*** (0,004)
CPI	-0,0598* (0,028)	-0,0174 (0,030)	-0,0592 (0,036)
TRD	-0,0017 (0,006)	-0,0735* (0,035)	-0,0023 (0,005)
PCNS	-0,1372*** (0,031)	-0,4208*** (0,073)	-0,1425*** (0,025)
TEL	-0,0002 (0,004)	-0,0198 (0.010)	-4,6800 (0.006)
MOB	0,0292* (0,012)	0,0999*** (0.015)	0,0308*** (0.009)
INT	0,0056 (0,006)	0,0008 (0,007)	0,0048 (0,005)
Number of observations	700	700	700
Number of countries	35	35	35
R^2	0.9972	0.9938	0.9972

Notes: The significance level of 10%, 5%, and 1% are indicated, respectively, by *, **, and ***. The coefficient estimates are followed by the standard errors, which are given in parentheses.

According to the Pooled OLS, Fixed Effect and Random Effect estimators' results, among the variables CPI, TRD, PCNS and TEL negatively affect GDP whereas GDP (-1), MOB and INT positively affect. In terms of significancy of the effects, in Pooled OLS estimator, GDP (-1), CPI, PCNS and MOB significantly affect the dependent variable, GDP, although TRD, TEL and INT do not significantly affect. According to Fixed Effect estimator results, the effect is significant in GDP(-1), TRD, PCNS and MOB, but is not significant in CPI, TEL and INT. Lastly, Random Effect estimator results show that GDP(-1), PCNS and MOB significantly affect GDP, whereas CPI, TRD, TEL and INT do not.

4.3. GMM Estimator

To examine the effect ICT on economic growth in the 35 selected European countries, we employ the System GMM approach. The System GMM method is particularly suitable for panel data analysis, as it effectively addresses endogeneity and allows for efficient estimation in the presence of persistent variables. By employing the System GMM method, this study aims to provide robust and reliable estimates of the relationship between ICT and economic growth in the selected European countries. Two-step system GMM test results have been shown in Table 5.

Table 5: Dynamic Panel Data Estimation, Two Step System GMM Results

Dependent variable: GDP per capita (GDP)						
Variables	Coef.	Corrected Std. Err.	t	P > t	[95% Conf. Interval]	
GDP (-1)	0.9255492	0.0213465	43.36	0.000***	0.8821678	0.9689306
CPI	-0.3192687	0.1484919	-2.15	0.039*	-0.6210405	-0.017497
TRD	-0.0166675	0.0146777	-1.14	0.264	-0.046496	0.0131611
PCNS	-0.2329599	0.0575615	-4.05	0.000***	-0.3499389	-0.1159809
TEL	0.0094694	0.017558	0.54	0.593	-0.0262127	0.0451515
MOB	0.0863847	0.0306785	2.82	0.008**	0.0240385	0.148731
INT	0.0477272	0.044741	1.07	0.294	-0.0431975	0.1386518
Arellano-Bond test AR (1):	z = – 2.95 Pr > z = 0.003					

Arellano-Bond test AR (2):	z = – 2.31 Pr > z = 0.121
Sargan test:	chi2(18) = 116.47 Prob > chi2 = 0.000
Hansen test:	chi2(18) = 19.08 Prob > chi2 = 0.387
Number of observations	700
Number of countries	35

Note: Variables with "*," "**," and "***" are significant at p<1%, p<5%, and p<10% respectively. The estimation includes year dummies as well.

According to the results of the two step system GMM estimator, GDP(-1), TEL, MOB and INT positively affect economic growth whereas CPI, TRD and PCNS negatively affect. In terms of significant levels of the effects, GDP (-1), CPI, PCNS and MOB significantly affect economic growth although TRD, TEL and INT insignificantly affect. All in all, ICT positively affects GDP in 35 selected European countries. And it means, we accept H1, H1a, H1b and H1c. The positive effect of ICT on economic growth findings were also found by Das et al. (2018), Erdil et al. (2010), Farhadi and Fooladi (2011), Kooshki and Ismail (2011) and Yousefi (2011).

The Arellano-Bond test AR(1) and AR(2) results in the table show the results of the statistical tests used to evaluate the presence of serial correlation.

- Arellano-Bond test AR(1): It tests the hypothesis of the first autoregressive (AR(1)) model. The z-value is – 2.95 and the p-value is 0.003. This indicates that the hypothesis is rejected and serial correlation exists. That is, there is a correlation between the previous period values of the dependent variable.
- Arellano-Bond test AR(2): It tests the hypothesis of the second autoregressive (AR(2)) model. The z-value is – 2.31 and the p-value is 0.121. In this case, the hypothesis cannot be rejected and no conclusive evidence can be provided for the existence of serial correlation. It indicates weak or no quadratic autoregressive correlation.

Sargan test and Hansen test are statistical tests used to evaluate the suitability and validity of the panel data regression model used.

- Sargan test: This test checks that it provides accurate and consistent estimates of instrumental variables. According to the results in the table, the chi-square statistic is 116.47 and the p value is 0.000. This indicates that the Sargan test rejects the hypothesis and that the instrumental variables are appropriate and consistent in the model.
- Hansen test: This test checks whether the regression model has specification errors. According to the results in the table, the chi-square statistic is 19.08 and the p value is 0.387. This indicates that the Hansen test does not reject the hypothesis and that the model has no speciation errors.

As a result, the Arellano-Bond test showed there is evidence of first-order autocorrelation but there is no evidence of second-order autocorrelation in the first difference, while the Sargan test

showed that the instrumental variables were correct and the model was appropriate. The Hansen test, on the other hand, shows that there are no specification errors.

The analysis of our research findings sheds light on some notable patterns in the complex interaction between ICT and economic growth. Our research highlights the positive influence of ICT components, such as telephone lines, mobile phone usage, and internet usage, on economic growth in the selected 35 European countries. These findings are consistent with the growing body of literature indicating that technological developments have the ability to promote economic progress. Furthermore, our research dives deeper by uncovering the subtle mechanisms by which improved communication technologies drive innovation, foster business connections, and facilitate market reach, ultimately promoting economic growth.

When compared to previous studies, our findings fit with and enhance current data supporting the favorable relationship between ICT and economic growth. Notably, the positive influence of ICT on economic growth contrasts with the found negative effects of the consumer price index, trade, and final consumption spending on economic growth in our environment. This disparity highlights the complex interplay of factors influencing economic performance, emphasizing the necessity for a complete analysis that considers both technological and macroeconomic components. Our research goes beyond past studies by delving further into specific ICT components and their direct contributions to economic growth, increasing the granularity of our understanding.

However, it is important to recognize that differences between our findings and earlier work may be due to differences in sample selection, econometric techniques, and contextual factors. As a result, the found detrimental effects of specific macroeconomic variables necessitate additional research to understand the underlying mechanisms and relevant policy consequences.

5. Conclusion

This paper aimed to investigate the effect of information and communication technologies on economic growth in 35 selected European countries during 2001-2021. By analyzing this relationship, we seek to shed light on the potential benefits and implications of ICT adoption for sustained economic development within the European countries' context. Understanding how ICT influences economic growth is essential for formulating effective policies and strategies that leverage digital technologies to foster prosperity, innovation and competitiveness.

To conduct our analysis, we have compiled a rich dataset incorporating relevant ICT and economic growth indicators for the selected European countries. The ICT indicators encompass various dimensions of digital technology adoption and infrastructure, such as fixed telephone lines, mobile subscriptions, and internet users. Additionally, an economic growth indicator, which is gross domestic product (GDP), has been incorporated into the dataset. This indicator captures the overall economic performance and provides insights into the relationship between ICT and key economic outcomes. In the study, apart from these variables, different variables such as consumer price index, trade openness and final consumption expenditure were also used according to the chosen method.

To examine the effect ICT on economic growth in the 35 selected European countries, we employed the System Generalized Method of Moments (GMM) approach. The System GMM method is particularly suitable for panel data analysis, as it effectively addresses endogeneity and allows for efficient estimation in the presence of persistent variables.

Since it is a necessary condition for the series to have stationarity in panel data analysis. The LLC unit root test was used to determine stationarity of the variables. According to the LLC unit root test, all variables are stationary at the (I0) level except TEL. But when we checked one difference for TEL, we saw that TEL became stationary at the (I1) level.

After the stationarity test, the pooled OLS, fixed and random effects estimators were used to estimate the effect of information and communication technologies on economic growth. According to the Pooled OLS, Fixed Effect and Random Effect estimators' results, among the variables CPI, TRD, PCNS and TEL negatively affected GDP whereas GDP (-1), MOB and INT positively affected. In terms of significancy of the effects, in Pooled OLS estimator, GDP (-1), CPI, PCNS and MOB significantly affected the dependent variable, GDP, although TRD, TEL and INT were not significantly affected. According to Fixed Effect estimator results, the effect was significant in GDP(-1), TRD, PCNS and MOB, but was not significant in CPI, TEL and INT. Lastly, Random Effect estimator results showed that GDP(-1), PCNS and MOB significantly affected GDP, whereas CPI, TRD, TEL and INT did not.

According to the results of the two-step system GMM estimator, GDP (-1), TEL, MOB, and INT positively affected GDP, although CPI, TRD and PCNS negatively affected. In terms of significance of the effects, the effect of GDP (-1), CPI, PCNS and MOB was significant, whereas the effect of TRD, TEL and INT were not significant. The Arellano-Bond test showed that there is no autocorrelation, and according to the Sargan and Hansen tests results, the instrumental variables are appropriate and consistent in the model and the model has no speciation errors. From the results it can be concluded that ICT positively affected GDP in 35 selected European countries. Based on the results of the study, some suggestions can be made for European countries to increase the positive effect of ICT on economic growth:

- Given that the developed countries that produce and export ICT have a high impact on economic growth, it can be stated that the sectors producing goods and services related to these technologies should be backed up by a variety of credit and incentive applications. As a result of the policies that will be adopted in this regard, the expanding sector will be able to contribute significantly to growth by increasing production and exports.
- Infrastructure expenditures in information and communication technology should be enhanced; however, because technology alone cannot affect growth, these investments should be accompanied by complementary investments such as physical and human capital investments.

- The employment of these technologies in economic activity, particularly as a basic factor of production, should be ensured. Because these technologies allow us to produce goods and services at a cheaper cost and in less time, they contribute to economic growth by increasing productivity.
- Foreign trade policies that restrict access to sophisticated technologies should be relaxed or eliminated entirely.

Our study's consequences go beyond the academic sphere, providing tangible insights that might influence policy decisions aimed at encouraging long-term economic growth. The favorable influence of ICT components such as telephone lines, mobile phone usage, and internet usage on economic growth emphasizes technology's vital role in promoting wealth. To ensure equal distribution across areas, policymakers should prioritize programs that promote universal access to these ICT tools, including investments in infrastructure development and connectivity advancements. Furthermore, creating an atmosphere that encourages innovation and entrepreneurship in the technology industry can increase the favorable impacts of ICT on economic growth.

Our findings also emphasize the significance of tackling negative factors including the consumer price index, trade, and final consumption expenditure. Policymakers should take steps to reduce inflationary pressures by implementing sensible monetary and fiscal policies, guaranteeing price stability, and increasing consumer purchasing power. Strategic trade policies that foster diversity of exports and imports can boost economic resilience and reduce a country's vulnerability to external shocks. Furthermore, policies focused at optimizing consumption patterns and fostering responsible resource allocation might assist in redirecting expenditures toward productive investments, boosting long-term economic growth.

This study adds to the current body of knowledge by providing unique insights on the relationship between ICT and economic growth in 35 European countries. While prior studies have acknowledged the overall importance of ICT in driving economic development, our work advances the field by giving a detailed analysis that identifies processes by which ICT influences economic growth. We reveal a nuanced and contextually rich perspective on how these ICT components contribute to the socioeconomic growth of European nations by methodically studying the combined influence of mobile phone usage, fixed telephone lines, and internet usage. Furthermore, our findings shed light on the complex interplay between ICT adoption, policy frameworks, and macroeconomic indicators, providing a new understanding of the multidimensional dynamics underlying the observed positive benefits. This study not only emphasizes the importance of ICT as a driver of economic growth, but it also presents a unique perspective that adds to the scholarly conversation in this field.

While this study provides useful insights on the relationship between ICT economic growth in European countries, some limitations should be considered. For starters, our analysis is limited to a subset of European countries, which may restrict the generalizability of our findings to a broader

global setting. Future study could broaden the analysis to include a broader range of countries, considering differences in economic structures, technical readiness, and policy contexts. Furthermore, the variables used in our analysis capture multiple aspects of ICT adoption but do not go into the qualitative components of technology implementation or examine the subtle impacts on different sectors. A more detailed examination of these issues could provide a more complete picture of the methods through which ICT promotes economic growth.

Additionally, our research assumes a linear link between ICT factors and economic growth, ignoring any nonlinearities or threshold effects. Investigating such nonlinear dynamics could lead to a better understanding of the complicated interplay between technology and economic progress. Furthermore, as technical improvements and economic policies evolve over time, the observed associations may be influenced by the time period under examination. A longitudinal investigation spanning multiple time intervals could shed light on temporal fluctuations in the ICT-economic growth nexus.

Future study could use different econometric approaches or explore causal linkages using experimental or quasi-experimental designs to improve the robustness of our findings. In addition, given the multifaceted character of economic growth, future research may include additional indicators that reflect aspects such as human capital development, social well-being, and environmental sustainability.

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