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How Does Information and Communication Technologies Affect Economic Growth? A Comparative Analysis of the Economies of the European Union and Asia-Pacific Region*

Bilgi ve İletişim Teknolojileri Ekonomik Büyümeyi Nasıl Etkiler? Avrupa Birliği ve Asya Pasifik Bölgesi Ekonomileri İçin Karşılaştırmalı Bir Analiz

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ABSTRACT

In the contemporary era of digitization, economies have been significantly influenced by the emergence of information and communication technology (ICT). In this digital age, the ICT sector all over the world has entered a period of rapid growth. The swift advancements within the ICT sector have played a pivotal role in shaping the global economy while simultaneously influencing the economic landscape of the European Union (EU) and Asia-Pacific region (APAC) countries. The purpose of this study is to comparatively evaluate ICT, its place in the EU and APAC countries' economies, and how it affected economic growth between 2007-2019. The dataset was analyzed using the Levin, Lin, and Chu unit root test, pooled ordinary least-squares (OLS), fixed effects, random effects, and two-step system generalized method of moments (GMM) estimators. The two-step system GMM findings show ICT's effects on economic growth to vary according to regional conditions. While Internet use has been found to contribute positively to the economic growth of the countries within the EU, this situation was observed to have had the opposite effect in the APAC region countries. These region-specific dynamics highlight the need for tailored policy considerations, suggesting the impact of ICT on economic development to be contingent upon regional conditions. The novelty of this research lies in its cross-regional perspective, thus contributing valuable knowledge for informed policy decisions in the increasingly interconnected global landscape. This study emphasizes the importance of regional dynamics in understanding the influence ICT has on economic growth and can guide policy makers and business leaders in shaping ICT strategies and investments according to regional characteristics.

Keywords: ICT, economic growth, GMM, European Union countries, Asia-Pacific region countries

Jel Code: O11, O20, O33

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ÖZ

Çağdaş dijitalleşme çağında ekonomi, bilgi ve iletişim teknolojilerinin (BİT) ortaya çıkmasından önemli ölçüde etkilenmektedir. İçinde bulunduğumuz dijital çağda tüm dünyada BİT sektörü hızlı bir büyüme sürecine girmiştir. Bu hızlı ilerlemeler, BİT sektörlerinde, dünya ekonomisini ve buna paralel olarak Avrupa Birliği (AB) ve Asya-Pasifik bölgesi (APAC) ülkelerinin ekonomisini etkileme eğilimindedir. Bu çalışmanın yürütülmesindeki amaç BİT'in AB ve APAC ülkeleri ekonomisindeki yeri ve ekonomik büyümeyi nasıl etkilediği konusunda 2007-2019 yılları arasında karşılaştırmalı bir değerlendirme yapmaktır. Veri seti Levin, Lin & Chu birim kök testi, Pooled OLS, Sabit Etkiler, Rastgele Etkiler ve iki adımlı sistem Genelleştirilmiş Momentler (GMM) tahmin edicileri kullanılarak analiz edilmiştir. İki aşamalı sistem GMM bulguları, BİT'in ekonomik büyüme üzerindeki etkilerinin bölgesel koşullara göre değişebileceğini göstermektedir. AB ülkelerinde internet kullanımının ekonomik büyümeyi olumlu etkilediği saptanırken, APAC bölgesi ülkelerinde bu durumun tam tersi etki yarattığı gözlemlenmiştir. Bu bölgeye özgü dinamikler, özel politika değerlendirmelerine olan ihtiyacın altını çiziyor ve BİT'in ekonomik kalkınmadaki rolünün bölgesel koşullara bağlı olduğunu öne sürüyor. Araştırmamızın yeniliği, giderek birbirine bağlanan küresel ortamda bilinçli politika kararlarına değerli bilgiler katan bölgeler arası perspektifinde yer almaktadır. Bu çalışma, BİT'in ekonomik büyüme üzerindeki etkilerinin anlaşılmasında bölgesel dinamiklerin önemini vurgulamakta ve politika yapıcılara ve iş dünyası liderlerine BİT stratejilerini ve yatırımlarını bölgesel özelliklere göre şekillendirmede yol göstermektedir.

Anahtar Kelimeler: BİT, ekonomik büyüme, GMM, Avrupa Birliği ülkeleri, Asya-Pasifik bölgesi ülkeleri

Jel Sınıflaması: O11, O20, O33

1. Introduction

While the boundaries of technology are expanding daily, information and communication technology (ICT) is transforming nations' economic structures and reshaping their growth capacities. Although this transformative impact on economic growth varies between developed and developing countries, broad consensus exists that the proliferation and use of ICT have profound and wide-ranging impacts on the global economy (Tunalı & Güz, 2021; Farhadi & Fooladi, 2020; Kurniawati, 2021). This paper aims to comparatively examine the effects ICT has on the economic growth in 27 European Union (EU) and 20 Asia-Pacific (APAC) region countries.

The EU is recognized as a region that has led the way in ICT adoption and innovation, as well as economic integration and policy coordination. Countries in this region have taken steps to increase their growth and competitiveness through their investments in ICT infrastructure and government policies. The APAC region also stands out with its rapidly changing technological landscape and dynamic growth in this field. While the region leads the way in adopting and disseminating technological innovations with its developed economies, it also seeks growth and development opportunities with its developing economies (Koç, 2021; Alper, 2018; David & Grobler, 2020).

The relationship between ICT and economic growth has been a focus of scholarly investigation in an era of rapid technological advancement. ICT's ability to revolutionize economies has attracted a lot of interest, which has made conducting in-depth studies necessary that explore the complex mechanisms at work. This research aims to further this conversation by performing a thorough examination of the relationship between ICT and economic growth, with a particular emphasis on identifying regional implications.

This study will not only provide a comprehensive understanding of how ICT shapes economic growth but will also aim to optimize the relationship between technological development and economic growth by providing policymakers with concrete recommendations. The results of the paper will provide strategic information for guiding future policy-making in EU and APAC countries and for maximizing the potential ICT has to contribute to economic growth. This information will provide an in-depth perspective on how digital transformation can play a role in reducing inequalities on a global scale and in achieving the Sustainable Development Goals (SDGs), as well as serve as a road map for decision makers in both regions.

The corpus of already completed research offers insightful information about how ICT generally affects economic development. However, ICT's varied impacts on economic growth and their regional variations remain barely understood. Comprehending these regional differences is essential for developing focused and efficient strategies that capitalize on ICT's potential in a variety of settings. In order to close this gap, this study uses the two-step system generalized method of moments (GMM) to analyze the effects ICT components (i.e., phone lines, mobile phone usage, and Internet usage) have on economic growth in different regions.

To examine in depth the role ICT has on economic growth, the study uses a comprehensive dataset obtained from 27 EU and 20 APAC region countries between 2007-2019. The paper evaluates the relationship between the development of ICT infrastructure and economic growth during this period using specific indicators such as number of fixed telephone lines, mobile phones, and Internet users. These indicators represent different aspects of technological access and

penetration, with gross domestic product (GDP) per capita being used as a proxy for economic growth. The two-step system GMM was particularly preferred to address the internal dynamics of these variables over time, as well as any potential endogeneity problems. The two-step system GMM analysis allows for both contemporaneous and lagged variables to be taken into account, thus enabling a more dynamic and constructive modeling of the impact ICT has on economic growth. This approach aims to provide policymakers with important insights while also allowing for a detailed assessment of the short- and long-term impacts of ICT investments. As a result, this analysis aims to elucidate the multidimensional structure of the relationship between ICT and economic growth and thereby contribute to the more effective design of regional developmental strategies.

In summary, the research moves forward with a thorough investigation in the following sections. Section 3 is titled Materials and Method and explains the research design with a focus on the selected variables and procedures. Section 4 is the findings and examines them in detail using econometric methods and stationarity conditions. Finally, Section 5, titled the Conclusion, summarizes these results alongside their implications and contributions. Together, these sections provide a thorough examination of how ICT affects economic growth regionally and will be able to inform future research and policy decisions.

2. Literature Review

This section examines existing research on the effects ICT has on economic growth. This review has been undertaken to understand the expanding role ICT plays in the global economy and how the impact of these technologies may vary within different economic structures. The literature review includes various theoretical and empirical studies that have analyzed ICT's contributions to economic growth and covers key theories, key findings, and current research trends in this field. This literature review provides in-depth context for the analysis of the research and relates the findings to existing academic studies.

Appiah-Otoo and Song (2021) examined the effects of ICT on economic growth in developed, developing, and underdeveloped countries using the panel analysis method between 2002-2017 over a total of 123 countries, including 45 developed, 58 developing, and 20 underdeveloped countries. As a result, their study showed having mobile phones, Internet access, and a fixed broadband connection to have a positive impact on economic growth in each country group. Koç (2021) used linear discrete-time stochastic state space models between 2001-2018 on data from Türkiye and established a model based on nine independent variables to explain growth. As a result, that study revealed individual Internet use and having a mobile phone subscription to have a growth-enhancing effect. The utilization of information technologies and the integration of ICT-based equipment contribute to the advancement of economic growth (Zhou et al., 2018). Moreover, ICT has the potential to boost economic performance by offering market information, facilitating the dissemination of information, promoting competition, supporting entrepreneurial activities, aiding job search processes, and facilitating the distribution of ideas (Czernich et al., 2011).

Tunalı and Güz (2021) conducted a study to examine the effect the ICT Development Index (IDI) has on economic growth using the panel analysis method between 2010-2016, based on the results of data from 79 countries, they observed the IDI to have a positive effect on economic growth. Myovella et al. (2020) used the GMM and ordinary least-squares (OLS) models between 2006-2016 over a total of 74 countries, including 41 sub-Saharan Africa (SSA) countries and 33 Organisation for Economic Co-operation and Development (OECD) countries. They discussed the comparative analysis they had made on the basis of countries whose growth had been impacted. According to their results, while mobile technologies had a greater effect on economic growth in SSA countries, this effect was not significant for OECD countries. They showed individual Internet usage to have a positive impact on economic growth for each country group; however, its impact on economic growth was low in SSA countries due to the underdevelopment of Internet infrastructures. The positive impact of ICT on economic growth has been substantiated by various research initiatives conducted at the cross-country level. Notably, the positive correlation between ICT and economic growth was confirmed by Khan et al. (2020) for South Asia, by Asongu and Odhiambo (2019) for Africa, by Alshubiri et al. (2019) for the Gulf Cooperation Council (GCC), by Kurniawati (2020) for the OECD, by Ghosh (2017) for the Middle East and North Africa (MENA), by Zhang and Danish (2019) for Asia, and by Donou-Adonsou and Lim (2018) for SSA.

Hekim Yılmaz and Kırışkan (2020) analyzed the effects of telecommunication infrastructure on economic growth using unit root tests and cointegration tests between 1980-2015 on data from Türkiye; their results showed the development of telecommunication infrastructure to have had an increasing effect on economic growth. Farhadi and Fooladi (2020) analyzed the effect of ICT-access on economic growth using GMM models between 2006-2015 based on data from 142 countries. According to the results of their studies, although the effect of ICT on economic growth was greater in high-income countries, it had an increasing effect in each country. In country-specific investigations,

numerous scholars have emphasized the significance ICT have in bolstering economic growth. For instance, the role ICT has in promoting economic development was underscored by Adedoyin et al. (2020) for the USA, by Chakpitak et al. (2018) for Thailand, by Kumar et al. (2016) for China, by Agarwal et al. (2018) for India, by Salahuddin and Gow (2016) for South Africa, by Ishida (2015) for Japan, and by Salahuddin and Alam (2015) for Australia.

Alper (2018) created two models using the panel data method for 24 countries between 1996-2016 and analyzed the relationship between ICT and economic growth. According to Alper's results, ICT increases economic growth. Niebel (2018) tried to explain the relationship between ICT and economic growth according to country groups (developed, developing, and underdeveloped countries) by performing a regression analysis on 59 countries between 1995-2010. According to the study's results, ICT contributes to economic growth. By using data from 1998-2016 for selected African countries, David and Grobler (2020) showed ICT penetration to have positive effects on economic growth and development. Moreover, Kurniawati's (2021) research found high Internet penetration to positively affect growth in the 25 Asian countries that were selected between 2000-2018. Nair et al. (2020) stated RD and ICT infrastructure to have contributed to economic growth in OECD countries between 1961-2018.

The literature review highlights the contribution ICT has made to economic growth, as well as the potential challenges and opportunities the diffusion of these technologies has on economic structures. The research has shown the findings from the literature to help at better understanding ICT's role throughout the analyzed period and in different regional contexts. This review has provided valuable insights into how the findings of the current study can be positioned within a broader academic dialogue.

3. Materials and Method

3.1. Methodology

This study section develops a two-step system GMM to examine the effects ICT has had on economic growth using data obtained from 27 EU and 20 APAC countries between 2007-2019. The two-step system GMM approach is a panel data method that takes into account both time-constant individual effects and specific time series characteristics. It has been developed specifically to provide consistent and efficient estimates in dynamic panel data models filled with potentially endogenous independent variables.

System GMM was first proposed by Arellano and Bover (1995) and Blundell and Bond (1998) and consists of two main components, the first being level equations and the second being difference equations. The instruments used in system GMM capture time-constant but individual-varying properties of the model, thereby mitigating potential endogeneity issues associated with time-dependent variables.

Mathematically, the econometric representation of the system GMM is expressed for the level equation as:

$$y_{it} = \alpha y_{i,t-1} + x_{it}^{'}\beta + \mu_i + \epsilon it \tag{1}$$

and for the difference equation as:

$$\Delta y_{it} = \alpha \Delta y_{i,t-1} + \Delta x_{it}^{'}\beta + \Delta \epsilon_{it} \tag{2}$$

where y_{it} represents the dependent variable of the i^{th} individual at time t, $x_{it}^{'}$ represents the vector of independent variables, μ_i represents the individual-specific constant, and ϵ_{it} represents the random error term. The Δ operator denotes first differences (i.e., $y_{it} - y_{i,t-2}$).

The econometric analysis applies Arellano and Bond's two-step estimation procedure, which first corrects the results obtained with the difference GMM estimator and then calculates the results obtained with the system GMM estimator using the corrected standard errors. This procedure aims to reduce the bias caused by potential endogenous variables in the model.

This study uses the program Stata 18 to conduct the system GMM analyses. Stata 18's xtabond2 command is standard for implementing the system GMM estimator and includes widely accepted tests such as the Arellano-Bond serial correlation test and Hansen's test for overidentification of instruments using the J statistic. These tests are critical for evaluating the appropriateness of the specification of the estimated model and the validity of the instruments that are used.

This analysis investigates the influence of ICT on economic growth with a specific focus on 27 EU and 20 APAC countries, each characterized by distinct geographical and economic structures. Conducted over the period from 2007-2019, this comparative study utilizes a two-step system GMM estimator separately for both groups. The primary

objective is to uncover the variations in the impact ICT has on economic growth within these regions, thus contributing to a nuanced understanding of the relationship. The findings will help policymakers understand ICT investments and the effects these have on economic growth. Each estimator is equipped with carefully selected instruments to better understand the impact of the dynamics and variables specific to one's geographic group. In this way, the obtained results will be more robust and valid by taking regional characteristics into account.

The study's econometric model aims to examine the effects of ICT on economic growth (i.e., GDP per capita). The model constructs the logarithm of GDP as a linear relationship dependent on the logarithm of historical GDP, the logarithm of ICT indicators, and the logarithm of other control variables. The formulation of the econometric model is as follows:

$$lnGDP_{ti} = \beta_0 + \beta_1 lnGDP_{ti-1} + \beta_2 lnICT_{ti} + \beta_s lnZ_{ti} + y_i + \eta_i + \varepsilon_{it} \quad (3)$$

where:

- ln GDP_{ti} is the natural logarithm of the ith country's GDP per capita at time t.
- ln GDP_{ti-1} is the natural logarithm of the ith country's GDP per capita at time $t1$, representing the time-lagged dependent variable and reflecting the past performance of the economy.
- ln ICT_{ti} is the natural logarithm of the variables showing the level of ICT usage in the ith country at time t. The study uses this as an indicator that includes the number of fixed telephone lines, mobile phone plans, and Internet users.
- ln Z_{ti} is the natural logarithm of the control variables of the ith country at time t and aims to control the effect of other factors. The study uses consumer price index, trade openness, and final consumption expenditure as the control variables.
- y_i refers to country fixed effects and captures unobserved country-specific constant characteristics.
- η_i expresses time fixed effects and captures unobserved time-constant properties.
- ε_{it} is the random error term and represents random variation due to other factors not accounted for in the model.

The model was estimated with the two-step system GMM approach. This methodology is particularly recommended when time-lagged variables such as ln GDP_{ti-1} are present and potentially endogenous. System GMM addresses endogeneity using a set of endogenous and exogenous instruments, thereby improving the consistency and efficiency of the estimators.

The model estimation evaluated the validity of the instruments by using the Arellano-Bond serial correlation test and Hansen's J statistic. These provide important information about the fit of the model and the validity of the instruments used. The Arellano-Bond test tests whether a first-order autocorrelation is present in the error term of the model (which is expected) but not a second-order autocorrelation (which is not expected). Hansen's J statistic checks the over-identification of the instruments used in the model; namely, it checks whether the instruments are actually correlated with the endogenous variables in the model. The results of both tests are critical to the validity of the model predictions.

The system GMM approach generally prefers to take the logarithms of the variables in order to ensure their stationarity and obtain econometrically sound results. Logarithmic transformation is more sensitive when measuring proportional changes and can normalize the skewed distribution of economic data. This approach also facilitates interpreting proportional effects in econometric models.

While estimating this model, the study used the advanced tools offered by the Stata 18 software for panel data analysis. This software facilitates implementing the system GMM estimator and evaluating the accuracy of the results with statistical tests. In addition, the study has taken time and country fixed effects in the model in order for the estimation results to reflect the changing economic structures and fixed characteristics of various countries over time.

Consequently, this econometric model has been designed to comprehensively examine the impact ICT has on economic growth. The developed econometric strategy and applied statistical tests were used to ensure the robustness and consistency of the estimates obtained in the model. These findings offer policymakers and researchers robust insights by supplying valuable information to enhance their understanding of how ICT investments influence economic growth.

3.2. Variables and Data Collection

The variables considered in this study represent different aspects of economic growth for both the 27 EU and 20 APAC countries. The roles of the variables vary depending on the economic structure and level of ICT adoption in each region.

The dependent variable is GDP per capita and directly reflects the economic performance of each region. While higher GDP-per-capita values are generally observed in the EU countries, these values were observed to be distributed over a wide range in the APAC region. This reveals economic homogeneity to be present within the EU and economic heterogeneity to be present in the APAC region. The numbers for fixed telephone lines (*TEL*), mobile phone users (*MOB*), and Internet users (*INT*) were chosen as the independent variables and measure ICT's prevalence and degree of penetration in each region.

The control variables are consumer price index (*CPI*), trade openness (*TRD*), and final consumption expenditures (*PCNS*) and were chosen to take into account the economic conditions of both regions and their reactions to external shocks. These indicators organize the economic context in order to more clearly reveal the impact ICT has on economic growth.

The sources, summary statistics, and normality tests for all the variables used in this study are given in Tables 1 and 2. These tables contain descriptive statistics regarding the datasets, the sources for the variables, and the operational definitions of the variables that are used so that readers can clearly see the basis of the analysis and the scope of the dataset. This transparent approach increases the reliability of the study and the reproducibility of the results.

Table 1. *Variables for EU Countries*

Variables	*Definition*	*Source*	*Values*	
GDP	GDP per capita	World Bank	Mean	10.21
			SD	0.64
			Min	8.68
			Max	11.72
			Skewness	0.7711
			Kurtosis	0.0012
			Jarque-Bera	0.0082
TEL	Fixed telephone lines (per 100 inhabitants)	World Bank	Mean	3.50
			SD	0.44
			Min	1.58
			Max	4.19
			Skewness	0.0000
			Kurtosis	0.0014
			Jarque-Bera	0.0000
MOB	Mobile phone user (per 100 inhabitants)	World Bank	Mean	4.80
			SD	0.12
			Min	4.49
			Max	5.14
			Skewness	0.0255
			Kurtosis	0.3787
			Jarque-Bera	0.0560
INT	Internet user (per 100 inhabitants	World Bank	Mean	4.26
			SD	0.22
			Min	3.34
			Max	4.58
			Skewness	0.0000
			Kurtosis	0.0006
			Jarque-Bera	0.0000
CPI	Consumer price index	World Bank	Mean	4.64
			SD	0.06
			Min	4.41
			Max	4.81
			Skewness	0.0001
			Kurtosis	0.0293
			Jarque-Bera	0.0002
TRD	Trade openness	World Bank	Mean	4.72
			SD	0.46
			Min	3.81
			Max	5.93
			Skewness	0.0014
			Kurtosis	0.4218
			Jarque-Bera	0.0072
PCNS	Final consumption expenditure	World Bank	Mean	4.30
			SD	0.12
			Min	3.72
			Max	4.52
			Skewness	0.0000
			Kurtosis	0.0000
			Jarque-Bera	0.0000

Table 2. *Variables for APAC Countries*

Variables	*Definition*	*Source*	*Values*	
GDP	GDP per capita	World Bank	Mean	8.52
			SD	1.39
			Min	5.95
			Max	11.12
			Skewness	0.0030
			Kurtosis	0.0000
			Jarque-Bera	0.0000
TEL	Fixed telephone lines (per 100 inhabitants)	World Bank	Mean	2.01
			SD	1.47
			Min	-1.81
			Max	4.10
			Skewness	0.0007
			Kurtosis	0.1333
			Jarque-Bera	0.0026
MOB	Mobile phone user (per 100 inhabitants)	World Bank	Mean	4.45
			SD	0.51
			Min	2.03
			Max	5.20
			Skewness	0.0000
			Kurtosis	0.0000
			Jarque-Bera	0.0000
INT	Internet user (per 100 inhabitants	World Bank	Mean	3.32
			SD	1.03
			Min	0.00
			Max	4.56
			Skewness	0.0000
			Kurtosis	0.8066
			Jarque-Bera	0.0001
CPI	Consumer price index	World Bank	Mean	4.72
			SD	0.18
			Min	4.17
			Max	5.24
			Skewness	0.0051
			Kurtosis	0.4329
			Jarque-Bera	0.0195
TRD	Trade openness	World Bank	Mean	4.28
			SD	0.62
			Min	3.19
			Max	6.08
			Skewness	0.0001
			Kurtosis	0.7326
			Jarque-Bera	0.0013
PCNS	Final consumption expenditure	World Bank	Mean	4.32
			SD	0.24
			Min	3.79
			Max	5.24
			Skewness	0.0000
			Kurtosis	0.0000
			Jarque-Bera	0.0000

This study performs separate analyses on two different datasets. The first dataset includes 27 countries that are EU members, while the second dataset covers 20 APAC countries. The relevant countries are detailed in Tables 3 and 4. The total number of observations for both groups is 564 observations, with 324 for the EU and 240 for the APAC countries. These observations were collected to cover the period between 2007-2019. A detailed examination of the datasets from the two regions allows the study to evaluate the impact ICT has on economic growth while taking into account geographical and economic diversity.

Table 3. *European Union (EU) Countries*

Austria	Estonia	Italy	Portugal
Belgium	Finland	Latvia	Romania
Bulgaria	France	Lithuania	Slovak Republic
Croatia	Germany	Luxembourg	Slovenia
Cyprus	Greece	Malta	Spain
Czechia	Hungary	Netherlands	Sweden
Denmark	Ireland	Poland	

Table 4. *Asia-Pacific Region Countries*

Australia	India	Nepal	Thailand
Bangladesh	Indonesia	New Zealand	Timor-Leste
Bhutan	Japan	Pakistan	Tonga
China	Korea, Rep.	Philippines	Vanuatu
Fiji	Malaysia	Singapore	Vietnam

4. Findings

This section conducts a comparative analysis involving 27 EU and 20 APAC countries to assess the impact of ICT on economic growth. The methods used in this analysis include a stationarity test, pooled OLS, fixed and random effects estimators, and the two-step system GMM estimations. The findings comparatively reveal the effects of ICT on economic growth based on the data that were obtained using the specified methods. The results obtained through the use of these analytical methods provide critical information about the economic performance of these country groups.

4.1. Stationarity Condition

The Levin, Lin, and Chu unit root test was applied to the macroeconomic time series data of 27 EU and 20 APAC countries, thus forming the basis of the study. This test is critical for understanding whether the series is stationary or not, because non-stationary series can produce misleading results. The test results are summarized in Table 5 for the 27 EU member countries and in Table 6 for the 20 APAC countries.

Table 5. *The Levin, Lin, and Chu Unit Root Rest Results for the EU Countries*

Variables	In level and with intercept	One difference and with intercept	Variable	In level and with intercept	One difference and with intercept
GDP	-8.21*** (.000)	-19.68*** (.000)	TEL	0.82 (.998)	-16.91*** (.000)
CPI	-3.36 (.488)	-13.68*** (.000)	MOB	-9.41*** (.000)	-20.63*** (.000)
TRD	-6.46*** (.006)	-33.84*** (.000)	INT	-13.44*** (.000)	-15.48*** (.000)
PCNS	-8.35 (.013)	-26.35*** (.000)			

Notes: p-value in parentheses; * significant at 10%; ** significant at 5%; * significant at 1%**

Table 6. *The Levin, Lin, and Chu Unit Root Rest Results for APAC Countries*

Variables	In level and with intercept	One difference and with intercept	Variable	In level and with intercept	One difference and with intercept
GDP	-6.12*** (.000)	-14.28*** (.000)	TEL	-11.44*** (.000)	-31.49*** (.000)
CPI	-7.71*** (.000)	-7.45 (.032)	MOB	-7.80*** (.000)	-11.58*** (.000)
TRD	-6.68*** (.002)	-15.87*** (.000)	INT	-3.31 (.058)	-22.79*** (.000)
PCNS	-7.61*** (.000)	-14.71*** (.000)			

Notes: p-value in parentheses; * significant at 10%; ** significant at 5%; * significant at 1%**

According to the Levin, Lin, and Chu unit root test results, some economic variables (i.e., gross domestic product (GDP) per capita [*GDP*], trade openness [*TRD*], mobile phone user [*MOB*], and internet user [*INT*]) are found to be stationary at both levels and first differences for the 27 EU countries. These variables have statistically significant unit root test results and can be used directly in models. Meanwhile, the variables of consumer price index [*CPI*], final consumption expenditure [*PCNS*], and fixed telephone lines [*TEL*] are not stationary at levels, but are stationary when taking first differences into account. According to the results, *GDP, TRD, MOB*, and *INT* should be used at level, and *CPI, PCNS*, and *TEL* should be used in the first-difference stationary form in econometric models.

According to the results for the 20 APAC countries, all variables (*GDP, CPI, TRD, PCNS, TEL,* and *MOB*) are found to be stationary at levels and first differences, while *INT* is not stationary at level but shows stationarity at first differences. These results show that most of the macroeconomic indicators in the APAC countries are stationary series that can be directly included in the analysis. The fact that *INT* is not stationary indicates that this variable should be used in the first-difference stationary form in econometric models.

4.2. Pooled OLS, Fixed Effect, and Random Effect Estimators

The first stage uses the pooled OLS, fixed effects, and random effects estimators to analyze ICT's impact on economic growth. Pooled OLS estimates an overall effect across all countries, while the fixed and random effects models focus more on countries' individual characteristics. The fixed effects model takes into account the unique characteristics of each country that do not change over time and attempts to control for the impact these characteristics have on the dependent variable. Meanwhile, the random effects model attempts to model country-specific random effects by taking into account random variations in the error term alongside fixed effects. The estimation results obtained for each

country group have been comprehensively examined for a better understanding of the dynamics of both regions and the impacts of ICT, as well as for the comparative analysis. The results are summarized in Tables 7 and 8.

Table 7. *Pooled OLS, Fixed Effect and Random Effect Results for EU Countries*

Dependent variable: GDP per capita (GDP)			
Variables	Pooled OLS	Fixed Effect	Random Effect
GDP (-1)	0,9758***	0,9896***	0,9758***
	(0,004)	(0,034)	(0,003)
ΔCPI	0,1385	0,1533	0,1385
	(0,200)	(0,196)	(0,157)
TRD	0,0114**	0,1030	0,0114**
	(0,003)	(0,065)	(0,003)
ΔPCNS	-0,7768***	-0,7457***	-0,7768***
	(0,128)	(0,166)	(0,152)
ΔTEL	0,0246	0,0471	0,0246
	(0,032)	(0.048)	(0.027)
MOB	0,0384**	0,0171	0,0384**
	(0,014)	(0.037)	(0.013)
INT	0,0505**	0,0376	0,0505***
	(0,020)	(0,038)	(0,012)
Number of observations	324	324	324
Number of countries	27	27	27
R^2	0.9974	0.9935	0.9974

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.**

Table 8. *Pooled OLS, Fixed Effect and Random Effect Results for APAC Countries*

Dependent variable: GDP per capita (GDP)			
Variables	Pooled OLS	Fixed Effect	Random Effect
GDP (-1)	0,9778***	0,7459***	0,9729***
	(0,007)	(0,041)	(0,010)
CPI	0,0323	0,2135*	0,0313
	(0,045)	(0,078)	(0,038)
TRD	-0,0009	-0,0791	-0,0006
	(0,007)	(0,063)	(0,100)
PCNS	-0,0532*	-0,1872*	-0,0648
	(0,022)	(0,079)	(0,034)
TEL	0,0053	0,0177	0,0096
	(0,007)l	(0.018)	(0.009)
MOB	-0,00002	-0,0335	-0,0105
	(0,015)	(0.024)	(0.019)
ΔINT	0,0281	-0,0098	0,0193
	(0,032)	(0,029)	(0,034)
Number of observations	240	240	240
Number of countries	20	20	20
R^2	0.9980	0.9931	0.9979

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 effects and random effects estimator results for the 27 EU countries, the previous year's *GDP* -1 year strongly affects the current year's *GDP* values, and this effect is statistically significant at the 1% level in all three models. The Δ*CPI* has a positive but not statistically significant effect on *GDP* in all three prediction models. *TRD* is also found to be positive and significant at the 5% level in the pooled OLS and random effects models, but is not significant in the fixed effects model. The Δ*PCNS* has a significantly negative impact on *GDP* at the 1% level

in all three models. The Δ*TEL* and *MOB* are positive in some models but not statistically significant in others. While *INT* is found to be positive and significant at the 5% and 1% levels in the pooled OLS and random effects models, it is not significant in the fixed effects model. The results generally show the ICT components to have had positive effects on economic growth in the 27 EU countries.

According to the pooled OLS, fixed effects, and random effects estimation results obtained using data from 20 Asia-Pacific countries, *GDP* -1 year has a significantly positive effect in all models, while *CPI* shows a significantly positive effect only in the fixed effects model. *TRD* and *PCNS* show a negative effect in all models, with the effect of *PCNS* being significant in the pooled OLS and fixed effects estimations. *TEL* and Δ*INT* do not have a significant effect on GDP in all three models, though the effects are positive; only Δ*INT* shows a negative effect in the fixed effects estimation. Meanwhile, *MOB* showed a negative but not statistically significant effect in all three models. These results show the ICT components of fixed telephone lines and Internet users to have a positive effect on economic growth in the 20 APAC countries, while the number of mobile phone users has a negative effect.

4.3. GMM Estimator

The two-step system GMM estimator was used to examine the impact of ICT on economic growth between 2007-2019. This estimator is ideal for addressing potential issues such as endogeneity and serial correlation regarding data for both the 27 EU and 20 APAC countries. Two-step system GMM takes into account the endogenous relationships between the dependent and independent variables and reduces biases in dynamic panel data models. This approach is particularly suitable for situations where past values can influence future changes in time series data. This method was used to analyze the impact of the ICT components on economic growth separately for both regions, with the results then being comparatively evaluated. The findings for each country group are summarized in Tables 9 and 10 and accompanied by detailed analyses and interpretations.

Table 9. *Dynamic Panel-Data Estimation: Two-Step System GMM Results for EU Countries*

Dependent variable: GDP per capita (GDP)						
Variables	Coef.	Corrected Std. Err.	t	P > t	[95% Conf.	Interval]
GDP(-1)	0.9353309	0.028855	32.41	0.000***	0.8760186	0.9946432
ΔCPI	0.9656473	0.384292	2.51	0.019*	0.1757239	1.755571
TRD	-0.0004139	0.0125927	-0.03	0.974	-0.0262986	0.0254709
ΔPCNS	-0.7263033	0.1788759	-4.06	0.000***	-1.093988	-0.3586187
ΔTEL	0.1001883	0.0742192	1.35	0.189	-0.0523715	0.2527481
MOB	0.0766612	0.047375	1.62	0.118	-0.0207195	0.1740419
INT	0.1690276	0.0706208	2.39	0.024*	0.0238645	0.3141908
Arellano-Bond test AR(1):		z = -1.99 Pr > z = 0.046				
Arellano-Bond test AR(2):		z = -0.59 Pr > z = 0.554				
Sargan test:		chi2(34) = 74.33 Prob > chi2 = 0.000				
Hansen test:		chi2(34) = 12.78 Prob > chi2 = 1.000				
Number of observations		324				
Number of countries		27				
Number of instruments		53				

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

Table 10. *Dynamic Panel-Data Estimation: Two-Step System GMM Results for APAC Countries*

Dependent variable: GDP per capita (GDP)						
Variables	Coef.	Corrected Std. Err.	t	P > t	[95% Conf.	Interval]
GDP(-1)	0.7626895	0.2055129	3.71	0.001**	0.332546	1.192833
CPI	-0.0109286	0.4189276	-0.03	0.979	-0.8877541	0.8658968
TRD	0.065531	0.0557888	1.17	0.255	-0.0512363	0.1822983
PCNS	0.9520769	1.128982	0.84	0.410	-1.410909	3.315063
TEL	0.1947948	0.180987	1.08	0.295	-0.1840154	0.5736049
MOB	0.2469984	0.2244638	1.10	0.285	-0.2228099	0.7168066
ΔINT	-0.6581321	0.2819701	-2.33	0.031*	-1.248302	-0.0679619
Arellano-Bond test AR(1):		z = -2.21 Pr > z = 0.027				
Arellano-Bond test AR(2):		z = -0.79 Pr > z = 0.427				
Sargan test:		chi2(36) = 70.02 Prob > chi2 = 0.001				
Hansen test:		chi2(36) = 2.04 Prob > chi2 = 1.000				
Number of observations		240				
Number of countries		20				
Number of instruments		77				

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

The two-step system GMM estimates show that the *GDP* -1 year and Δ*CPI* to have had a significantly positive effect on *GDP* for the 27 EU countries, while *TRD* and Δ*PCNS* had a negative effect on *GDP*. The effect was insignificant for *TRD* and at a 1% level of significance for Δ*PCNS*. Moreover, Δ*TEL*, *MOB*, and *INT* had positive effects on *GDP*; while this effect was insignificant for Δ*TEL* and *MOB*, it is at a 5% significance level for *INT*. Similar results were also found by Appiah-Otoo and Song (2021), Kurniawati (2021), Tunalı and Güz (2021), and Farhadi and Fooladi (2020).

In addition, the validity of the model was confirmed by the Arellano-Bond and Sargan tests; however, the Sargan test indicates potential overidentification problems. The Hansen test verified the suitability of the model's instruments. These test results have been used to test the validity of the two-step system GMM estimator and the appropriateness of the instruments used in the model.

- ***Arellano-Bond Test AR(1).*** This test checks for a first-order autocorrelation, namely whether the error terms of the previous period in time series data are correlated with the current period. Due to the test statistic equaling -1.99 ($p = 0.046$), statistically significant evidence exists for a first-order autocorrelation in the model. This is generally an expected result because the error terms of the first lag are usually correlated.
- ***Arellano-Bond Test AR(2).*** This test checks for a second-order autocorrelation, namely whether the error terms of the two previous periods in time series data correlate with the current period. Due to the test statistic equaling -0.59 ($p = 0.554$), no second-order autocorrelation is present, indicating the GMM estimator to be valid.
- ***Sargan Test.*** This tests whether the instruments used in the model are over-identified. Due to the chi-square equaling 74.33 ($p = 0.000$), strong evidence exists that the instruments are over-specified, and thus some of them may be invalid.
- ***Hansen Test.*** Similar to the Sargan test, this tests the validity of instruments but is more robust for cases where the model is over-specified. Chi-square value is found to equal 12.78 (p = 1.000). This result indicates the instruments in the model to not be over-identified with the endogenous variables of the model and the specification of the model to be appropriate. In other words, the instruments used in the model are valid, and the predictions are reliable. This is a sign that the model is sound.

To briefly summarize the above results, according to the two-step system GMM estimation results, ICT had a positive impact on GDP for the 27 EU countries between 2007-2019.

According to the two-step system GMM results, consumer price index, fixed telephone lines, mobile phone users, and Internet users were observed to positively affect economic growth in the 27 European Union countries, while trade openness and final consumer expenditures had a negative effect. To explain the possible reasons for these results, *CPI* is an indicator of general price levels. A rise in *CPI* in Europe may reflect the buoyancy of economic activity and the strength of consumer demand. In this case, a mild inflation rate may increase consumer spending and investments, which then stimulates economic growth. Developing ICT infrastructure contributes to economic growth by increasing efficiency and innovation. In particular, fixed and mobile telephone services and Internet access facilitate communication between businesses and consumers, reduce transaction costs, and expand market access. Additionally, ICT stimulates growth in wider areas of the economy by supporting the digital economy and new business models such as e-commerce. A decline in trade volume may reflect a decline in global trade or the dependence of European economies on foreign trade. The negative impact on trade volume may be due to external factors such as global trade wars, protectionist policies, or economic crises. A decline in consumer spending may be related to factors such as economic uncertainty or low income growth. A decrease in consumer confidence in EU countries may limit consumption expenditures and therefore negatively affect economic growth.

According to the two-step system GMM results for the 20 APAC countries as shown in Table 10, *GDP* -1 year has a positive and statistically significant effect on *GDP* at a significance level of 1%. On the contrary, CPI had a negative and statistically insignificant effect on *GDP*. At the same time, *TRD, PCNS, TEL*, and *MOB* had a positive but insignificant effect on *GDP*, while Δ*INT* had a negative and statistically significant effect on *GDP* at a significance level of 5%. Other test results yielded the following results:

- ***Arellano-Bond Test AR(1).*** Due to the z-value equaling -2.21 ($p = 0.027$), a significant serial correlation is concluded to be present at the first lag of the model. This is an expected situation in panel data models.
- ***Arellano-Bond Test AR(2).*** Due to the z-value equaling -0.79 ($p = 0.427$), no significant serial correlation has been concluded to be present at the second lag. This indicates the model to be appropriate because no serial correlation should ideally exist at the second lag.
- ***Sargan Test.*** The chi-square(36) equaling 70.02 ($p = 0.001$) indicates overidentification problems to be present in the model. This may mean that some of the instruments that were used may be correlated with the endogenous variables of the model.

- ***Hansen Test.*** The chi-square(36) equaling 2.04 ($p = 1.000$) indicates the instruments in the model to be valid and no overidentification problem to be present.

According to these results, consumer price index had a negative and insignificant effect on GDP in the 20 APAC countries, while trade openness and final consumption expenditures had a positive and insignificant effect. To explain the possible reasons for this, the negative and insignificant effect of the consumer price index on GDP indicates that this variable does not have a direct impact on economic growth in APAC countries. This may be due to reasons such as countries in the region following different policies to combat inflation or changes in consumer prices having a less-than-expected impact on economic growth. The positive but insignificant effect of trade openness indicates the effect of this variable on economic growth to perhaps differ between countries in the region or the effect to be very small. This may indicate that the benefits some countries in the region derive from foreign trade may not be directly reflected onto economic growth or that the impact of trade policies and global trade conditions may be heterogeneous. The positive but insignificant impact of final consumption expenditures indicates these expenditures to not be a significant driver of GDP in regional economies. This can be explained by the fact that the contribution of consumption expenditures to GDP varies in the countries of the region due to different economic structures and consumption habits. Additionally, the impact of consumption expenditures on economic growth may vary depending on factors such as the structure, distribution, and financing of these expenditures.

Meanwhile, ICT can be said to have a complex impact on economic growth. In other words, neither fixed telephone lines nor mobile phone users showed a significant impact on GDP. This indicates these ICT features to have no direct positive impact on economic growth. However, the change in Internet users had a negative and statistically significant impact on GDP. This indicates that increased Internet usage may have a negative impact on economic growth in this region. Overall, these results indicate ICT to have no significant positive impact on economic growth in APAC countries, with an increase in Internet usage perhaps even having a negative impact. These findings may be related to the specific economic conditions of the region, the quality of ICT infrastructure, levels of access and use of technology, education level, and other socioeconomic factors.

Upon comparing the two-step system GMM results obtained for the 27 EU and 20 APAC countries:

- For both regions, the previous year's GDP had a positive and significant impact on the current year's GDP, indicating continuity of economic growth.
- While the consumer price index was significantly positive in the EU countries, it did not show a significant effect in APAC countries.
- Trade openness and final consumption expenditures showed no significant impact in either region.
- While the number of Internet users had a significantly positive effect in the EU, it was significantly negative in APAC. The other ICT variables showed no significant effects in either region.

This comparison shows that the impact of ICT on economic growth may vary depending on geographical and regional differences. Internet usage was seen to positively affect economic growth in the EU countries but to have the opposite effect in APAC countries. These differences may be related to the economic structure, technological infrastructure, policies, and socio-economic conditions of both regions.

5. Conclusion

This study has aimed to comparatively investigate the effects of ICT on economic growth over the 2007-2019 period covering 27 EU and 20 APAC countries. Because ICT is recognized as a major driver of the global economy and is rapidly evolving, examining how these impacts are shaped in different economic and geographical contexts is crucial. This study has been designed to better understand the contributions ICT makes to economic growth and to reveal how these technologies interact with different regional dynamics.

The analyses considered GDP per capita, which is a basic indicator of macroeconomic performance, as the dependent variable and took into account the number of fixed telephone lines, mobile phone users, and Internet users, which represent ICT, as the independent variables. Additionally, the analyses also included such control variables as consumer price index (*CPI*), trade openness (TRD), and final consumption expenditure (*PCNS*). This dataset was used to examine the effects ICT has on regional economic growth and to understand the dynamics between different economic structures. The data collection and analyses were carried out in order to reveal the regional differences and characteristics of the impact these technologies have on economic growth.

The two-step system GMM method was used to evaluate the effects of ICT on economic growth. This econometric method was preferred in order to address the time dependence and endogeneity problems that are especially encountered

in dynamic panel datasets. The two-step system GMM is able to deal with potentially endogenous variables in a dataset, as well as in particular to appropriately model the effects of past period values on the current period. This method takes into account time series characteristics and individual effects, allowing past values of the dependent variable to be used as instruments. This approach allows one to more accurately estimate the impact of ICT on economic growth and understand regional differences.

The Levin, Lin, and Chu unit root test was applied to the macroeconomic time series data for each country group. For the 27 EU countries, the LLC unit root test revealed *GDP, TRD, MOB*, and *INT* to be stationary at both levels and first differences. However, *CPI, PCNS*, and *TEL* were not stationary at levels but instead exhibited stationarity when first differences were taken into account. The analyses for the EU countries used *GDP, TRD, MOB*, and *INT* at the level while utilizing *CPI, PCNS,* and *TEL* in their first-difference stationary form. Conversely, the results for the 20 APAC countries indicated *GDP, CPI, TRD, PCNS, TEL*, and *MOB* to be stationary at both levels and first differences. However, INT was not stationary at the level but demonstrated stationarity at first differences. The analyses for the APAC countries used only the INT variable in its first-difference stationary form, while the other variables were employed at the level.

This study used pooled OLS, fixed effects, and random effects estimators for both country groups in the first stage. According to the pooled OLS, fixed effects, and random effects estimation results, all ICT components were found to have positive effects on economic growth in the 27 EU countries, while only the ICT components of fixed telephone lines and Internet users were observed to have a positive effect on economic growth in the 20 APAC countries, with the number of mobile phone users having a negative effect. A number of factors (e.g., market saturation, the limited economic benefits of basic mobile use, unequal access to advanced mobile technologies, differences in economic structures, regulatory challenges, and mismatched skill development within the workforce) may contribute to the negative effect that the number of mobile phone users had on economic growth in the APAC countries. These elements alone or in combination may lessen the favorable economic effects usually linked to the rise in mobile phone usage.

The results from the two-step system GMM estimation for EU countries revealed *GDP* (-1) and Δ*CPI* to have significantly and positively impacted GDP, while *TRD* and Δ*PCNS* had had a negative effect on *GDP*, with *TRD* being statistically insignificant and Δ*PCNS* being insignificant at the 1% level. Additionally, Δ*TEL*, *MOB*, and *INT* had exhibited a positive effect on GDP, with Δ*TEL* and *MOB* being insignificant and *INT* showing significance at the 5% level. In summary, ICT has demonstrated a positive impact on GDP for EU countries. Conversely, the two-step system GMM results for APAC countries indicated *GDP* (-1) to have had a positive and statistically significant effect on *GDP* at the 1% significance level. Contrarily, *CPI* had a negative and statistically insignificant effect on *GDP*. Additionally, *TRD, PCNS, TEL*, and *MOB* had positive and insignificant effects on *GDP*, while Δ*INT* had a negative and statistically significant effect on *GDP* at the 5% significance level. In conclusion, these findings suggest that ICT did not significantly contribute to positive economic growth in the APAC countries and that an increase in Internet usage may even have had a negative impact. Appiah-Otoo and Song (2021), Kurniawati (2021), Tunalı and Güz (2021), and Farhadi and Fooladi (2020) also reported similar findings.

The results from the Arellano-Bond test for both country groups indicated statistically significant evidence of first-order autocorrelation in the model with no second-order autocorrelation being observed, thus affirming the validity of the GMM estimation. Furthermore, the Sargan test results suggested strong evidence of instrument overspecification, implying that some instruments may be invalid. However, the Hansen test demonstrated the instruments in the model to not be over-identified concerning the endogenous variables, confirming the model's appropriateness and the validity of the instruments. In essence, the robustness of the model has been supported by these tests, indicating its predictions to be reliable and valid.

When comparing the two-step system GMM results obtained for the EU and APAC countries:

- For both regions, the previous year's GDP demonstrated a significantly positive impact on the current year's GDP, indicating a continuity of economic growth.
- The consumer price index exhibited a significantly positive effect in EU countries but showed no significant impact in APAC countries.
- Trade openness and final consumption expenditures demonstrated no significant impact in either region.
- Internet use had a significantly positive effect in the EU but was significantly negative in the APAC region. The other ICT variables exhibited no significant effects in either region.

This comparison shows the impact of ICT on economic growth to possibly vary depending on geographical and regional differences. Internet usage was seen to have positively affect economic growth in EU countries but to have had the opposite effect in APAC countries.

Based on the results of the study, the following recommendations can be stated regarding the impact of ICT on economic growth for both EU and APAC countries:

For EU Countries:

- ***Increase Digital Infrastructure Investments.*** When considering the positive impact of Internet use on economic growth, EU countries should increase investments to improve broadband access and digital infrastructure.
- ***Promote Education and Skills Development.*** Including technology and digital skills in education programs is important for being able to use ICT effectively and contribute to innovation.
- ***Support ICT R&D and Innovation.*** The development and dissemination of new technologies should be encouraged by investing more in research and development in the ICT sector.

For APAC Countries:

- ***Focus on Internet Access.*** When considering the negative impact Internet use had on economic growth, importance is had in reviewing Internet access policies in the region and developing strategies to improve the integration of Internet use into the economy.
- ***Improve Digital Literacy.*** Digital literacy and education programs need to be strengthened in order to encourage the effective use of technology and to reduce the digital divide.
- ***Invest in Technological Innovations.*** Regional countries should invest in R&D activities to develop technological solutions suitable for local conditions and integrate these into the economy.

These recommendations are aimed at optimizing the effects of ICT on economic growth in both regions and at maximizing the economic benefits of technological developments. Additionally, these recommendations should be tailored to take into account the unique circumstances and needs of each region.

The findings show how the effects of ICT on economic growth may vary geographically and regionally. This study makes a significant contribution to future research, especially research that wishes to examine the relationship between ICT and economic growth in different regional and economic contexts. Researchers can use this study's findings to analyze the effects of ICT on economic growth in more detail and to better understand how these effects vary under different geographical conditions. Additionally, this study provides important insights for policymakers and business leaders on how ICT strategies and investments should be shaped. By adopting the methodological approach of this research, future studies can evaluate the social and economic benefits of ICT in a broader framework and customize the effects of ICT investments on economic growth for different sectors and regions.

This study has some limitations regarding the analyses that were conducted on 27 EU and 20 APAC countries. Firstly, the datasets that were used cover a specific time period (2007-2019), which means that more recent developments and trends have been excluded. As the econometric model used in the analyses, the two-stage system GMM is also based on certain assumptions that necessitate caution when interpreting the results. In particular, the model's choice of instruments and the validity of these instruments may affect the accuracy of the study's results. Additionally, the selection and measurement of the variables used in the analyses may limit the study's findings. For example, more detailed indicators of ICT infrastructure and use may produce different results. Finally, this study is a quantitative analysis based on macroeconomic data and may not fully reflect the impact of qualitative factors or individual country conditions with regard to understanding the impact ICT has on economic growth. Future studies can take these limitations into consideration to examine the issue in greater depth using different methodologies and datasets.

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