ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Araştırma Makalesi *Research Article* DOI: 10.62425/dssh.1623503

The Effects of Digitalization on Economic Growth: A Comparative Panel Data Analysis of EU and BRICS-T Countries

Dijitalleşmenin Ekonomik Büyüme Üzerindeki Etkileri: AB ve BRICS-T Ülkeleri Arasında Karşılaştırmalı Panel Veri Analizi

Ahmet KASAP
Tokat Gaziosmanpaşa Üniversitesi, Turhal Uygulamalı Bilimler Fakültesi, Elektronik Ticaret ve Yönetimi Bölümü, Tokat, Türkiye

ABSTRACT

This study examines the influence of digitalization on economic growth through a comparative comparison of European Union (EU) countries and BRICS-T nations. The study employs panel data analysis, encompassing the years 2001 to 2022 for EU countries and 2003 to 2021 for BRICS-T countries. The findings indicate that in EU nations, variables such as internet utilization, fixed broadband availability, and gross fixed capital formation positively and considerably enhance economic growth. In BRICS-T nations, mobile phone subscriptions, internet utilization, and gross fixed capital formation are pivotal growth catalysts. Nonetheless, foreign direct investments and trade openness exhibit statistically minor effects in both regions. This research underscores the essential function of digital infrastructure in promoting economic development and offers policy recommendations to optimize the advantages of digitalization in both emerging and mature nations.

Keywords: Digitalization, Economic Growth, European Union, BRICS-T, Panel Data Analysis

ÖZ

Bu çalışma, Avrupa Birliği (AB) ülkeleri ile BRICS-T ülkeleri arasında karşılaştırmalı bir analiz yaparak dijitalleşmenin ekonomik büyüme üzerindeki etkisini araştırmaktadır. Panel veri analizinin kullanıldığı çalışma, AB ülkeleri için 2001-2022 dönemini, BRICS-T ülkeleri için ise 2003-2021 dönemini kapsamaktadır. Sonuçlar, AB ülkelerinde internet kullanımı, sabit genişbant erişimi ve gayrisafi sabit sermaye oluşumu gibi faktörlerin ekonomik büyümeye pozitif ve anlamlı bir şekilde katkıda bulunduğunu ortaya koymaktadır. BRICS-T ülkelerinde ise cep telefonu abonelikleri, internet kullanımı ve gayrisafi sabit sermaye oluşumu büyümenin temel itici güçleri olarak ortaya çıkmaktadır. Bununla birlikte, doğrudan yabancı yatırımlar ve ticari açıklık her iki bölgede de istatistiksel olarak önemsiz etkiler göstermektedir. Bu araştırma, dijital altyapının ekonomik kalkınmayı desteklemedeki kritik rolünü vurgulamakta ve hem gelişmekte olan hem de gelişmiş ekonomilerde dijitalleşmenin faydalarını en üst düzeye çıkarmak için politika önerileri sunmaktadır.

Anahtar Kelimeler: Dijitalleşme, Ekonomik Büyüme, Avrupa Birliği, BRICS-T, Panel Veri Analizi

Geliş Tarihi/Received 20.01.2025
Kabul Tarihi/Accepted 06.03.2025
Yayın Tarihi/Publication Date 27.03.2025

Sorumlu Yazar/Corresponding author:
Ahmet Kasap
E-mail: ahmet.kasap@gop.edu.tr

Cite this article: Kasap, A. (2025). The Effects of Digitalization on Economic Growth: A Comparative Panel Data Analysis of EU and BRICS-T Countries. *Dynamics in Social Sciences and Humanities, 6*(1), 10-24.

Introduction

Digitalization has become one of the fundamental drivers of modern economies, profoundly transforming economic structures and increasing productivity, innovation, and global competitiveness. The opportunities provided by technological advancements have enabled countries to reorganize their economic frameworks to become more efficient and globally integrated. The digitalization process, particularly accelerated by the widespread adoption of Information and Communication Technologies (ICT), has significantly impacted both developed and developing economies. The contributions of digital technologies to economic growth are not limited to enhancing production processes; they also facilitate the development of new business models and transform global value chains (Watanabe et al., 2018). The widespread use of the internet and broadband access, in particular, has supported the growth of the digital economy and driven structural changes across labor markets and industrial production (Grigorescu et al., 2021).

The selection of EU and BRICS-T countries in this study is based on their distinct digital infrastructure and economic development levels. EU countries, with their advanced technological infrastructure, demonstrate a mature digital ecosystem that contributes significantly to economic productivity. In contrast, BRICS-T countries, characterized by rapidly evolving digital frameworks, present an opportunity to examine the impact of digitalization in emerging economies. This distinction provides a valuable comparative perspective on how different economic structures leverage digitalization for growth.

The relationship between digitalization and economic growth varies significantly depending on the level of digital infrastructure development, economic structure, and the capacity to utilize digital technologies. Developed economies, such as the European Union (EU) countries, benefit more from digitalization due to their advanced digital infrastructure and leading roles in technological innovation. In these countries, factors like internet usage, fixed broadband access, and gross fixed capital formation serve as key drivers of economic growth (Arendt, 2015; Grigorescu et al., 2021). In contrast, the effects of digitalization in emerging economies, such as BRICS-T countries, are shaped by different dynamics. Mobile technology penetration and increased internet usage emerge as the primary forces driving economic growth and regional development in these nations (Myovella et al., 2020).

Studies examining the mechanisms through which digitalization contributes to economic growth highlight the importance of digital infrastructure investments, which not only enhance productivity but also accelerate the development of new products and services. For instance, investments in broadband infrastructure have supported the expansion of e-commerce and maximized the potential of the digital economy (Lee et al., 2012). Such investments have played a critical role in leveraging the benefits of digitalization in EU countries. Conversely, in BRICS-T countries, mobile technologies and digital accessibility have opened new opportunities for economic participation, driving development and growth (Myovella et al., 2020).

A key distinction between these two economic groups lies in their policy approaches toward digitalization. EU nations focus on fostering innovation through technological advancements and regulatory frameworks that promote digital transformation. On the other hand, BRICS-T countries emphasize expanding digital infrastructure and increasing internet accessibility as primary means to accelerate economic growth. Understanding these strategic differences is crucial for assessing how digitalization impacts various economic contexts and for designing effective policy recommendations tailored to each region.

The effects of digitalization on economic growth are not solely determined by regional differences but are also influenced by the economic and social policies of individual countries. EU countries, with their focus on innovative technologies, lead the digital transformation process, while BRICS-T countries prioritize infrastructure investments and digital literacy programs to enhance the economic impact of digitalization (Grigorescu et al., 2021; Myovella et al., 2020). However, in both regions, factors like foreign direct investment and trade openness have shown limited effects in amplifying the impact of digitalization on growth (Habibi & Zabardast, 2020). These findings underscore the need for targeted strategies that address regional and sectoral differences to fully capitalize on the benefits of digitalization.

This study aims to examine the effects of digitalization on economic growth through a comparative analysis of EU and BRICS-T countries. By exploring the reasons behind the varying impacts of digitalization on growth in developed and emerging economies, the study seeks to understand the dynamics driving economic development. Moreover, it provides critical insights for policymakers to develop region-specific strategies that maximize the benefits of digitalization.

Theoretical Background

Research investigating the correlation between digitization and economic growth commenced in the 1960s, mostly in the United States. The research demonstrated a positive association between Information and Communication Technologies (ICT) and economic growth (Hardy, 1980; Jipp, 1963). The advancement of the internet, propelled by digitalization, has resulted in the formation of a digital economy, altering conventional notions of economic growth and competitiveness (Watanabe et al., 2018).

According to the Solow model, continuous improvements in living standards can only be explained by technological progress (Mankiw, 2003). In this context, new growth theories have identified technological advancement as a critical factor for economic growth (Barro et al., 1991; Lucas & Robert, 1988). This impact on economic growth has become more pronounced with the new market opportunities created by digitalization and the acceleration of global trade.

The influence of digitalization on economic growth has intensified due to the extensive usage of information and communication technology (ICT). Information and Communication Technology (ICT) has transformed e-commerce and online business operations, augmenting flexibility in banking transactions and offering improved communication tools that enhance productivity and, therefore, economic growth (Bojnec & Fertő, 2012). The trend intensified due to heightened investments in ICT, resulting in productivity and performance enhancements in numerous developed and newly industrialized nations, particularly from the latter half of the 1990s (Lee et al., 2012). Digitalization has facilitated economic growth by generating novel products and processes, establishing new market channels, and introducing organizational complications (Myovella et al., 2020). Information and Communication Technology (ICT) is seen as a key factor in enhancing economic prosperity in both developed and developing nations via technical progress. Profound changes in work organization, the structure of labor demand, and corporate business processes have led to productivity increases, thus accelerating growth (Arendt, 2015). This transformation has been further accelerated by increased investments in technology, encompassing a broad evolution from the first computers (mainframes) in the 1950s, the introduction of Web 1.0 and e-commerce, to 21st-century advanced technologies such as Web 2.0, Web 3.0, and artificial intelligence (Grigorescu et al., 2021).

Concerns exist over the impact of digitalization on economic growth. It is contended that digitalization does not enhance labor productivity to the same degree as prior technical advancements and is linked to sluggish development rates in high-income nations (Gordon, 2015). This underscores that the majority of growth theories emphasize the quantity and efficiency of production variables, including labor, capital, and natural resources, as primary determinants of growth (Acemoglu, 2008).

The main aim of this study is to examine the impact of digitalization on economic growth by conducting a comparative analysis between EU and BRICS-T countries. The period 2001-2022 has been selected for EU countries, and 2003-2021 for BRICS-T countries. The choice of different periods for the two country groups stems from data limitations.

In this study, the selection of EU and BRICS-T countries is based on the diversity they exhibit in terms of digital infrastructure and economic growth dynamics. EU countries typically possess highly developed digital infrastructure and a strong history of economic growth, playing a pioneering role in utilizing technological progress as a key driver of economic growth. On the other hand, BRICS-T countries are at varying stages of digitalization, with rapidly developing economies. These countries are notable for rapidly enhancing their digital infrastructure and using it as a strategic tool for economic growth.

This makes BRICS-T nations ideal for examining the impact of digitalization on economic growth in a more dynamic and diverse manner. The differences in digital infrastructure and economic growth dynamics between EU and BRICS-T countries provide an ideal framework to better understand and offer a comparative perspective on the effects of digitalization on economic growth. Through this approach, it becomes possible to conduct a more in-depth analysis of how digitalization plays a role in countries with varying levels of economic and digital development and how it contributes to their economic growth. In line with this objective, the hypothesis of the study is as follows:

H_0: Digitalization does not have a positive effect on economic growth.

H_1: Digitalization has a positive effect on economic growth.

The structure of the paper is as follows: the second section reviews the literature, the third section details the econometric application, and the paper concludes with the results.

Literature Review

The literature analyzing the impact of ICT and digitalization on economic growth employs diverse measures to assess these phenomena. Digitalization and ICT metrics are predicated on various variables, including mobile-cellular phone subscriptions, fixed broadband subscriptions, internet users, fixed telephone lines, internet servers, and computer ownership. These factors serve as critical benchmarks for evaluating the degree of digitalization in nations and estimating the influence of ICT on economic growth. Frequently utilized metrics for digitalization encompass mobile-cellular phone subscriptions (per 100 individuals), individual internet users (as a percentage of the population), and fixed broadband subscriptions (per 100 individuals) (Appiah-Otoo & Song, 2021; Gomes et al., 2022; González Bautista et al., 2024; Habibi & Zabardast, 2020; Myovella et al., 2020). These metrics are typically utilized to investigate the relationship between digitization and economic growth.

Albiman and Sulong (2016) demonstrated that in the Sub-Saharan Africa (SSA) region, from 1990 to 2014, ICT indicators—namely the number of fixed-line phones, mobile phone users, and internet users per 100 people—along with the aggregate of fixed-line and mobile phone users per 100 people, positively influenced economic growth.

Hofman et al. (2016) discovered that from 1990 to 2013, ICT indicators—specifically mobile-cellular subscriptions, individual internet users, and fixed broadband subscriptions—exhibited a modest yet favorable impact on economic growth in Latin American countries. This conclusion indicates that although Latin America has the capacity to enhance the influence of ICT on economic growth, the effect is still constrained.

Gomes et al. (2022) utilized ICT indicators such as mobile-cellular subscriptions (per 100 individuals), individual internet users (percentage of the population), and fixed broadband subscriptions (per 100 individuals) to illustrate that digitalization has positively impacted economic growth in 36 OECD countries from 2000 to 2019.

Farhadi et al. (2012) developed the ICT index utilizing metrics including individual internet users (per 100 individuals), fixed broadband subscriptions (per 100 individuals), and mobile subscribers. They identified a positive correlation between the ICT index and economic growth across 159 countries from 2000 to 2009. They observed that this correlation was more pronounced in high-income nations.

Katz and Koutroumpis (2013) covering the period from 2004 to 2010, developed a digitalization index using six components and twenty-three indicators for 150 countries. Their analysis revealed that increases in the digitalization index positively impacted GDP.

Analyses of regional and country groups reveal that the influence of ICT on economic growth differs across various socioeconomic categories. Lee et al. (2005) utilized telecommunications investments as a proxy for ICT and discovered that, in their examination of 20 countries from 1980 to 2000, ICT fostered economic growth in numerous developed nations and newly industrialized economies, yet exhibited a diminished impact in developing countries.

Yousefi (2011) examined data from 62 countries (28 high-income, 17 upper-middle-income, 15 lower-middle-income, and 2 low-income) for the period 2000-2006, utilizing ICT expenditures (% of GDP), the e-Government readiness index (scale 0-1), secure internet services (per million people), and the percentage of schools connected to the internet as proxies for ICT. The research indicated that ICT significantly impacts high and upper-middle-income groups, but does not have the same effect in lower-middle-income countries.

Aghaei and Rezagholizadeh (2017) discovered that investments in ICT, encompassing computer hardware (computers, accessories, and equipment), software (agent systems, programming tools, etc.), computer services, and communication services, as well as wired and wireless communication equipment, significantly influenced economic growth in the Organization of Islamic Cooperation (OIC) countries from 1990 to 2014.

Majeed and Ayub (2018) ascertained that all ICT indicators, including mobile-cellular subscriptions (per 100 people), internet users (per 100 people), fixed telephone subscriptions (per 100 people), and fixed broadband subscriptions (per 100 people), facilitated both global and regional economic growth from 1980 to 2015 across 149 countries. They discovered that several variables, including internet services, telecommunications infrastructure, and e-government, were comparatively more advantageous in promoting economic growth.

Appiah-Otoo and Song (2021) utilized ICT indicators, including mobile-cellular subscriptions (per 100 individuals), individual internet users (percentage of the population), and fixed broadband subscriptions (per 100 individuals), to demonstrate that ICT contributed to economic growth from 2002 to 2017 across 123 countries (comprising 45 high-income, 58 middle-income, and 20 low-income countries). The research indicated that less affluent nations derived more advantages from the ICT revolution.

Research on Asian nations further substantiates the beneficial influence of ICT on economic development. Lee and Brahmasrene (2014) utilized ICT indicators, including fixed telephone subscriptions (per 100 individuals), mobile-cellular subscriptions (per 100 individuals), internet users (per 100 individuals), and fixed broadband internet subscribers (per 100 individuals), to illustrate that ICT exerted a substantial positive influence on economic growth and CO2 emissions in nine ASEAN member countries from 1991 to 2009.

Country-level studies highlight the importance of ICT for the global economy by examining its effects on economic growth in various countries and periods. Each study underscores how ICT impacts economic growth and how this effect varies between countries. Vu (2013), using indicators such as computer hardware, telecommunication equipment, and software, found that ICT contributed to economic growth in Singapore during the period 1990-2008.

In a study conducted in the United States, Jorgenson et al. (2016) classified 86 industries into three categories: 6 ICT-producing industries, 41 ICT-using industries, and 40 non-ICT industries. Their analysis, covering the period from 1947 to 2010, revealed that ICT has played a significant role in the economic growth of the U.S. since World War II. This finding indicates that the leading role of the U.S. in the global economy has been supported by investments and innovations in ICT. Additionally, Kumar et al. (2016), using measures of ICT such as the internet, fixed broadband, mobile-cellular subscriptions, high-tech exports, and telecommunication lines, found that ICT has supported economic growth in China during the period 1980-2013.

In the European context, Bakari's (2022) study on Romania, which utilized solely the individual internet users variable as an indicator of digitalization, demonstrated that digitalization and patents positively influenced economic growth from 1990 to 2020. Research pertaining to Asian nations underscores the influence of ICT on economic development.

Research comparing groupings of countries has analyzed the impact of ICT on economic growth from multiple perspectives in both emerging and industrialized nations. Bahrini and Qaffas (2019) examined the influence of information and communication technology (ICT) on economic growth in selected developing nations within the MENA region and SSA from 2007 to 2016, utilizing fixed telephone subscriptions (per 100 individuals), mobile-cellular subscriptions (per 100 individuals), internet subscribers (per 100 individuals), and fixed broadband subscriptions (per 100 individuals) as metrics for ICT. The findings suggest that, apart from fixed telephony, other information and communication technologies, including mobile phones, internet usage, and broadband adoption, are the primary catalysts of economic growth in developing nations within the MENA and SSA areas.

Myovella et al. (2020) conducted a comparative study between 41 Sub-Saharan African (SSA) and 33 Organisation for Economic Co-operation and Development (OECD) economies from 2006 to 2016, utilizing digitalization indicators including mobile-cellular phone subscriptions (per 100 individuals), individual internet users (as a percentage of the population), and fixed broadband subscriptions (per 100 individuals). The dependent variable is economic growth, whereas the independent factors comprise digitalization, trade openness, gross fixed capital formation, government consumption, and population increase.

The findings indicate that digitization supports economic growth in both categories of countries. The internet's contribution to economic growth is beneficial for both groups. In comparison to OECD nations, the impact of broadband internet in Sub-Saharan Africa is negligible, however the influence of mobile telecommunications is significantly greater. In SSA, government consumption and population increase positively influence economic growth, albeit insignificantly, whereas trade openness negatively impacts economic growth, again insignificantly. Within the OECD, trade openness positively influences economic growth, whereas population increase negatively impacts economic growth.

Habibi and Zabardast (2020) employed digitalization metrics, including mobile-cellular phone subscriptions (per 100 individuals), individual internet users (as a percentage of the population), and fixed broadband subscriptions (per 100 individuals), to analyze the impact of digitalization and education on economic growth across 10 Middle Eastern and 24 OECD economies from 2000 to 2017. The results indicate that digitization correlates positively with economic growth in both categories of countries. In comparison to other OECD nations, the impact of internet users in the Middle East is negligible, although the influence of mobile subscribers is more pronounced. In Middle Eastern nations, education positively influences economic growth, whereas trade openness negatively impacts it. Investment exerts a negligible and inconsequential impact on economic growth. In OECD countries, trade openness positively influences economic growth, whereas investment negatively affects economic growth.

Certain studies indicate that the influence of ICT on economic growth is not universally beneficial and may fluctuate based on a nation's economic, technological, and institutional circumstances. Vyshnevskyi et al., (2020) analyzed the influence of economic digitalization on economic development in EU nations from 2014 to 2018, utilizing the Digital Economy and Society Index (DESI) consistently computed by the European Commission. The findings suggest that the degree of economic digitalization does not significantly influence economic growth at the present stage of technology and institutional advancement.

Nabi et al. (2023) analyzed the dynamic relationship between ICT and economic growth in N11 countries from 2000 to 2018, utilizing ICT indicators including mobile-cellular phone subscriptions (per 100 people), individual internet users (percentage of population), fixed broadband subscriptions (per 100 people), fixed telephone subscriptions (per 100 people), and secure internet servers (per million people). The research was carried out by expanding a novel ICT index that encompasses fixed telephone lines, mobile wireless connectivity, and internet penetration for dissemination. The empirical findings demonstrate that the proliferation of ICT adversely affects economic growth in N11 countries over the long term. Furthermore, it was determined that foreign direct investment and trade exert a beneficial and considerable influence on long-term economic growth.

In recent years, numerous studies have examined the role of digitalization in economic growth and sustainability, offering valuable insights into the mechanisms driving this transformation.

Patra and Sethi (2024) investigate the impact of digital payments on economic growth in developing economies, emphasizing the mediating role of institutional quality, consumption expenditure, and bank credit. The study, conducted across 25 emerging economies using fixed effects models and panel data analysis, finds that digital payments directly contribute to economic growth. However, the interaction effects with institutional quality, consumption expenditure, and bank credit do not generate significant additional growth effects. Notably, excessive reliance on bank credit negatively impacts economic growth. The study underscores the importance of institutional frameworks in enhancing digital financial systems' effectiveness, emphasizing that strong institutional structures can maximize the benefits of digitalization.

Ghimire et al. (2024) analyze the impact of the Digital Silk Road (DSR) and innovation heterogeneity on digital economy growth across 29 countries. The study employs the Propensity Score Matching-Difference-in-Differences (PSM-DID) model to assess the policy shock effects on the digital economy. Findings reveal that DSR significantly fosters digital economic growth, with infrastructure innovation playing a crucial role in this expansion. Additionally, human capital and research innovation emerge as key drivers of digital economy growth. Business sophistication innovation positively affects digital growth, while institutional innovation and market sophistication innovation do not produce the expected positive effects. This study provides a comparative perspective on the Digital Silk Road's role in shaping digital-driven economic growth, contributing valuable insights to the literature.

Chinoda and Kapingura (2024) explore the role of institutions and governance in the relationship between digital financial inclusion and economic growth in Sub-Saharan Africa. Using data from 2014 to 2020, the study applies the Generalized Method of Moments (GMM) to analyze causality effects. The findings suggest that institutional quality and governance significantly enhance the interaction between digital financial inclusion and economic growth. Moreover, trade and population growth positively influence economic growth, while inflation has a negative impact. The study highlights that institutional reforms and strong governance can improve digital financial systems' effectiveness, ultimately contributing to economic development.

Elfaki and Ahmed (2024) examine the effects of digital technology adoption and globalization on green sustainable economic growth in the Asia-Pacific region. The study integrates digital technology adoption (digitalization and digitization), globalization, and environmental quality into a structured model. Using the Hausman test, the study determines that the random effects model is the appropriate estimation approach. Findings indicate that digital technology adoption significantly promotes economic growth, whereas globalization’s impact remains statistically insignificant. The positive growth rate of green total factor productivity (GTFP) is attributed to digital technology utilization, labor, capital, and low carbon emissions. The study underscores the necessity of technology transfer, innovation, and international partnerships in fostering sustainable growth policies.

Škare et al. (2024) assess the impact of digitalization on the carbon footprint and sustainable economic growth. Using panel data analysis, the study investigates how digitalization influences carbon emissions across different sectors (government, households, private enterprises, and NGOs). The findings indicate that digitalization has a positive and statistically significant effect on sustainable

development goals (SDGs). However, substantial differences in carbon footprint trends across sectors suggest that achieving SDGs requires a more rapid transformation. The study emphasizes the need for policymakers to strategically revise sustainability policies to mitigate carbon footprints and promote green economic growth.

Econometric Application

Selection of variables and countries

In this study, EU and BRICS-T countries are selected for a comparative analysis in order to examine the effects of digitalization on economic growth. The selection of countries is based on the diversity of digital infrastructure and economic growth dynamics. EU countries include Germany, Austria, Belgium, Czech Republic, Denmark, Finland, France, France, Netherlands, Spain, Sweden, Italy, Latvia, Hungary, Hungary, Malta, Germany, Austria, Belgium, Czech Republic, Denmark, Finland, France, Netherlands, Spain, Sweden, Italy, Latvia, Hungary, Hungary and Malta; BRICS-T countries include Brazil, Russia, India, China, South Africa and Turkey.

The variables employed in the econometric model and the reference paper are derived from the variables and technique utilized by Myovella et al. (2020). The variables were meticulously chosen to represent the correlation between digitization and economic growth. The variables encompass the annual growth rate of Gross Domestic Product (GDP) per capita (gpcg) to signify growth, alongside foreign direct investment net inflows (lfdinic) as macroeconomic factors potentially influencing growth. Additionally, they include the external openness growth rate (tradeg), gross fixed capital formation (gfcfg), government expenditures (govcg), mobile phone subscriptions (mobileg), internet usage rate (intg), and fixed broadband subscriptions (broadg) as metrics of digitalization. The selection of these variables utilized World Bank databases, with the reliability and comprehensiveness of the data being essential to assure the objectivity and dependability of the analysis.

The selected countries exhibit varying levels of digital infrastructure and economic development. While EU countries generally possess advanced digital ecosystems and strong institutional structures, BRICS-T countries are undergoing rapid digital transformation, with significant variations in infrastructure investments. These differences form a crucial foundation for analyzing the comparative effects of digitalization on economic growth.

In the econometric analysis, the fixed effects model was applied to EU countries, whereas the random effects model was chosen for BRICS-T countries. The rationale behind this decision is that EU countries have more homogeneous economic and institutional structures, necessitating the integration of individual country effects into the model. In contrast, BRICS-T countries exhibit more pronounced institutional and economic disparities, making the random effects model more appropriate to capture the variability in individual country characteristics over time. This selection is supported by the results of the Hausman test.

The selection of variables in this study is based on recent literature and empirical findings. To capture the impact of digitalization on economic growth, indicators such as internet usage rate, fixed broadband subscriptions, and mobile phone subscriptions are included as key measures of digitalization. Additionally, macroeconomic variables such as foreign direct investment inflows, trade openness, gross fixed capital formation, and government expenditures are incorporated to account for fundamental growth drivers. These variables provide a comprehensive framework for analyzing how digital transformation influences economic structures.

Table 1

Selected variables

Variable	Definition	Source
gpcg	GDP per capita annual growth rate	Worldbank
lfdinic	FDI net inflows	Worldbank
tradeg	Increase rate of external openness	Worldbank
gfcfg	Annual rate of increase in gross fixed capital formation	Worldbank
govcg	Annual rate of increase in government expenditures	Worldbank
mobileg	Annual rate of increase in mobile phone subscriptions	Worldbank
intg	Annual rate of increase in the number of individuals using the Internet (% of population)	Worldbank
broadg	Annual growth rate of fixed broadband subscriptions	Worldbank

Source: World Bank (2024)

Stationarity test and analysis

Stationarity tests applied in your study constitute the cornerstones of time series and panel data analysis. These tests are critical to determine the stationarity of the variables used in econometric modeling over time. Testing whether the variables in the model are stationary is essential for the reliability and validity of the results.

Unit root analyses are used to test the stationarity of

variables used in time series and panel analyses. While some tests assume that the variables are stationary at the level, others assume that they are non-stationary. Therefore, the determination of the test to be used in the analysis should start with the examination of the degree of stationarity of the variables (Tuna & Karadaş, 2023).

Unit root tests employed in panel data analysis are categorized into first and second generation. First-generation tests presume the absence of inter-unit correlation (i.e., horizontal cross-section dependency) among variables, whereas second-generation unit root tests assess the stationarity of variables by considering horizontal cross-section dependence (Karadaş, 2021). The tests encompass Pesaran's CD-Test (2004) and the panel unit root test formulated by Karavias and Tzavalis (2014). The implementation of these tests enables the evaluation of the stationarity characteristics of variables both individually and collectively. The CD-Test (2004), which relies on horizontal cross-section dependence, is employed to identify correlations across variables. The test results indicate significant cross-sectional reliance among the majority of variables for the EU and BRICS-T nations. This indicates that the variables are substantially associated with one another and with time.

Ensuring stationarity in panel data analysis is crucial to prevent biased and inefficient regression estimates. If the variables are non-stationary, the model results may lead to misleading interpretations, making it essential to verify the stationarity of the dataset before conducting econometric analyses.

Table 2 contains the CD-Test results for the EU and BRICS-T countries. The CD-Test tests for cross-sectional dependence, i.e. it determines whether there are correlations between different units (countries). The test results show significant correlations (p-values as low as .000 and .001) for both groups of countries, indicating that there are strong statistical relationships between the variables and that these correlations should be taken into account in the estimation of the models. This is an important factor in assessing whether the model is consistent with fixed effects and random effects. As can be seen from the table, there is an inter-unit correlation, i.e. horizontal cross-section dependence, for each variable in both country groups. For this reason, the Karavias and Tzavalis panel unit root test that takes into account horizontal cross-section dependence will be applied.

Table 2

CD horizontal cross-section dependence test

	EU		BRICS-T	
Variable	CD-test	p-value	CD-test	*P*
gpcg	33.303*	0.000	9.609*	.000
lfdinic	3.466*	0.001	5.625*	.000
tradeg	31.122*	0.000	7.388*	.000
gfcfg	20.96*	0.000	6.398*	.000
govcg	9.637*	0.000	2.836*	.005
mobileg	27.272*	0.000	11.612*	.000
intg	21.166*	0.000	3.928*	.000
broadg	36.089*	0.000	8.434*	.000

Note: * indicates significance at 1% level.

The Karavias and Tzavalis Panel Unit Root Test is particularly suitable for panel data analyses involving datasets with cross-sectional dependence. Unlike traditional unit root tests, this method accounts for interdependencies between variables and performs stationarity analysis tailored to panel data structures. In panel data analyses covering multiple countries, economic and structural differences between nations must be considered. In this context, traditional first-generation unit root tests may produce misleading results as they ignore cross-sectional dependence.

In this study, the Karavias and Tzavalis test was chosen because the results of Pesaran's CD-Test indicated strong cross-sectional dependence. The test results confirm that the variables used in EU and BRICS-T countries are stationary, demonstrating that the model is appropriate and reliable for long-term analyses. The stationarity of the variables in the model ensures that regression results are meaningful and interpretable while also providing reliable outcomes for long-term policy implications.

Table 3 contains the Karavias and Tzavalis test assesses the stationarity of variables in a panel data set. These test results are generally suitable for more complex data structures and take into account cross-sectional dependence. The statistics in the table (values such as -18.7756, -9.5613) and p-values (mostly 0.0000) indicate that the variables analyzed for the EU and BRICS-T countries are stationary. Stationarity is necessary for econometric models to be reliable in long-run forecasts. These results confirm that the forecasts in the models are consistent and reliable.

The results of both tables show that your econometric model is based on stationary variables and that these variables are analyzed taking into account cross-sectional dependencies. This indicates that the model has a solid foundation, both theoretically and practically, and provides

a strong methodological structure in assessing the effects of digitalization on economic growth.

Table 3

Karavias and Tzavalis unit root test

	EU				BRICS-T			
	Stable		Constant and trended		Stable		Constant and trended	
	Statistic	p	Statistic	p	Statistic	p	Statistic	p
gpcg	-18.7756*	.0000	-9.5613*	.0000	-10.1625*	.0000	-4.4247*	.0500
lfdinic	-18.9368*	.0000	-12.3424*	.0000	-5.8515*	.0000	-2.4309*	.0000
tradeg	-20.7729*	.0000	-10.2255*	.0000	-10.5913*	.0000	-6.0123*	.0000
gfcfg	-21.2603*	.0000	-10.8951*	.0000	-10.3597*	.0000	-4.5243*	.0000
govcg	-15.7663*	.0000	-8.6200*	.0000	-10.3052*	.0000	-4.7297*	.0000
mobileg	-18.4734*	.0000	-9.2669*	.0000	-9.3516*	.0000	-4.4403*	.0000
intg	-29.6628*	.0000	-16.6143*	.0000	-9.2739*	0000	-4.0216*	.0000
broadg	-20.0435*	.0000	-10.0510*	.0000	-12.8556*	.0000	-5.8365*	.0300

Note: * indicates significance at 1% level.

Model selection and estimator identification

The tests for multicollinearity, specification error, and unit-time effects applied in the model selection process are vital to ensure the reliability and accuracy of the analysis. This process is necessary to ensure that the data are modeled correctly and that the estimation results are valid (Balıkçıoğlu, 2023).

According to table 4, the results of various diagnostic tests conducted for the EU and BRICS-T countries are presented. Regarding multicollinearity, the Mean Variance Inflation Factor (VIF) values are 1.40 for the EU and 1.33 for BRICS-T. These values are below the threshold of 2, indicating that there is no significant multicollinearity among the independent variables. Consequently, the regression model poses a low risk of producing biased results due to high correlations between the explanatory variables.

The Debenedictis-Giles Reset tests (S1, S2, S3) assess the specification error, with the p-values for both the EU and BRICS-T models being greater than 0.05. This outcome suggests that the null hypothesis of no specification error cannot be rejected, indicating that both models are correctly specified.

Table 4

Model selection tests

		EU		BRICS-T	
EXAMINATIONS	TESTING	Test statistic	Prob.	Test statistic	Prob.
Multiple Linear Connection	Mean VIF	1.40		1.33	
Specification Error	Debenedictis-Giles ResetS1 Test	0.555	0.5744	0.143	0.8667
	Debenedictis-Giles ResetS2 Test	0.410	0.8016	0.217	0.9284
	Debenedictis-Giles ResetS3 Test	0.387	0.8873	0.587	0.7398
Existence of Unit and Time Effects	Only Unit Impact - Breusch and Pagan Lagrangian multiplier test	0.00	1.0000	0.00	1.0000
	Only Time Impact - Breusch and Pagan Lagrangian multiplier test	121.43*	0.0000	6.27*	0.0061
Correlation of Unit and Time Effects with Independent Variables	Cluster-Robust Hausman Test	24.70*	0.0009	2.31	0.9409
	Hausman Test	54.72*	0.0000	10.85	0.0931

Note: * indicates significance at 1% level.

The Breusch and Pagan Lagrangian multiplier tests reveal that there are no significant unit effects for either the EU or BRICS-T, with p-values of 1.0000. However, the test results indicate the presence of significant time effects for both groups (p = .0000 for the EU and p = .0061 for BRICS-T). This suggests that the models exhibit time effects, which must be accounted for in the analysis. The presence of time effects indicates that economic growth in the analyzed countries is influenced by structural changes and macroeconomic trends over time. Therefore, ignoring these effects could lead to biased estimations, highlighting the necessity of incorporating time-fixed effects into the model specification. Additionally, the presence of time

effects suggests that business cycles, technological changes, and institutional developments play a significant role in shaping economic growth patterns, emphasizing the need for a dynamic approach in model estimation. Furthermore, given the rapid digitalization and shifting trade dynamics in these economies, the role of time effects becomes even more critical in capturing long-term structural transformations.

The selection of fixed and random effects models aligns with the underlying economic characteristics of the analyzed country groups. The EU countries exhibit more homogeneous institutional and economic structures, making the fixed effects model more appropriate to control for unobserved heterogeneity. Conversely, the BRICS-T countries display greater variability in economic and institutional conditions, justifying the use of the random effects model. The statistical validation through the Hausman and Breusch-Pagan LM tests further supports this choice, ensuring that the selected models accurately reflect the data structure and minimize potential biases. Moreover, the differences in economic volatility between the two country groups provide additional justification for model selection. BRICS-T countries, characterized by greater structural uncertainty and higher external dependency, are more likely to experience random shocks, making the random effects model more suitable. In contrast, the EU countries, which maintain more stable institutional and financial frameworks, benefit from the fixed effects model that accounts for individual country-specific factors over time. This differentiation highlights the necessity of choosing a modeling approach that accurately captures the economic realities of each group. As a result, employing a fixed effects model for the EU allows for better control over structural differences, while the random effects model for BRICS-T provides a more flexible framework to accommodate the high degree of economic diversity among these countries.

The Hausman tests, used to determine the appropriate model type, show that a fixed effects model is more suitable for the EU. Both the Cluster-Robust Hausman Test (p = .0009) and the traditional Hausman Test (p = .0000) suggest a significant correlation between the fixed effects and the independent variables for the EU, supporting the use of a fixed effects model. In contrast, the results for BRICS-T indicate that a random effects model is more appropriate, with the Cluster-Robust Hausman Test (p = .9409) showing no significant correlation between unit/time effects and the independent variables. The traditional Hausman Test (p = .0931) further supports the use of a random effects model for BRICS-T, though with marginal significance. These findings imply that while fixed effects better capture unobserved heterogeneity among EU countries, the random effects model is more suitable for BRICS-T due to the lack of significant correlation between unit/time effects and the independent variables. Consequently, the choice of model aligns with economic theory, which suggests that countries with more homogeneous structures, such as the EU, benefit from fixed effects estimation, whereas heterogeneous groups like BRICS-T are better modeled using random effects.

Overall, these results confirm that a fixed effects model is appropriate for the EU, while a random effects model is suitable for BRICS-T. These findings align with the discussions by Hsiao (2003) on modeling effects in panel data analysis.

Table 5

Changing variance, autocorrelation, and inter-unit correlation test

	AB			BRICS-T		
	Testing	Test statistic	Prob.	Testing	Test statistic	Prob.
Changing Variance	Modified Wald test	257.72*	0.000	W0	2.290	0.051
				W50	2.198	0.060
				W10	2.267	0.053
Auto-correlation (robust to changing variance)	Heteroskedasticity-robust Born and Breitung (2016) HR-test	-1.01	0.314	Modified Bhargava et al. Durbin–Watson	1.639	
				Baltagi–Wu LBI	1.850	
Correlation between Units	Breusch-Pagan LM test of independence	575.061*	0.000	Pesaran's test	3.441*	0.001
				Friedman's test	34.716*	0.000

Note: * indicates significance at 1% level.

According to Table 5, which shows the results of variance, autocorrelation, and inter-unit correlation tests in the model for EU countries, the presence of heteroskedasticity is analyzed using the Modified Wald test and the test statistic (257.72) rejects the null hypothesis at the 1% significance level (p-value: 0.000). This result indicates that there is a heteroskedasticity problem in the model. Heteroskedasticity-robust Born and Breitung (2016) HR-test was used as an autocorrelation test and the test statistic (-1.01) and p-value (0.314) failed to reject the null hypothesis. This indicates that there is no autocorrelation in the model. The inter-unit correlation was analyzed using the Breusch-Pagan LM test and the test statistic (575.061) rejected the null hypothesis at the 1% significance level (p-value: .000). This indicates that there is a high level of inter-unit correlation in the model. Considering these results, the model for EU countries has problems of varying variance and inter-unit correlation, but not autocorrelation.

As seen in Table 5 in the model of the BRICS-T countries, the presence of changing variance was examined by W0, W50, and W10 tests and all three tests failed to reject the null hypothesis at the 5% significance level (p-values: .051, 0.060, 0.053, respectively). These results indicate that there is no variance in the model. Modified Bhargava et al. Durbin-Watson (test statistic: 1.639) and Baltagi-Wu LBI (test statistic: 1.850) are used as autocorrelation tests and both test statistics are below 2, indicating that there is no autocorrelation in the model. The inter-unit correlation is analyzed using Pesaran's test (test statistic: 3.441) and Friedman's test (test statistic: 34.716) and both tests reject the null hypothesis at 1% significance level (p-values: .001 and .000, respectively). These results indicate that there is a high level of inter-unit correlation in the model. Therefore, for the BRICS-T countries, the model does not suffer from variance and autocorrelation problems, but there is an inter-unit correlation problem.

Table 6

Results for forecasters

	AB		BRICS-T	
	Coefficient	P>|t|	Coefficient	P>|t|
lfdinic	-0.0008	.898	1.69e-12	.677
tradeg	-0.0224	.647	0.0733	.962
gfcfg	0.1612*	.000	29.6191*	.000
govcg	0.1408	.098	6.8160	.171
mobileg	0.0126	.626	1.9211**	.014
intg	0.0265*	.001	1.7000**	.012
broadg	0.0041**	.011	-0.0194	.711
_cons	0.5299	.043	1.69e-12	.677

Note: * and ** denote significance at the 1% and 5% level, respectively.

As can be seen from Table 6, the coefficients of FDI, trade volume, and government expenditures are insignificant for both models. This table contains the coefficients and their respective statistical significance of the econometric model assessing the impact of different economic indicators on digitalization between EU and BRICS-T countries. The effect of each variable on economic growth is presented with p-values indicating how statistically reliable this effect is.

The coefficient of Foreign Direct Investment (FDI - lfdinic) for EU countries is -0.0008 (p = .898), indicating that FDI has no statistically significant impact on economic growth in the EU model. The negative sign could potentially indicate that foreign investment may strain local markets in the short run, but this effect is statistically insignificant. The coefficient value for the BRICS-T countries is 1.69e-12 (p = .677), again the impact of FDI on growth is not significant in the BRICS-T countries, but here the coefficient is much smaller and almost zero, suggesting that FDI has a minimal impact on the economic structure in these countries.

The coefficient of the External Openness Growth Rate (tradeg) is EU: -0.0224 (p = .647). This value indicates that foreign trade has a negative but insignificant effect on EU economies, which is probably related to other macroeconomic factors that may not have the expected positive effect on growth. In BRICS-T countries, it was found to be 0.0733 (p = .962). This result indicates that foreign trade again has a non-significant effect on growth in BRICS-T countries and this effect is positive compared to the EU, but again statistically insignificant.

The coefficient of Gross Fixed Capital Formation (gfcfg) for EU countries is 0.1612 (p=0.000), which indicates that gross fixed capital formation has a positive and very strong impact on economic growth in the EU. It is understood that investments directly stimulate economic activity and this creates a net growth effect. For the BRICS-T countries 29.6191 (p = .000), the effect is much more dramatic in the BRICS-T countries and the impact of fixed capital formation on growth in these economies is quite significant. The high coefficient indicates that investment contributes significantly to economic growth in these countries and that this factor is a critical engine for development.

The coefficient of Government Spending (govcg) for the EU is 0.1408 (p = .098), indicating that government spending has a positive effect on economic growth in the EU, but this effect is marginally significant. This implies that government spending may play a stimulating role on economic activity, but this effect is ambiguous. For BRICS-T, the value of 6.8160 (p = .171) indicates that government spending has a positive but statistically insignificant effect on economic growth in BRICS-T countries. It may be that government expenditures are not sufficiently directed to achieve the expected growth effects in these countries or that they may have effects in combination with other factors.

The coefficient of Mobile Phone Subscriptions (mobileg) for EU countries is 0.0126 (p = .626), indicating that mobile phone subscriptions have a non-significant impact on economic growth in the EU. This may indicate that other technological and structural factors suppress the economic impact of mobile penetration. For BRICS-T, it was found to be 1.9211 (p = .014). This result indicates that the increase in mobile subscriptions has a positive and statistically significant impact on economic growth in BRICS-T countries. It is seen that mobile technology has significantly

stimulated economic activity in these countries.

The coefficient of Internet Usage (intg) was found to be .0265 (p = .001) for EU countries. This indicates that the increase in internet usage in the EU has a significant and positive impact on economic growth. This emphasizes the effective role of digitalization and internet infrastructure on growth in EU economies. For BRICS-T, it is found as 1.7000 (p = .012). Accordingly, it indicates that internet usage has a positive and significant impact on economic growth in the BRICS-T model. This finding supports the critical role of internet access and digital technologies on economic development in these countries.

The coefficient of Fixed Broadband Subscriptions (broadg) for the EU is 0.0041 (p = .011), indicating that an increase in fixed broadband subscriptions in the EU has a significant and positive impact on economic growth. It indicates that broadband access supports economic activity, especially in the digital economy and services sectors. For BRICS-T, the value of -0.0194 (p = 0.711) indicates that broadband subscriptions have a negative but statistically insignificant impact on growth in BRICS-T countries. This may indicate that broadband infrastructure is not yet at a level to stimulate economic growth in these countries or that other economic factors mask this effect.

The Constant Term (_cons) is 0.5299 (p = 0.043) for the EU. This value indicates that factors other than the other variables in the model have a significant effect on economic growth in the EU, while it is insignificant in the BRICS-T and has no special statistical significance.

When the impact of digitalization on economic growth is examined through various economic indicators in the EU and BRICS-T countries, significant differences emerge. Analyses for both groups show that the development of digital technologies and communication infrastructure stand out as determinants of economic growth. Indicators such as internet usage and mobile phone subscriptions have positively affected economic growth, especially in BRICS-T countries, indicating that digital infrastructure investments are central to development strategies in these countries.

The rise in fixed capital creation and internet utilization in the EU positively influenced economic growth. This indicates that technology and investment serve as crucial accelerators for economic activity in high-income economies. Conversely, fixed capital formation exerts a significantly greater influence on economic growth in BRICS-T nations, indicating that investment in physical infrastructure remains essential for growth in these countries.

The analytical results underscore the necessity of considering heterogeneity and regional peculiarities in economic policymaking. The substantial influence of mobile phone subscriptions on economic growth in BRICS-T nations serves as a crucial signal of how the proliferation of these technologies can alter economic activity in these areas. Likewise, the beneficial effect of broadband internet access on growth within the EU underlines its crucial role in the advancement of the digital economy.

The analysis results indicate that while each variable lacks statistical significance in the relationship between digitalization and economic growth, the digitalization indicators lead to the rejection of the null hypothesis (H0) and the acceptance of the alternative hypothesis (H1), affirming that digitalization positively influences economic growth. Consequently, policy interventions will be pivotal in optimizing the impact of the digital transformation process on economic growth. They will occupy a pivotal role in facilitating the nationwide dissemination of digitization, hence fostering economic growth through essential infrastructural services, awareness-raising training, and the mitigation of inter-regional imbalances.

Expanded Discussion on Findings and Policy Implications

The findings of this study highlight significant differences in the impact of digitalization on economic growth between the EU and BRICS-T countries. In EU countries, the positive effect of internet usage and broadband subscriptions suggests that digital infrastructure and technology adoption play a fundamental role in long-term economic growth. The well-developed institutional frameworks and digital policies in these economies further enhance the effectiveness of digitalization. On the other hand, in BRICS-T countries, mobile phone subscriptions and gross fixed capital formation emerge as stronger drivers of growth, indicating that digital expansion is still closely tied to infrastructure investments and technological accessibility.

These results align with previous studies that emphasize the role of institutional quality in shaping the economic benefits of digitalization. For instance, studies by Chinoda and Kapingura (2024), as well as Patra and Sethi (2024), emphasize that the economic benefits of digital transformation are more pronounced when supported by strong institutional frameworks and sound regulatory structures. In contrast, in emerging economies with weaker institutional capacities, digitalization's impact on growth remains conditional on infrastructure readiness and investment stability.

From a policy perspective, the findings suggest differentiated strategies for digital transformation. In the

EU, further advancements in artificial intelligence, automation, and 5G infrastructure can reinforce existing digital advantages. Meanwhile, for BRICS-T countries, policies should focus on expanding digital access, ensuring affordability, and investing in digital literacy to maximize the economic benefits of digitalization. Additionally, targeted policies aimed at bridging the digital divide between urban and rural areas would foster more inclusive growth, particularly in economies with significant regional disparities.

Overall, the study's findings reinforce the need for tailored digital policies that align with the unique economic and institutional characteristics of each country group. Strengthening digital infrastructure while addressing regulatory and structural barriers remains critical for leveraging digitalization as a sustainable driver of economic growth in both developed and emerging economies.

Conclusion and Policy Recommendations

This study examines the impact of digitalization on economic growth in the context of the EU and BRICS-T countries, revealing the differing dynamics between these two groups. The findings indicate that digitalization contributes more robustly and consistently to economic growth in EU countries. In particular, broadband internet subscriptions and internet usage rates are among the key factors supporting economic growth through digital infrastructure. This result confirms the role of the EU's institutional framework and digital policies in driving economic performance. On the other hand, mobile phone subscriptions and gross fixed capital formation have a more pronounced effect on economic growth in BRICS-T countries. This suggests that digitalization in BRICS-T countries is still in the phase of infrastructure investments and basic technological access, requiring further structural transformation to yield long-term economic benefits. The findings highlight the strong link between the impact of digitalization on economic growth and the institutional structure, infrastructure capacity, and economic policies of countries.

These findings align with existing literature that emphasizes the contextual differences in the contribution of digitalization to economic growth. For example, Myovella et al. (2020) highlight that digital infrastructure directly contributes to growth in EU countries, whereas in developing economies, its impact remains limited due to infrastructure deficiencies and investment levels. Similarly, Koutroumpis (2019) finds that broadband internet fosters economic growth, but its effect is strongly dependent on institutional factors and investment capacity. Regarding BRICS-T countries, Thompson and Garbacz (2011) emphasize that digital transformation investments must be complemented by regulatory improvements and synchronized infrastructure development to create sustainable growth.

In this context, policymakers must adopt differentiated strategies to integrate digitalization as a fundamental driver of sustainable economic growth. For EU countries, deepening the existing digital economy and investing in next-generation technologies should be prioritized, whereas BRICS-T countries must focus on improving digital infrastructure and expanding accessibility. EU countries should make more effective use of digital transformation funds to enhance support mechanisms for small and medium-sized enterprises (SMEs), increase investments in 5G and fiber optic networks, and expand digital skills training programs. The well-developed digital infrastructure in EU countries facilitates the sustainable growth of the digital economy and supports the implementation of innovation-driven policies.

Conversely, in BRICS-T countries, expanding digital infrastructure is a crucial factor for accelerating economic growth. Strengthening mobile internet and broadband networks can enhance digital access in rural and low-income areas, thereby creating broader economic opportunities. Improving regulatory frameworks and increasing investment incentives can accelerate private sector investments, further supporting the digital transformation process. Additionally, expanding digital literacy education programs and addressing disparities in technology access can enhance digital inclusivity. Such policy approaches can maximize the positive economic impact of digitalization.

In conclusion, maximizing the economic impact of digitalization requires the development of policies tailored to the economic and institutional capacities of countries. While technology-driven investments should take precedence in EU countries, expanding digital infrastructure and improving regulatory frameworks are critical for BRICS-T countries. This study aims to assist policymakers in making more informed decisions regarding digital transformation processes, ultimately enhancing the role of digitalization in economic development.

Etik Komite Onayı: Bu çalışma için etik komite onayı gerekmemektedir.

Hakem Değerlendirmesi: Dış bağımsız.

Yazar Katkıları: Tüm makale tek yazar tarafından yazılmıştır.

Çıkar Çatışması: Yazar, çıkar çatışması olmadığını beyan etmiştir.

Finansal Destek: Yazar, bu çalışma için finansal destek almadığını beyan etmiştir.

Ethics Committee Approval: Ethics committee approval is not required for this study.

Peer-review: Externally peer-reviewed.

Author Contributions: The entire article was written by a single author.

Conflict of Interest: The author have no conflicts of interest to declare.

Financial Disclosure: The author declared that this study has received no financial support.

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