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DIGITAL TRANSFORMATION AND ECONOMIC GROWTH OF THE ASEAN-6 COUNTRIES

Thi Anh Tuyet Le[1]

Abstract. This study employs a panel data approach to analyse the impact of digital transformation on economic growth in the ASEAN-6 countries from 2000 to 2023. The research framework delineates economic growth (EG) as the dependent variable, while pivotal independent variables concentrate on diverse dimensions of digital transformation. These include broadband infrastructure (FixB), fixed-line telephony (FixT), Internet access (IV), mobile technology (MB), and ICT-related trade (ICTE, ICTI). Furthermore, the model incorporates several control variables to account for other economic influences, including investment (INV), trade openness (TO), population growth (POP), inflation (INF), urbanisation (Urban), and electricity access (Electric). The utilisation of panel data facilitates the management of unobserved country- and time-specific effects, thereby ensuring a more robust analysis. However, potential econometric issues such as heteroscedasticity and autocorrelation are mitigated through the application of the Generalised Least Squares (GLS) method, which enhances the precision of estimations. A descriptive statistical analysis was conducted to highlight notable variations in economic growth, trade patterns, and digital penetration across the ASEAN-6 region. The average GDP growth rate over the study period was approximately 4.8%, though individual country experiences exhibited significant fluctuations. Internet penetration levels also exhibited substantial differences, ranging from as low as 0.25% to as high as 97.69%, reflecting disparities in technological adoption and infrastructure development. Furthermore, a significant disparity was observed in the domains of high-tech manufacturing and ICT trade, suggesting that the process of digital transformation has occurred in a non-uniform manner across these nations. Preliminary correlation analysis suggests that the primary influence of digital transformation on economic growth stems from infrastructure development and technology adoption rather than direct contributions to GDP. The findings of the regression analysis, as conducted via the Pooled OLS model, suggest a positive and significant relationship between investment (INV) and trade openness (TO) on economic growth. However, it is notable that broadband infrastructure (FixB) appears to exert a negative effect, which is presumably a consequence of the substantial initial investment costs associated with the deployment of digital infrastructure. The findings reveal that other digital transformation indicators, such as mobile technology and Internet penetration, do not demonstrate significant direct effects on economic growth. Furthermore, the OLS model reveals severe multicollinearity issues, necessitating the use of more refined estimation techniques. Diagnostic tests demonstrate that heteroscedasticity does not pose a concern, as substantiated by the White test, while the Wooldridge test detects autocorrelation. Consequently, the employment of Fixed Effects (FEM) or Random Effects (REM) models with clustered standard errors is recommended, as these approaches yield more reliable estimation results. In conclusion, while investment and trade integration emerge as key drivers of economic growth in the ASEAN-6, the economic benefits of digital transformation may require a longer timeframe to materialise. It is therefore vital to enhance investment strategies in digital infrastructure and to address issues of multicollinearity if more accurate estimations are to be obtained and a more complete understanding of the role of digital transformation in economic development to be achieved.

Keywords: digital transformation, digital economic, economic growth, ASEAN, ASEAN-6.

JEL Classification: O33, O40

[1] Ho Chi Minh University of Banking, Vietnam
E-mail: tuyetlta@hub.edu.vn
ORCID: https://orcid.org/0009-0007-6091-7821

1. Introduction

Digital transformation has emerged as a pivotal catalyst for economic growth in the digital era. A substantial body of research has demonstrated that advancements in information and communication technology (ICT), including the proliferation of Internet users, mobile subscribers, and the expansion of broadband infrastructure, can substantially boost a country's economic performance.

In the preceding decade, the rapid progression of digital technologies, including artificial intelligence (AI), cloud computing, the Internet of Things (IoT), blockchain, and 5G wireless networks, has precipitated a paradigm shift in the manner in which governments, businesses, and individuals interact with one another, thereby ushering in a global digital revolution. Despite the absence of a universally accepted definition of digital transformation, it can be comprehended as the substantial changes in production, living, and working brought about by digital technology.

Nevertheless, the advantages of digital transformation are not immediately apparent. Park and Choi (2019) posit that the impact of new technologies is non-instantaneous, and that the consequences may vary between developed, developing, and emerging countries. Steinmueller (2001) contends that technology can facilitate a "leapfrogging" effect, enabling developing countries to circumvent initial stages of productivity gains. Conversely, Niebel (2018) asserts that developing and emerging countries frequently experience diminished returns due to their inability to effectively absorb technology and invest in research and development.

This study sets out to examine the impact of digital transformation on economic growth in the six largest ASEAN countries. Specifically, the study will focus on identifying the benefits and challenges of digital transformation in promoting GDP growth, raising labour productivity, and improving business performance. The present study will analyse economic and technological data in order to assess the impact of digital transformation and propose strategies and policies to help ASEAN-6 countries maximise the benefits of digital transformation. The objective is to furnish policymakers and businesses with insights and concrete recommendations, empowering them to leverage technology to drive sustainable economic growth.

2. Theoretical Basis

2.1. The Concept of Digital Transformation and Measurement Indicators

Digital transformation can be defined as the comprehensive and rapid changes in business operations, processes, capabilities, and business models aimed at maximising opportunities arising from advancements in digital technology (Demirkan, Spohrer & Welser, 2016). According to Hess et al. (2016), digital transformation encompasses not only technological innovation but also the emergence of new business models, innovative products and services, and the automation of operational processes. Evidence of these changes is apparent in the growing demand for online communication platforms, which in turn are reshaping traditional business structures. The assessment of the degree of digital transformation has been the subject of numerous studies, which have proposed a variety of indicators reflecting the development of technology infrastructure, the extent of digital application, and the population's access to technology. These indicators are based on three main aspects:

– Telecommunications and connection to digital infrastructure. This includes the number of fixed broadband subscribers (FixB), fixed telephone subscribers (FixT), mobile subscribers (MB), and the percentage of the population using the Internet (IV). These metrics are utilised to assess individuals' access to and utilisation of digital technology.

– Technology application in production and trade. This aspect is represented by the added value of medium and high technology manufacturing (MHT) and the export (ICTE) and import (ICTI) ratios of information technology goods, which reflect the level of technological integration within the economy.

– Supporting conditions and readiness for digital transformation. The factors under consideration include the urban population ratio (Urban) and access to electricity (Electric), both of which are essential for the deployment of digital technology.

The selection of these indicators is grounded in the theoretical framework of digital infrastructure, technology access, application in production and trade, and the supportive conditions for digital transformation. Utilising these indicators to measure digital transformation enables a comprehensive evaluation of an economy's preparedness to adopt digital technology to promote growth and sustainable development.

2.2. Economic Growth

Economic growth, as defined by Samuelson and Nordhaus (1985), refers to the increase in the production of goods and services within an economy over a given period of time, typically represented by the expansion of GDP or GNP. This process is reflected in the outward shift of the production possibility frontier (PPF) and is closely linked to increases in per capita output, signalling an improvement in the economic welfare of the population. Economic growth plays a key role in

promoting macroeconomic stability, raising living standards and laying the foundations for sustainable development. Various indicators are used to measure economic growth, including the growth rate of real GDP, GDP per capita, labour productivity, the ratio of investment to GDP and the Human Development Index (HDI). Nevertheless, among these metrics, the annual GDP growth rate (annual percentage GDP growth) is the most widely utilised and significant, as it directly reflects the level of economic expansion over time. The utilisation of GDP growth as a metric facilitates the evaluation of the efficacy of economic policies, the assessment of the overall health of the economy, and the establishment of a basis for the comparison of development levels across countries.

2.3. Economic Theory on the Relationship between Digital Transformation and Economic Growth

Endogenous growth theories proposed by Romer (1986) and Lucas (1988) underscore the pivotal role of endogenous factors, including knowledge and human capital, in promoting sustained economic growth. Romer (1986) contends that knowledge functions as a factor of production, exhibiting increasing returns to scale. The impact of technological advancements and innovations is such that their effects are felt beyond the scope of individual firms or industries, extending to the broader economic landscape. In the context of digital transformation, knowledge and digital technologies can be accumulated and shared at negligible marginal costs, particularly through tools such as big data, artificial intelligence, and blockchain. This finding is consistent with the theoretical framework proposed by Romer (1986), which posits that the process of digitalisation can serve to accelerate the rate of innovation, enhance returns to scale, and promote long-term economic growth.

In contrast, Lucas (1988) emphasises the significance of human capital and its spillover effects on labour productivity and economic growth. Lucas's (1988) argument posits that investments in education and training not only enhance individual productivity but also generate favourable spillover effects throughout the broader economy. The digital transformation has fundamentally changed the way in which human capital is accumulated and utilised, through the use of online learning platforms, AI-driven personalised training and digital technologies to enhance workforce skills. Consequently, the accumulation of human capital becomes more efficient, thereby aligning with Lucas's (1988) assertion regarding the influence of human capital on economic growth. Consequently, these theoretical frameworks imply that endogenous factors function as pivotal catalysts for economic growth. In the contemporary context, digital transformation plays a pivotal role in amplifying these factors, contributing to the sustenance of long-term growth rates.

Eaton and Kortum's (1999) technology diffusion theory focuses on the diffusion of technology across countries and its impact on economic growth. The present study develops a theoretical model combined with empirical evidence to measure the extent of international technology diffusion, emphasizing the role of trade, foreign investment, and other channels in the diffusion of knowledge and innovation.

According to Eaton and Kortum (1999), technology is not only developed within a country but can also spread across borders through various mechanisms. One of the most important channels is international trade, as countries can gain access to more advanced technology by importing goods and services from countries that are leaders in innovation. When a country imports machinery, equipment or software from advanced economies, it gains access not only to the products but also to the associated production processes and technologies. Foreign direct investment (FDI) also plays an important role in technology diffusion, as multinational companies bring new technology and know-how to other countries. Domestic firms can learn from foreign firms through collaboration, hiring, or observing how advanced firms operate. An important point in the study by Eaton and Kortum (1999) is that the degree of technology absorption is uneven across countries and depends on the absorptive capacity of each economy. Factors such as the skills of the labour force, education systems, economic institutions and the level of investment in research and development (R&D) determine the effectiveness of the technology diffusion process. Countries with a strong educational base and a favourable business environment are more likely to absorb and apply new technologies, thereby achieving faster economic growth.

In their 2019 study, Banileva and Dhanaraj examined the impact of digital transformation on economic growth from the perspective of internalisation theory. Their analysis suggests that digital transformation facilitates the reduction of transaction costs, enhances transparency, and optimises global value chains, thereby enabling businesses to expand into new markets without the necessity of owning all local operations. The advent of digital platforms and innovative business models, including the sharing economy and on-demand services, has been instrumental in catalysing innovation, enhancing labour productivity and expanding market reach. Consequently, this phenomenon has emerged as a substantial catalyst for global economic growth. Nevertheless, the study also acknowledges the challenges related to data governance and security. Consequently, the authors emphasise

that digital transformation not only alters business strategies but also plays a critical role in sustaining long-term economic growth.

Recent studies have illuminated the relationship between information technology, the digital economy, and economic growth from various perspectives. Barro, Mankiw, and Sala-i-Martin (1995) analysed the impact of capital mobility on global economic growth, indicating that capital mobility can promote growth if managed effectively. In their 2011 study, Badran et al. examined the impact of broadband infrastructure on economic growth in Egypt and several Arab countries. Their findings indicated that such infrastructure has a significant positive impact on the economy, especially in developing countries. In a similar vein, Bahrini and Qaffas (2019) posited that the implementation of information and communication technology (ICT) fosters economic growth in developing countries, primarily through the enhancement of production efficiency and market connectivity. Grossman and Helpman (1993) emphasised the pivotal role of innovation in the realm of global economic growth, proposing that innovation has the capacity to yield novel products and processes, thus catalysing growth. Fernández-Portillo et al. (2020) conducted a study of the impact of ICT development on OECD countries of the European Union, determining that ICT has a significant positive impact on economic growth. Gomes, Lopes, and Ferreira (2022) also confirm that the digital economy contributes significantly to economic growth in OECD countries through improved efficiency and value creation. Furthermore, Fernández-Portillo et al. (2019) argue that ICTs can support sustainable development if they are used and managed effectively. Odhiambo (2022) explores the relationship between information technology, income inequality and economic growth in sub-Saharan African countries, showing that ICT can promote growth but can also increase inequality without appropriate regulatory policies. Jurayevich and Bulturbayevich (2020) show that the digital economy has a positive impact on economic growth by creating new opportunities and improving productivity. Finally, Chakpitak et al. (2018) and Guo, Ding, and Lanshina (2017) emphasise that digital technology and the digital economy can promote sustainable economic growth by improving efficiency and encouraging innovation. Overall, the studies show that information technology and the digital economy play an important role in promoting economic growth, although the specific impact may vary depending on the national and regional context. While there are many studies on the impact of technology and digital transformation on economic growth, there is a significant gap in the application of these findings to the ASEAN-6 countries. Existing research frequently focuses on developed economies or global scales, with insufficient attention paid to developing economies such as the ASEAN-6. The present study aims to address this research gap by offering a comprehensive and accurate perspective on the impact of digital transformation on economic growth in the ASEAN region. The study will assist countries in the region in formulating suitable policies and strategies to maximise the benefits of digital transformation.

3. Research Methods

Based on the above theory, the research model has the following form:

gEG = f(FixB, FixT, IV, MB, ICTE, ICTI, MHT, Urban, Electric, INV, TO, POP,INF)

With the basic regression equation:

$$EG_t = \beta_0 + \beta 1 FixB_t + \beta_2 FixT_t + \beta_3 IV_t + \beta_4 MB_t + \beta_5 ICTE_t + \beta_6 ICTI_t + \beta_7 MHT_t + \beta_8 Urban_t + \beta_9 Electric_t + \beta_{10} INV_t + \beta_{11} TO_t + \beta_{12} POP_t + \beta_{13} INF_t$$

In this study, the dependent variable is EG, which represents the rate of economic growth. The key independent variables that reflect aspects of digital transformation include FixB, which measures the level of access to broadband infrastructure; FixT, which indicates the number of fixed telephone subscribers per 100 people in a country or region, reflecting the prevalence of fixed telephone service; IV, which reflects the penetration of Internet access, which is a critical factor in digital transformation; MB, which reflects the level of mobile technology penetration; ICTE, which assesses the contribution of the information and communications technology sector to the economy; ICTI, which assesses the degree of dependence on imported technology; MHT, which reflects the technological level in the economy; Urban, which assesses the impact of urbanization; and Electric, which measures the level of access to basic infrastructure. The control variables include INV, which measures investment in the economy; TO, which assesses the level of international economic integration; POP, which reflects changes in population; and INF, which controls for the impact of inflation on economic growth.

The data for this study was collected at the country level from 2000 to 2023. The utilisation of panel data, which integrates spatial (country) and temporal (year) dimensions, enables the control of unobserved factors within each country or year, thereby enhancing the accuracy of the model. However, it should be noted that both Fixed Effects (FEM) and Random Effects (REM) models may be subject to issues of autocorrelation and heteroscedasticity, which have the potential to undermine the efficiency of estimates and result in biased standard errors. To address these issues, the Generalised Least Squares (GLS) method is employed to adjust for heteroscedasticity and autocorrelation, thereby improving the precision of the estimates. GLS employs

a covariance matrix to rectify biases in the data, thereby yielding more efficient estimates in comparison to the conventional Least Squares method. The modelling process commences with the aggregation of complete and consistent data, followed by model suitability testing, such as the Hausman test, to ascertain whether a Fixed Effects or Random Effects model is appropriate. The model is then estimated and evaluated using statistical indicators such as R-squared and the F-statistic. Finally, the results of the analysis are used to draw conclusions and make recommendations on factors influencing economic growth, such as investment, urbanisation and information technology.

4. Empirical Results and Discussion

4.1. Descriptive Statistics of Variables in the Research Model

A thorough examination of the descriptive statistics for ASEAN-6 (2000–2023) reveals substantial disparities across economic, trade and technological indicators. The average annual GDP growth rate was 4.80% (SD = 2.99), with Vietnam and Indonesia demonstrating stability, while Thailand and Singapore experienced recessions that resulted in fluctuations between -9.5% and 14.5%. Inflation averaged 3.61%, ranging from -1.7% (Singapore) to 23.1% (Indonesia, Philippines). Investment averaged 26.26% of GDP,

Table 1
Description of research variables and hypotheses

Variable	Variable interpretation and unit	Research hypothesis	Data source
EG	GDP growth per year of ASEAN-6 countries from 2000 to 2023 (annual %)	/	World Bank
FixB	Fixed broadband subscriptions per year of ASEAN-6 countries from 2000 to 2023 (per 100 people)	+/–	World Bank
FixT	Fixed telephone subscriptions per year of ASEAN-6 countries from 2000 to 2023 (per 100 people)	+/–	World Bank
MB	Mobile cellular subscriptions per year of ASEAN-6 countries from 2000 to 2023 (per 100 people)	+/–	World Bank
IV	Individuals using the Internet per year of ASEAN-6 countries from 2000 to 2023 (% of population)	+/–	World Bank
MHT	Medium and high-tech manufacturing value added per year of ASEAN-6 countries from 2000 to 2023 (% manufacturing value added)	+/–	World Bank
ICTE	ICT goods exports per year of ASEAN-6 countries from 2000 to 2023 (% of total goods exports)	+/–	World Bank
ICTI	ICT goods imports per year of ASEAN-6 countries from 2000 to 2023 (% total goods imports)	+/–	World Bank
Urban	Urban population per year of ASEAN-6 countries from 2000 to 2023 (% of total population)	+/–	World Bank
Electric	Access to electricity per year of ASEAN-6 countries from 2000 to 2023 (% of population)	+/–	World Bank
INF	Inflation, consumer prices per year of ASEAN-6 countries from 2000 to 2023 (annual %)	+/–	World Bank
INV	Gross capital formation per year of ASEAN-6 countries from 2000 to 2023 (% of GDP)	+/–	World Bank
TO	Trade per year of ASEAN-6 countries from 2000 to 2023 (% of GDP)	+/–	World Bank
POP	Population growth per year of ASEAN-6 countries from 2000 to 2023 (annual %)	+/–	World Bank

Source: result using the stata 14 software

Table 2
Descriptive statistics of variables in the research model

Variable	Obs	Mean	Std. Dev.	Min	Max
EG	144	4.797917	2.994575	-9.5	14.5
INF	144	3.613194	3.43579	-1.7	23.1
INV	144	26.26458	5.223568	15.7	39.6
TO	144	151.4903	103.8191	32.97218	437.3267
POP	144	1.343056	0.9641586	-4.2	5.3
FixB	144	7.73349	8.574489	0.0011	28.5393
FixT	144	14.20361	12.36937	2.434818	49.71947
MB	144	101.3633	51.08577	0.9981615	181.767
IV	144	43.19688	29.55023	0.254248	97.6927
MHT	144	44.49372	16.2638	19.08404	83.72707
ICTE	144	25.47167	15.00655	2.66	54.97
ICTI	144	21.17208	11.84956	3.5	51.48
Urban	144	57.27944	22.96956	24.374	100
Electric	144	95.56736	6.107748	74.7	100

Source: result using the stata 14 software

ranging from 15.7% (Thailand) to 39.6% (Vietnam and Indonesia).

Trade openness exhibited significant variation (32.97% in Indonesia to 437.33% in Singapore), while population growth ranged from -4.2% (Thailand) to 5.3% (Philippines). Telecommunications infrastructure exhibited considerable disparities, with fixed broadband subscriptions averaging 7.73 per 100 people (0.0011 in Vietnam to 28.54 in Singapore) and mobile subscriptions ranging from 0.99 to 181.77.

Digital penetration exhibited significant disparities, with Internet usage averaging 43.19% (0.25% to 97.69%). The high-tech manufacturing sector contributed an average of 44.49%, with Malaysia and Singapore leading at 83.72%. Furthermore, the ICT trade exhibited variability, with exports averaging at 25.47% and imports at 21.17%.

Urbanization levels ranged from 24.37% (Vietnam) to 100% (Singapore), while the average electricity access rate was 95.57%, with some regions in Indonesia and the Philippines exhibiting a lower rate of 74.7%. These disparities necessitate adjustments, such as Generalised Least Squares (GLS), to address heteroscedasticity and autocorrelation in the data.

4.2. Correlation Analysis

The model under scrutiny in this study examines the impact of digital transformation on economic growth, highlighting the pivotal role of infrastructure and information technology in economic development. The study finds a modest correlation between GDP growth (EG) and inflation (INF) as well as investment (INV), suggesting that these factors exert only a limited direct influence on economic expansion. Conversely, telecommunications infrastructure (FixB, FixT) has been found to be strongly correlated with mobile penetration (MB) and Internet usage (IV), indicating that advancements in these areas are key drivers of technological adoption and increased investment in high-tech industries (MHT).

Furthermore, urbanisation (Urban) and electricity access (Electric) have been shown to have a significant impact on high-tech production and Internet penetration, thereby reinforcing the importance of infrastructure in the context of digital transformation. In conclusion, whilst digital transformation exerts a primary influence on economic growth through infrastructure and technological development, its direct effect on GDP remains negligible. The correlation analysis suggests that regression models can effectively examine the relationship between digital transformation and economic growth. However, issues of multicollinearity should be given careful consideration.

4.3. Estimation by Regression Model Using Least Squares Method (POOL OLS)

The findings of the Pooled OLS model demonstrate that the impact of digital transformation on economic growth (EG) in the ASEAN-6 countries is not uniform. Investment (INV) has a statistically significant positive impact ($p = 0.002$), thus highlighting the critical role of capital investment in driving GDP growth. Furthermore, trade openness (TO) has been demonstrated to exert a positive effect ($p = 0.016$), thereby underscoring the significance of international economic integration in the promotion of economic development. However, a notable finding is that broadband infrastructure (FixB) has a negative impact ($p = 0.026$), potentially due to high investment costs that have yet to yield immediate benefits.

Table 3
Correlation of variables in the model

	EG	INF	INV	TO	POP	FixB	FixT	MB	IV	MHT	ICTE	ICTI	Urban	Electric
EG	1.0													
INF	0.20	1.0												
INV	0.20	0.28	1.0											
TO	0.05	-0.26	-0.03	1.0										
POP	0.04	0.11	-0.13	0.22	1.0									
FixB	-0.14	-0.29	0.00	0.70	-0.03	1.0								
FixT	0.01	-0.22	-0.03	0.89	0.22	0.57	1.0							
MB	-0.18	-0.21	0.11	0.21	-0.16	0.66	0.20	1.0						
IV	0.17	-0.35	-0.01	0.51	-0.05	0.81	0.46	0.77	1.0					
MHT	-0.06	-0.41	-0.28	0.85	0.17	0.71	0.83	0.30	0.53	1.0				
ICTE	-0.03	-0.35	-0.51	0.38	0.21	0.22	0.30	0.08	0.29	0.46	1.0			
ICTI	-0.03	-0.34	-0.52	0.38	0.26	0.19	0.31	-0.0	0.23	0.48	0.88	1.0		
Urban	-0.09	-0.35	-0.24	0.77	0.22	0.67	0.86	0.38	0.62	0.88	0.37	0.40	1.0	
Electric	-0.09	-0.26	0.34	0.46	-0.13	0.55	0.46	0.69	0.71	0.35	0.02	-0.10	0.46	1.0

Source: result using the stata 14 software

Table 3
Estimation results by regression model using least squares method (POOL OLS)

EG	Coef.	Std. Err.	t	P>|t|	Beta
INF	0.1158538	0.0863608	1.34	0.182	0.1329235
INV	0.2166148	0.0686951	3.15	0.002	0.3778507
TO	0.0222566	0.0090819	2.45	0.016	0.7716168
POP	-0.281151	0.286522	-0.98	0.328	-0.0905218
FixB	-0.2043058	0.0908059	-2.25	0.026	-0.5849973
FixT	-0.1001099	0.0697041	-1.44	0.153	-0.4135134
MB	0.0076088	0.0104468	0.73	0.468	0.129801
IV	0.0126856	0.0220741	0.57	0.566	0.1251808
MHT	0.0064925	0.0477371	0.14	0.892	0.0352612
ICTE	0.0258156	0.0366388	0.70	0.482	0.1293684
ICTI	-.0218108	0.048721	-0.45	0.655	-0.0863054
Urban	0.0247301	0.0340316	0.73	0.469	0.1896894
Electric	-0.1600445	0.0920692	-1.74	0.085	-0.3264275
_cons	10.77249	7.986473	1.35	0.180	

Source: result using the stata 14 software

Whilst other factors, including inflation (INF), population growth (POP), mobile subscriptions (MB), Internet usage (IV) and ICT goods trade (ICTE, ICTI), demonstrate certain coefficients, these are not statistically significant ($p > 0.05$), indicating insufficient evidence of their direct impact on economic growth. Electricity access (Electric) has been found to have a negative coefficient and is close to statistical significance ($p = 0.085$), suggesting that the expansion of electricity infrastructure alone may not contribute effectively to economic growth without complementary efficiency-enhancing policies.

The model indicates that economic growth in the ASEAN-6 is predominantly driven by investment and trade integration. However, the impact of digital transformation remains uncertain and may necessitate a more extended timeframe to become evident. Consequently, optimising investments in digital technology and infrastructure is imperative to ensure that digital transformation effectively fosters sustainable economic growth.

The OLS diagnostic tests indicate strong multicollinearity, with high Variance Inflation Factor (VIF) values observed for variables such as TO, FixT, Urban, FixB and MHT, which may undermine the reliability of the estimated coefficients. Therefore, the elimination or combination of some variables should be considered.

The White test confirms the absence of heteroskedasticity (p-value = 0.3347), but the Wooldridge test detects first-order autocorrelation (p-value = 0.0238). Consequently, the employment of a Fixed Effects Model (FEM) or a Random Effects Model (REM) with clustered standard errors would be a more appropriate course of action. To ascertain the most suitable model, the Hausman test should be conducted, and any necessary adjustments should be made to address multicollinearity and enhance estimation accuracy.

4.4. Estimation According to Fixed Effects and Random Effects Models

The present analysis of the impact of digital transformation on economic growth in the ASEAN-6 countries indicates that factors related to digitalisation have not yet demonstrated a clear role in driving GDP growth. Specifically, indicators such as Internet usage, mobile subscriptions, high-tech manufacturing value-added, and ICT goods trade lack statistical significance in both the Fixed Effects Model (FEM) and the Random Effects Model (REM). This finding indicates that digital transformation is still in its nascent stages and has not yet exerted a strong short-term influence on economic growth. Of particular note is the statistically significant negative impact of fixed broadband subscriptions in the REM model. This suggests that the expansion of digital infrastructure may initially result in costs that could potentially hinder growth, subsequently yielding long-term benefits.

In contrast, investment (INV) and trade openness (TO) have been shown to have a statistically significant positive effect on GDP growth, thereby highlighting the pivotal role of capital inflows and economic integration in the region. Conversely, population growth (POP) exhibits a significantly negative impact in the FEM model, reflecting demographic pressures on resources and economic productivity. Additionally, access to electricity (Electric) has a negative impact on the REM model, potentially indicating infrastructure cost challenges.

The Hausman test indicates that the REM model is more appropriate, suggesting that random effects

Table 4
Estimation results by fixed effects model (FEM) and random effects model (REM)

EG	FEM model	REM model
INF	0.0413614 (0.45)	0.1158538 (1.34)
INV	0.2171126*** (2.61)	0.2166148*** (3.15)
TO	0.0444339*** (3.29)	0.0222566*** (2.45)
POP	-0.7717006*** (-2.56)	-0.281151 (-0.98)
FixB	-.0987167 (-1.03)	-.2043058** (-2.25)
FixT	-0.0124231 (-0.15)	-.1001099 (-1.44)
MB	0.0156829 (1.08)	0.0076088 (0.73)
IV	-0.0047071 (-0.17)	0.0126856 (0.57)
MHT	0.0846883 (1.31)	0.0064925 (0.14)
ICTE	-0.0370536 (-0.80)	0.0258156 (0.70)
ICTI	-0.0382172 (-0.66)	-0.0218108 (-0.45)
Urban	-0.1125088 (-0.83)	0.0247301 (0.73)
Electric	-0.1556667 (-1.24)	-0.1600445* (-1.74)
Số quan sát	144	
Hausman test results: chi2(13) = (b-B)'[(V_b-V_B)^(-1)](b-B) = 16.80 Prob>chi2 = 0.2084		

*: Statistically significant at 10% significance level ***: Statistically significant at 1% significance level

Source: result using the stata 14 software

across ASEAN-6 countries have a more significant role than country-specific fixed effects. In conclusion, while digital transformation holds substantial potential for economic growth, it is vital for ASEAN-6 nations to implement supportive policies to maximise the benefits of digital technology and ensure the sustainability of this process.

However, the Breusch-Pagan test indicates that the variance of random effects is zero, suggesting that the Pooled OLS model may be a more suitable alternative to REM. Furthermore, the Wooldridge test detects first-order autocorrelation, which has the potential to impact the precision of regression estimates. To address these limitations, the Generalised Least Squares (GLS) method should be considered, as it can correct for heteroskedasticity and autocorrelation in panel data, leading to more efficient estimations. Furthermore, the application of robust standard errors using the Arellano method or the integration of FEM with GLS has the potential to enhance the reliability of estimates, particularly in light of the varying levels of development and digital transformation across ASEAN-6 countries.

4.5. Estimated Results According to the GLS Model

The findings of the Generalised Least Squares (GLS) model demonstrate that the impact of digital transformation on the economic growth of ASEAN-6 countries remains ambiguous. Investment (INV) and trade (TO) have been identified as two factors that exert a positive and statistically significant influence on GDP growth, with coefficients of 0.2303 and 0.0229, respectively. These findings underscore the pivotal role of capital flows and economic integration in fostering growth. However, some factors related to digital transformation show negative effects. In particular, the number of fixed broadband subscribers (FixB) has a coefficient of -0.2098 and is significant at the 5% level, suggesting that fixed broadband infrastructure has not been used

Table 6
Estimated results according to the GLS model

EG	Coef.	Std. Err.	z	P>|z|	95% Conf. Interval	
					Min	Max
INF	0.1155669	0.0837539	1.38	0.168	-0.0485878	0.2797215
INV	0.2303102	0.0684124	3.37	0.001	0.0962243	0.3643961
TO	0.0228641	0.0090775	2.52	0.012	0.0050725	0.0406557
POP	-0.372637	0.2791301	-1.33	0.182	-0.9197219	0.174448
FixB	-0.2097923	0.0901574	-2.33	0.020	-0.3864975	-0.033087
FixT	-0.1053592	0.0699876	-1.51	0.132	-0.2425324	0.0318141
MB	0.0079904	0.0105044	0.76	0.447	-.0125978	.0285787
IV	0.0120181	0.021721	0.55	0.580	-0.0305543	0.0545905
MHT	0.0046748	0.0470923	0.10	0.921	-0.0876243	0.096974
ICTE	0.025027	0.0368265	0.68	0.497	-0.0471517	0.0972057
ICTI	-0.0166689	0.0489308	-0.34	0.733	-0.1125715	0.0792336
Urban	0.0288901	0.0341122	0.85	0.397	-0.0379686	0.0957489
Electric	-0.1635324	0.0907312	-1.80	0.071	-0.3413623	0.0142976
_cons	10.64144	7.896804	1.35	0.178	-4.836009	26.11889

Source: result using the stata 14 software

effectively, possibly due to high initial investment costs or limited accessibility. In addition, access to electricity (Electric) also has a negative impact on GDP growth, with a coefficient of -0.1635 and a significance level of 10%, indicating that limitations in electricity infrastructure can hinder digital transformation and economic development. Meanwhile, other factors such as mobile subscribers (MB), internet penetration (IV), value added of medium and high tech manufacturing (MHT), ICT import/export (ICTE, ICTI) or urban population ratio (Urban) are not statistically significant, meaning that there is no clear evidence of their impact on GDP growth. Overall, this model shows that while digital transformation has the potential to support economic growth, ASEAN-6 countries need a strategy to optimise investment in digital infrastructure, improve power quality and increase technology efficiency to more effectively promote this process.

5. Comment on Research Results and Policy Implications

The research findings highlight several key aspects of the impact of digital transformation on economic growth in the ASEAN-6 countries. First, investment (INV) and trade openness (TO) play a critical role in driving economic growth, with strong statistical significance. This suggests that ASEAN-6 countries should continue to strengthen investment promotion policies, especially in technology and digital infrastructure, while fully exploiting trade integration to promote sustainable economic growth.

However, the study also reveals that fixed broadband infrastructure (FixB) and access to electricity (Electric) have a negative effect on growth. This phenomenon may be attributed to the disparate deployment of telecommunications infrastructure, which has yet to generate substantial economic value, while limitations in stable energy access could impede the development of the digital economy.

A further salient finding is that technological factors, such as Internet penetration (IV) and ICT goods trade (ICTE, ICTI), do not manifest a discernible impact on economic growth. This phenomenon may be attributed to the presence of disparities in the development of digital technology across the ASEAN-6 countries, as well as the inadequate utilisation of digital technologies within production and business operations. Furthermore, population growth (POP) and urbanisation (Urban) have been found to be statistically insignificant in terms of influencing economic growth. This suggests that expanding urban areas or increasing population alone does not guarantee economic progress without a well-structured development strategy.

Based on these findings, there are several key policy implications for ASEAN-6 countries to enhance economic growth through digital transformation. First, governments need to increase investment in digital infrastructure and technology to maximise the benefits of digitalisation. Policies should focus on helping firms adopt advanced technologies and creating an enabling regulatory environment to attract investment in the technology sector.

In addition, the expansion of trade and the integration of the digital economy should be further prioritised, in particular through free trade agreements and policies that promote e-commerce. This will allow businesses to capitalise on the opportunities of the digital economy and improve access to international markets.

Another critical issue is the enhancement of the quality of telecommunications and energy

infrastructure, as opposed to the mere expansion of their scale. It is recommended that ASEAN-6 nations allocate resources to the enhancement of telecommunications networks, with a view to ensuring that digital infrastructure provides effective support to businesses and individuals. Addressing challenges related to electricity access is also imperative to improve the business environment and facilitate digitalization efforts.

Furthermore, it is imperative for ASEAN-6 governments to adopt a strategic approach to smart urban development and effective human resource management, as the findings indicate that population growth and urbanisation have not significantly contributed to economic growth. Policies aimed at developing digital skills, training a tech-savvy workforce, and assisting businesses in transitioning to digital business models will enhance the efficiency of digital transformation.

Finally, given the limitations of the research model, further in-depth studies are necessary to analyse the impact of digital transformation across specific industries and sectors. The formulation of targeted development strategies, the optimisation of digital economic policies, and the enhancement of ASEAN-6's competitiveness in the digital era will be facilitated by this analysis.

6. Limitation

This study provides insights into the relationship between digital transformation and economic growth in the ASEAN-6 countries, but is subject to several limitations.

Firstly, the study is dependent on secondary data from the World Bank and other sources, which may contain inconsistencies or errors. Furthermore, structural changes within countries during the 2000–2023 period have the potential to introduce biases.

Secondly, while econometric methods such as GLS, FEM and REM address heteroscedasticity and autocorrelation, issues such as multicollinearity among variables remain, affecting result reliability. Future research could explore machine learning or dynamic panel models for better accuracy.

Thirdly, the inclusion of key digital transformation indicators is commendable, yet it is regrettable that qualitative factors, such as cybersecurity, digital literacy, and policy effectiveness, have not been given full consideration. This limitation regrettably results in a lack of country-specific insights.

Fourthly, the study assumes a linear relationship between digital transformation and growth, overlooking the possibility of non-linear effects. It is recommended that future research explore threshold effects and variable interactions.

The present study focuses on short- to medium-term effects; however, it should be noted that digital transformation may also have long-term impacts. The utilisation of a more extended temporal framework, or longitudinal studies, has the potential to discern these delayed effects.

In future research, these limitations should be addressed in order to strengthen the findings and their policy relevance.

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