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Digital transformation indicators and GRDP in the former Hau Giang Province, Vietnam: An exploratory analysis for 2015-2023

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Abstract:

In the context of the Fourth Industrial Revolution, digital transformation has become a crucial driver of economic growth. In Vietnam, this process has made a positive contribution to economic development, particularly in the information and communication technology (ICT) sector. In Hau Giang Province (before the administrative merger) in 2025, digital transformation has yielded promising results; however, its specific impact on economic growth has not been comprehensively assessed. This study examined the relationship between digital transformation and economic growth in Hau Giang during the period 2015-2023. Data from the Hau Giang Statistical Yearbook and reports from the Department of Information and Communications were used to estimate an Ordinary Least Squares (OLS) regression model using STATA software. The results indicate that digital transformation positively impacts Gross Regional Domestic Product (GRDP). Specifically, information technology infrastructure (HTCN) and investment capital (K) have significant effects, whereas information technology human resources infrastructure (HTNL) has not demonstrated a clear impact, indicating the need for greater investment in workforce training. Based on the research findings, the paper proposes several solutions, including investment in IT infrastructure development, encouraging businesses to adopt digital technologies, enhancing workforce training, and providing incentives for digital transformation projects. These solutions will enable Hau Giang to effectively leverage digital transformation, foster sustainable economic growth, and establish a modern digital economy.

Keywords: **digital transformation, economic growth, Hau Giang Province, Ordinary Least Squares.**

Classification numbers: **2.1, 2.3, 7**

1. Introduction

The Fourth Industrial Revolution has ushered in a new era of economic development, driven by the rapid advancement of digital technologies such as artificial intelligence (AI), the Internet of Things (IoT), cloud computing, and big data analytics. These innovations are reshaping the foundations of governance, business operations, and social interactions on a global scale. Digital transformation, in this context, is not merely a technological shift but a systemic restructuring of production, management, and service delivery models [1].

Numerous empirical studies confirm that digital transformation plays a critical role in enhancing productivity, fostering innovation, and accelerating growth. The World Bank [2] highlights digital technologies as a key driver of development, particularly in lower-middle-income countries. In Asia, digital economy activities were projected to contribute up to 60% of regional GDP by 2021 [3]. More recent projections suggest that effective digitalisation strategies can raise GDP growth by 1.5-2.5% in emerging economies [4]. These findings reinforce the view that digital transformation is not optional but a strategic imperative for long-term economic competitiveness.

In Vietnam, digital transformation has been officially recognised as a national priority through Resolution No. 52-NQ/TW and the National Digital Transformation Programme to 2025, with a vision to 2030. Provinces are encouraged to develop and implement localised digital agendas aligned with national goals [5]. Among them, Hau Giang Province, located in the Mekong Delta, stands out for its early and comprehensive digital adoption. Unlike other rural provinces, Hau Giang has systematically promoted digital governance, the digital economy, and a digital society since 2020, following Resolution No. 02-NQ/TU of the Provincial Party Committee [6].

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Between 2021 and 2023, the province invested more than 338 billion VND in digital transformation, prioritising the development of ICT infrastructure, cloud-based administrative systems, and AI-assisted platforms in public services [7]. In addition, 525 digital community groups with over 3,700 grassroots members have been formed to raise awareness and enhance digital skills [6]. Hau Giang ranked second in the Mekong Delta and 17th nationwide in the 2021 and 2022 Digital Transformation Index (DTI), and was among the top ten provinces in digital infrastructure readiness in 2023 [8]. These achievements position Hau Giang as a regional leader in digital transformation despite its rural context.

Yet, despite these developments, no empirical study to date has systematically quantified the economic impact of digital transformation at the provincial level in Hau Giang. The lack of evidence limits the ability of local authorities to optimise strategies and allocate resources effectively. Additionally, while many studies have examined digitalisation at the national or cross-country level [1, 4], there remains a gap in understanding how such transformation unfolds in smaller, less developed provinces - particularly within the Vietnamese context.

This study offers three key innovations. First, it fills a significant empirical gap by examining the economic impact of digital transformation at the provincial level, specifically in Hau Giang - a rural province in the Mekong Delta that has achieved notable progress in digital development. Second, the study extends the traditional Cobb-Douglas production function by incorporating digital transformation indices as explanatory variables alongside capital and labour, providing a more comprehensive analytical framework. Third, the analysis draws on localised data from 2015 to 2023, contributing valuable insights for policy formulation in contexts where digital infrastructure and human capital remain unevenly distributed. These contributions enhance both the theoretical and practical understanding of digital transformation in Vietnam's subnational settings.

Therefore, this study aims to empirically assess the impact of digital transformation on economic growth in Hau Giang Province between 2015 and 2023. To achieve this, the study applies an extended Cobb-Douglas production function and estimates the model using the OLS method. Digital transformation is operationalised through three main dimensions: digital infrastructure, digital human resources, and digital application. The ultimate goal is to generate evidence-based policy recommendations to support Hau Giang's aspiration of becoming a smart, inclusive, and sustainable province in the digital age.

2. Theoretical framework

2.1. Literature review

2.1.1. Digital transformation

Digital transformation (DT) has become a central concept in scholarly debates on economic modernisation, institutional restructuring, and innovation-led development. As Gregory Vial (2019) argues, DT can be defined as "a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies" [9]. This definition emphasises DT as a strategic and systemic transformation, extending beyond the technical deployment of digital tools. It involves profound and multidimensional changes in organisational structure, value creation logic, business models, and institutional arrangements.

The literature highlights the persistent terminological conflation between digitisation, digitalisation, and digital transformation, which has hindered conceptual precision in prior studies [9]. Digitisation refers to the technical process of converting analogue information into digital form to enhance data storage, access, and processing capacities. Digitalisation involves integrating digital technologies into existing organisational processes to improve operational efficiency, automate workflows, and reduce transaction costs, while leaving the organisational structure largely unchanged. Digital transformation, by contrast, entails a strategic reconfiguration of systems, including value chain restructuring, redefinition of customer interfaces, organisational culture shifts, and the adoption of entirely new business models (Table 1).

Table 1. Conceptual clarification: Digitisation, digitalisation, and digital transformation.

Concept	Core focus	Objective	Scope of impact	Example
Digitisation	Data conversion	Enhancing data storage and access	Technical, operational	Scanning paper documents into digital files
Digitalisation	Process automation	Improving operational efficiency	Organisational processes	Automating accounting or sales workflows
Digital Transformation	Strategic restructuring	Innovation and value creation	Organisational, sectoral, societal	Transitioning from traditional retail to platform-based business

Source: Adapted from G. Vial (2019) [9].

This conceptual distinction is not merely semantic. It delineates incremental technological upgrading from transformational, system-wide change, with DT typically characterised by disruptive technologies such as SMACIT (Social, Mobile, Analytics, Cloud, and IoT). These technologies reshape industries, redefine competitive boundaries, and alter institutional configurations.

2.1.2. Economic growth

Economic growth remains a fundamental goal in development economics and policy. Classical growth theory identifies labour, capital, and technological progress as key drivers [10, 11]. In the neoclassical model, technological change is treated as exogenous, whereas Romer's endogenous growth theory conceptualises innovation as an outcome of intentional investment in knowledge and human capital [12].

The Cobb-Douglas production function provides a widely accepted empirical framework to model the relationship between inputs (e.g., labour, capital, and technology) and output. Contemporary extensions of this model incorporate ICT infrastructure and digital capacity as production inputs to capture the role of DT in enhancing productivity [13, 14]. These models help explain regional growth differentials based on digital readiness.

In Vietnam, Gross Regional Domestic Product (GRDP) serves as the standard measure of provincial economic performance. GRDP reflects the total value of goods and services produced within a locality, offering a comprehensive indicator for subnational economic analysis. Incorporating lagged GRDP as an explanatory variable in time-series models helps account for inertia and path dependency in regional growth [15].

2.2. Related studies

2.2.1. International evidence

A substantial body of international research has established that DT is closely associated with economic growth, innovation, and productivity improvements. At the national level, cross-country panel analyses demonstrate that investments in ICT infrastructure significantly contribute to GDP growth and productivity gains in both advanced and developing economies [16-18]. These studies emphasise the role of digital infrastructure as a core production input that complements labour and capital, thereby enhancing total factor productivity (TFP).

At the firm level, DT fosters innovation and efficiency through multiple mechanisms, including automation, data-driven decision-making, and resource optimisation. Z. Lei, et al. (2023) [19] provide empirical evidence from Chinese firms showing that digitalisation leads to significant improvements in TFP by reducing transaction costs and strengthening technological capabilities. At the sectoral and regional levels, DT acts as a catalyst for foreign direct investment inflows, structural transformation, and deeper economic integration, particularly in emerging economies [20, 21].

Moreover, DT is increasingly recognised as a leapfrogging mechanism that enables latecomer economies to bypass traditional industrialisation paths, accelerating their transition towards knowledge- and innovation-based growth models. A.P. Sharma, et al. (2023) [13] demonstrate that digital infrastructure enhances disaster resilience and institutional responsiveness in India, while H. Guo, et al. (2020) [14] show that digital readiness contributes to improved environmental and economic performance in Chinese provinces. These findings underscore the multidimensional impacts of DT beyond conventional economic indicators.

2.2.2. National and subnational evidence

In Vietnam, the relationship between DT and economic growth has recently gained scholarly attention, particularly in the context of regional disparities. H.Q. Vu, et al. (2025) [22] provide robust empirical evidence showing that ICT development significantly enhances provincial GDP growth by increasing the productivity of both capital and labour and amplifying the effects of foreign direct investment (FDI) and governance efficiency. Their findings highlight the strategic role of DT in fostering regional competitiveness and accelerating economic development in Vietnam.

At the subnational level, H.T.T. Ngan, et al. (2021) [23] conducted an empirical study on eight provinces in Vietnam's Southern Key Economic Region using the Difference GMM (DGMM) method. Their findings show that a 1% increase in the ICT readiness index leads to a 0.84% increase in provincial GRDP. The ICT infrastructure and application components have significant positive effects on economic growth, while human resource infrastructure has no statistically significant impact, indicating a digital skills gap at the local level. These findings highlight both the potential and the structural challenges of subnational digital transformation in Vietnam.

In empirical applications, DT in Vietnam is often operationalised through composite indices encompassing three key dimensions: (i) HTCN, representing the availability and accessibility of ICT infrastructure; (ii) HTNL, measuring digital literacy and workforce readiness; and (iii) UDCN, capturing the adoption of digital technologies across public and private sectors (Ministry of Information and Communications of Vietnam, 2023) [24]. These dimensions align with international digital readiness frameworks and provide a useful basis for subnational economic analysis.

Table 2. Selected empirical studies on digital transformation and economic growth.

No.	Author(s) and year	Country/Region	Methodology	Key variables	Main findings
1.	T. Niebel (2018) [16]	59 countries	Panel econometrics (OLS, RE, FE, IV)	ICT capital, non-ICT capital, labour, GDP	ICT capital positively impacts GDP growth (elasticity≈0.09); effect similar across country groups; leapfrogging not confirmed.
2.	G. Vial (2019) [9]	Global	Systematic literature review	8 DT building blocks (disruption, strategy, value creation, structure, culture, barriers, outcomes, ethics)	SMACIT technologies drive disruption; digital strategy and organisational transformation are central; emphasises ethical and social dimensions.
3.	B.G. Choy (2020) [25]	Russia	Bayesian multilevel GLMM + MCMC	Digital transformation index, labour productivity, GDP	DT positively affects GDP in both fixed and random effects; productivity effect stronger in random effect; short-run price increase observed.
4.	H.T.T. Ngan, et al. (2021) [23]	Vietnam (8 provinces)	DGMM (Arellano & Bond)	ICT Readiness Index, Digital Infrastructure (HTCN), Digital Human Resources (HTNL), Digital Application (UDCN), GRDP	1% increase in ICT readiness → GRDP ↑ 0.84%; infrastructure and application have significant positive effects; human resources not significant.
5.	M. Olczyk, et al. (2022) [18]	EU-28	Panel FE	Digital Economy and Society Index (DESI), GDP per capita, TFP	DESI has a positive and significant impact on GDP per capita; strongest in lower-income countries; connectivity and digital integration are key drivers.
6.	M.B. Tudose, et al. (2023) [26]	46 high-income countries	OLS panel regression	Network Readiness Index (NRI), Future Technologies (FTH), Business (BUS), Economic Impact (ECN), GDP per capita	NRI significantly increases GDP per capita; FTH and BUS positive; ECN negative; stronger effects pre-pandemic.
7.	A. Wardhono, et al. (2023) [27]	Indonesia	PVAR, IRF, VD	Internet usage, investment, credit, inflation, GRDP	Internet contributes ~25% to GRDP variation; investment short-run negative but long-run positive; credit positive, inflation negative.
8.	Z. Lei, et al. (2023) [19]	China	Panel regression, 2SLS	Digital transformation index, total factor productivity (TFP), R&D expenditure, human capital	Digital transformation increases TFP through technological innovation, cost reduction, and human capital improvement; stronger effect in private and competitive sectors.
9.	X. Zheng, et al. (2023) [28]	China (Yangtze River Delta, 25 cities)	Feder Two-Sector Model, Mediation Analysis	Digital transformation in manufacturing (DOM), Advanced Industrial Structure (AL), Rationalised Industrial Structure (RI), Industrial Integration (II), Industrial Chain Length (Length), Human Capital Stock (HCS), Government Size (CS), Total Fixed Assets (TFA), Enterprise Size (ES)	DOM drives economic growth through four mediating mechanisms: industrial upgrading, rationalisation, integration, and value chain extension; AL and Length strongest mediators.
10.	H. Jangid, et al. (2024) [29]	G20	Panel ARDL	Secure Internet servers, commercial bank branches, gross fixed capital formation (GFCF), population, GDP	Digitalisation has a significant long-run positive but short-run negative impact on GDP; capital and population have positive long-run effects.
11.	Q. Zhang, et al. (2024) [30]	China (286 cities)	Fixed-effects, Spatial Durbin Model (SDM), 2SLS	Digital Industrialisation (supply of digital technologies, products, infrastructure), Industrial Digitisation (digital upgrade of traditional sectors), Economic Growth Efficiency	Both digitalisation factors positively affect growth efficiency; strong spatial spillovers; policy should reduce regional digital gaps.
12.	W.J. Jiang, et al. (2024) [31]	China (listed firms)	Firm-level panel regression	Digital transformation index, resource allocation efficiency, productivity	Digital transformation significantly improves corporate resource allocation efficiency and productivity at the firm level.

Source: Authors' synthesis. OLS = Ordinary Least Squares; RE = Random Effects; FE = Fixed Effects; IV = Instrumental Variables; ARDL = Autoregressive Distributed Lag; PMG = Pooled Mean Group; DFE = Dynamic Fixed Effects; DGMM = Difference Generalized Method of Moments (Arellano & Bond); GLMM = Generalized Linear Mixed Model; MCMC = Markov Chain Monte Carlo; PVAR = Panel Vector Autoregression; IRF = Impulse Response Function; VD = Variance Decomposition; 2SLS = Two-Stage Least Squares; SDM = Spatial Durbin Model; DESI = Digital Economy and Society Index; NRI = Network Readiness Index; ICT = Information and Communication Technology; DT = Digital Transformation; SMACIT = Social, Mobile, Analytics, Cloud, Internet of Things; GRDP = Gross Regional Domestic Product; TFP = Total Factor Productivity; GFCF = Gross Fixed Capital Formation; HTCN = Digital Infrastructure Index; HTNL = Digital Human Resources Index; UDCN = Digital Application Index; DOM = Digital transformation in Manufacturing; AL = Advanced Industrial Structure; RI = Rationalised Industrial Structure; II = Industrial Integration; HCS = Human Capital Stock; CS = Government Size; TFA = Total Fixed Assets; ES = Enterprise Size.

2.2.3. Research synthesis

To systematically synthesise empirical evidence on the relationship between DT and economic growth across different levels of analysis, this section reviews and classifies key studies according to country context, methodology, variables, and main findings. The inclusion criteria are: (i) peer-reviewed journal articles from reputable academic sources; (ii) clear operationalisation of digitalisation or digital transformation (e.g., ICT capital, DESI, firm-level digital indices, internet usage); and (iii) quantitative analysis linking DT to economic outcomes such as GDP growth, productivity, and structural transformation. This structured synthesis enables meaningful cross-country, cross-sector, and subnational comparisons, thereby identifying empirical gaps. Table 2 presents the key studies that inform this research.

2.2.4. Research gap and contribution

As Table 2 illustrates, across global and regional studies, digital transformation consistently shows a positive and statistically significant impact on economic growth, though the magnitude and transmission mechanisms differ depending on national income levels, institutional capacity, and digital readiness.

• National and global studies [16, 18, 26] underline the macroeconomic significance of digital infrastructure.

• Firm- and sector-level analyses [19, 31] reveal mechanisms through innovation, cost reduction, and resource allocation.

• Subnational evidence from developing contexts [23, 27] highlights infrastructure and digital literacy gaps as critical bottlenecks.

• Recent Chinese studies [28, 30] emphasise structural transformation and spatial spillovers as essential pathways through which digitalisation enhances growth efficiency.

• Finally, G. Vial (2019) [9] provides a conceptual foundation for understanding DT beyond technology - as a strategic, structural, and institutional shift.

This synthesis shows that while evidence is robust at the global and national levels, empirical research remains limited at subnational scales, especially in rural and latecomer regions - which is precisely where this study on Hau Giang Province aims to contribute.

To address this gap, the present study investigates the relationship between HTCN, HTNL, and UDCN, and subnational economic growth - measured by GRDP - in Hau Giang Province from 2015 to 2023. By integrating these DT dimensions into an extended Cobb-Douglas production framework, the study contributes localised empirical evidence from a rural province, offering both theoretical insights and policy implications for inclusive digital transformation strategies.

The theoretical framework of the study is illustrated in Fig. 1, which depicts the relationships among HTCN, HTNL, UDCN, and GRDP within an extended Cobb-Douglas production function framework.

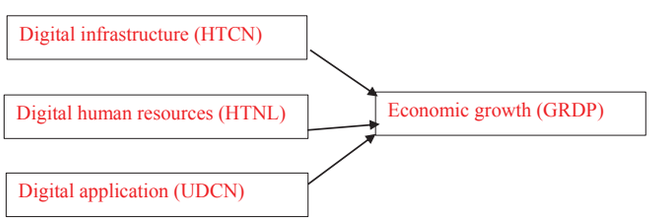

Fig. 1. The theoretical framework. Source: Authors' research results.

3. Research methodology

3.1. Research model

To analyse the factors influencing economic growth in Hau Giang Province, this study constructs an econometric model grounded in classical and contemporary growth theories, while integrating empirical insights from digital transformation research.

The Cobb-Douglas production function, introduced by Cobb and Douglas in the 1920s, serves as a foundational framework for modelling the relationship between output and inputs of production. It posits that economic output depends primarily on two input factors: capital and labour. The model assumes constant returns to scale and has been widely adopted in empirical studies due to its analytical simplicity and explanatory power [32].

The standard form of the Cobb-Douglas function is represented as follows:

$$GRDPt = \beta 0 + \beta 1Kt + \beta 2Lt + \varepsilon t$$

In addition to this classical structure, the model is extended to incorporate the effects of digital transformation, based on contemporary theories and empirical findings. Solow's neoclassical growth model (1956) highlighted the role of technological progress as an exogenous determinant of long-term growth [11], while Romer's endogenous growth theory (1990) emphasised that innovation and knowledge accumulation - especially in the form of technological investment - are key drivers of sustainable growth from within the economic system [12].

Further empirical evidence supports the inclusion of DT as a production factor. Studies by H. Aly (2020) [33] and S.A. Gusarova, et al. (2023) [34] found that digital technologies significantly enhance productivity, support innovation, and contribute to national and regional economic growth. These insights provide justification for extending the Cobb-Douglas model as follows:

$$\ln GRDPt = \beta_0 + \beta_1 \ln K_t + \beta_2 \ln L_t + \beta_3 DT_t + \varepsilon_t$$

where, t represents the year, K represents capital, L represents labour, and DT represents the digital transformation variable.

This extended model allows for empirical investigation of the direct impact of digital transformation on regional economic performance, while controlling for traditional growth inputs - capital and labour.

Based on prior research, all three independent variables (Kt, Lt, DTt) are expected to exert a positive influence on GRDP. Specifically, capital investment is expected to improve infrastructure and productive capacity, labour reflects the quality and availability of human capital, and digital transformation enhances innovation, efficiency, and connectivity.

While classical growth models treat technology as an exogenous factor (R.M. Solow (1956) [11]) or as part of human capital investment [12], recent empirical studies conceptualise digital transformation as a distinct, multidimensional driver that affects production efficiency, coordination, and innovation beyond traditional inputs [33, 34]. Therefore, in this study, DT is included as an independent variable to reflect its direct and indirect impact on economic output.

The proposed research model is synthesised in Table 3, which outlines the variables, measurement methods, and expected signs for hypothesis testing.

Table 3. Research model.

References and foundation for model construction	Variable	Notation	Measurement	Sign expectation	Data source
	Dependent variable				
	Economic growth	$GRDP_t$	The natural logarithm of the gross domestic product of the locality in year t.		Statistical Yearbook of Hau Giang Province 2015-2023.
	Independent variable				
Cobb-Douglas production function; growth theory proposed by R.M. Solow (1956) [11] and P.M. Romer (1990) [12]	Investment Capital	K_t	The natural logarithm of the investment capital of the locality in year t.	+	
	Human Capital	L_t	The natural logarithm of the labour force of the locality in year t.	+	
H. Aly, (2020) [33] (Ministry of Information and Communications, 2023) [34]	Digital transformation	Information and Communication Technology (ICT)	The readiness index for information technology application and development	+	Report on the Readiness Index for Information Technology and Communication Development and Application of Hau Giang Province (2021) [35]
		Digital Infrastructure (HTCN)	Information technology infrastructure index	+	
		Digital Human Resources (HTNL)	Information technology human resources infrastructure index	+	
		Digital Applications (UDCN)	Information technology human resources infrastructure index	+	

Source: Research team compilation, 2024. GRDP = Gross Regional Domestic Product; ICT = Information and Communication Technology Readiness Index; HTCN = Digital Infrastructure Index; HTNL = Digital Human Resources Index; UDCN = Digital Application Index. All monetary variables (GRDP and K) are transformed into natural logarithms to reduce heteroscedasticity and interpret coefficients as elasticities.

The ICT Index is disaggregated into three components:

• HTCN (Digital Infrastructure): Measures availability and quality of internet, cloud computing, and digital platforms.

• HTNL (Digital Human Resources): Captures percentage of ICT-trained workers, digital literacy programmes, and e-government training.

• UDCN (Digital Applications): Reflects adoption of digital technologies in public administration and business, including e-services and integrated databases. These indices are sourced from the Hau Giang Provincial ICT Readiness Reports (2015-2023) and are constructed based on guidelines from the Ministry of Information and Communications.

The three DT indices used in this study - HTCN, HTNL, and UDCN - are constructed following the framework developed by the Ministry of Information and Communications [24] for evaluating provincial digital transformation performance.

• HTCN (IT Infrastructure Index) reflects access to and deployment of digital infrastructure (e.g., broadband internet, fibre-optic cable, 4G/5G coverage). It is computed as a weighted composite index of four sub-indicators: (1) broadband access rate, (2) percentage of households with internet connection, (3) public Wi-Fi coverage, and (4) mobile network density. Weights are assigned according to MIC guidelines (e.g., 30%, 30%, 20%, and 20%).

• HTNL (IT Human Resources Index) captures the availability of digitally skilled human capital in the public sector. It includes: (1) the ratio of ICT-trained staff in local government, (2) participation in digital skills training, and (3) ICT staff per capita. The MIC allocates equal weights (33.3%) to these indicators.

• UDCN (IT Application Index) measures the extent and effectiveness of digital technology applications in public administration and services. Sub-indicators include: (1) the rate of online public service provision, (2) usage rate of digital platforms (e.g., e-portal, e-Cabinet), and (3) integration of administrative procedures. Weights are 40%, 30%, and 30%, respectively.

These indices range from 0 to 1, with higher values indicating better performance. The raw data were obtained from the Annual Provincial Digital Transformation Reports (2015-2023) issued by the Hau Giang Department of Information and Communications.

3.2. Research data

For this study, the research team uses secondary data from the Statistical Yearbook of Hau Giang Province and the Report on the Readiness Index for the Development and Application of Information and Communication Technology in Hau Giang Province, provided by the Department of Information and Communications of the Province. The data collection period spans from 2015 to

2023. Data for 2023 were obtained from official provincial reports finalised in early 2024, thus reflecting actual outcomes rather than projections.

3.3. Estimation method

This study employs the OLS method to estimate the parameters of the proposed regression model. Originally introduced by C.F. Gauss in 1809, OLS remains one of the most widely used techniques in econometric analysis due to its simplicity, computational efficiency, and capacity to yield unbiased and efficient estimators under the classical linear regression assumptions [36].

OLS operates by minimising the sum of squared residuals - the differences between observed and predicted values of the dependent variable. The coefficients obtained under this method are considered Best Linear Unbiased Estimators (BLUE) if key assumptions are satisfied, including linearity, absence of multicollinearity, homoscedasticity, no autocorrelation, and correct model specification [37]. To ensure the robustness and reliability of the model, this study performs the following diagnostic tests:

Model fit and significance test: The F-test is used to assess the overall statistical significance of the model. The null hypothesis H0 assumes that all regression coefficients (except the intercept) are jointly equal to zero, implying no explanatory power of the independent variables. Rejecting H0 at the 5% significance level indicates that the model is well fitted and statistically significant [38].

Homoscedasticity test: Homoscedasticity assumes that the variance of the error terms is constant across all observations. The Breusch-Pagan/Cook-Weisberg test is employed to detect heteroscedasticity. A p-value greater than 0.05 indicates that the null hypothesis of homoscedasticity cannot be rejected, validating this assumption of the OLS model [39].

Autocorrelation test: The absence of autocorrelation in residuals is another assumption of OLS. The Breusch-Godfrey test is used to examine serial correlation in the residuals. A p-value above 0.05 suggests that the residuals are not autocorrelated, confirming that the model does not violate this assumption [40].

Model specification test: The Ramsey RESET test is applied to evaluate the functional form and detect any model specification errors, such as omitted variables or incorrect transformations. If the p-value exceeds 0.05, the null hypothesis that the model is correctly specified cannot be rejected, supporting the adequacy of the chosen model structure [41].

Together, these diagnostic procedures ensure the reliability of the OLS estimates and reinforce the internal validity of the study's findings.

4. Results and discussion

4.1. Descriptive statistics

Table 4 presents descriptive statistics for the variables used in the regression analysis, covering the period from 2015 to 2023. The data were compiled from the Statistical Yearbook of Hau Giang Province and ICT Readiness Reports issued by the Department of Information and Communications.

Table 4. Descriptive statistics of variables in the model.

Variable	Unit	Obs	Mean	Std. Dev.	Min	Max
Gross regional domestic product	Billion VND	9	37,109.38	10,680.32	25,247.45	58,504.99
Investment capital	Billion VND	9	18,497.53	2,791.71	14,328.50	22,700.36
Labor force	Persons	9	436,677.6	36,490.68	394,077	481,200
ICT readiness index	Ratio (0-1)	3	0.3436	0.1250	0.1031	0.4834
IT infrastructure index	Ratio (0-1)	9	0.2867	0.1990	0.0500	0.5300
IT human resources index	Ratio (0-1)	9	0.4656	0.1379	0.2500	0.6200
IT application index	Ratio (0-1)	9	0.2922	0.1450	0.0600	0.4900

Source: Compiled from the Statistical Yearbook of Hau Giang Province [42-44] and the ICT Readiness Reports by the Department of Information and Communications (2015-2023) [35, 45-47].

During this period, the average GRDP was approximately 37,109.38 billion VND, with a standard deviation of 10,680.32 billion VND, ranging from 25,247.45 to 58,504.99 billion VND. The mean investment capital (K) reached 18,497.53 billion VND, while the labour force (L) averaged 436,677.6 persons, suggesting a stable human capital base.

With regard to digital transformation, the ICT averaged 0.3436, based on three years of available data (2021-2023). The HTCN showed a mean value of 0.2867, while HTNL and UDCN recorded average values of 0.4656 and 0.2922, respectively. These indices, which range from 0 to 1, indicate moderate levels of digital maturity in Hau Giang Province across infrastructure, human capital, and application dimensions.

This statistical overview reflects both economic and technological development patterns in Hau Giang Province and provides an empirical foundation for the regression analysis presented in subsequent sections.

4.2. Discussion of model specification and non-significant coefficients

Using STATA software and data provided by the Hau Giang Provincial Statistics Bureau and the Hau Giang Department of Information and Communications, the

descriptive statistics measuring the characteristics of the research variables are presented in Table 4.

The research team used STATA software to perform the data analysis for Hau Giang Province, covering the period from 2015 to 2023. This period is significant, as it marks numerous economic and social changes in the region. Therefore, analysing data from this period is crucial for gaining a deeper understanding of local economic development trends.

Applying statistical techniques to estimate the economic models, the use of STATA not only ensures high accuracy in data processing but also allows for the effective execution of complex analyses. The variables and models were carefully selected to accurately reflect the economic conditions of the locality over the study period. The results of this estimation process are summarised and presented in Table 5.

Table 5. The estimated results of the models regarding the impact of digital transformation on economic growth in Hau Giang Province.

Explanatory variable	Model 1	Model 2	Model 3	Model 4
Investment capital	1.481975**	1.18414**	0.5113313	1.310142**
Human capital	0.5602741	1.339615	-2.946819	-0.528588
Digital transformation				
Readiness index	0.7886264			
IT infrastructure index		0.9887265*		
IT human resource infrastructure index			-1.120669	
IT application index				0.4494669
Prob>F	0.0104	0.0040	0.0079	0.0076
R-squared	0.8767	0.9160	0.8898	0.8916
Adj R-squared	0.8028	0.8656	0.8238	0.8266
Breusch-Pagan/Cook-Weisberg p-value	0.2262	0.3523	0.2701	0.4137
Breusch-Godfrey p-value	0.4208	0.0667	0.1571	0.2472
Ramsey RESET p-value	0.6171	0.2295	0.1500	0.5257

Source: Statistical Yearbook of Hau Giang Province 2015-2023. **, * denote statistical significance at the 5% and 10% levels, respectively.

The estimation results of the models examining the impact of digital transformation on economic growth in Hau Giang Province were obtained using the OLS method. Prob>F represents the p-value of the F-test, indicating the statistical significance of the overall regression model. R-squared (coefficient of determination) shows the proportion of variation in the dependent variable explained by the independent variables in the model. Adjusted R-squared is the adjusted coefficient of determination and serves as an important indicator for assessing model strength (expected >50%). The Breusch-Pagan/Cook-Weisberg p-value refers to the p-value of the Breusch-Pagan/Cook-Weisberg test, which is used to detect heteroscedasticity (i.e. non-constant error variance). The Breusch-Godfrey p-value denotes the p-value of the Breusch-Godfrey test, used to detect autocorrelation in the regression residuals. The Ramsey RESET p-value represents the p-value of the Ramsey RESET test, which is applied to examine potential omitted variables or functional form misspecification in the linear regression model.

The estimation results presented in Table 5 indicate that the proposed regression models are statistically significant. The p-values associated with the F-tests are below the conventional threshold, suggesting that at least one independent variable exerts a statistically significant influence on the GRDP. Moreover, the R-squared and adjusted R-squared values exceed 50%, implying that the models explain a substantial proportion of the variation in economic growth and demonstrate good overall fit.

Regarding diagnostic testing, the Breusch-Pagan/Cook-Weisberg test for heteroscedasticity yields p-values greater than 0.05, indicating no statistical evidence to reject the null hypothesis of constant error variance. This result supports the assumption of homoscedasticity and, consequently, the efficiency and validity of the OLS estimators [39].

The Breusch-Godfrey test for autocorrelation produces p-values exceeding the 5% significance level across all four models. Notably, Model 2 yields a p-value of 0.0667, which lies close to the 5% threshold. Although this value does not warrant rejection of the null hypothesis of no autocorrelation at the 5% level, its proximity suggests that caution is advisable. Specifically, while the assumption of independent errors holds statistically, this result may indicate weak evidence of potential serial correlation. This nuance should be considered when interpreting the reliability of Model 2, and additional tests incorporating further lags may enhance robustness [40].

Furthermore, the Ramsey RESET test yields p-values above 0.05, indicating no evidence of functional form misspecification. This suggests that the models are appropriately specified and that no significant explanatory variables have been omitted [41].

4.2.1. Impact of digital transformation

The regression coefficient for the variable HTCN (information technology infrastructure index), representing digital transformation, is estimated at 0.9887 and is statistically significant at the 10% level. This result indicates a positive relationship between digital transformation and economic growth in Hau Giang Province. Specifically, a 1% increase in the HTCN index is associated with an approximate 0.99% increase in GRDP, ceteris paribus. This finding is consistent with previous research by S. Gomes, et al. (2022) [48], E. Kvochko (2013) [49], and R.L. Katz (2017) [50], which

emphasise the critical role of digital infrastructure in promoting economic development. Additionally, the results corroborate the study by H.T.T. Ngan, et al. (2021) [23], which found that a 1% increase in the digital infrastructure index led to a 0.84% increase in GDP among provinces in the Southern Key Economic Region, also significant at the 10% level.

However, the variables ICT, HTNL, and UDCN are not statistically significant in the Hau Giang context. There are several potential explanations for this outcome.

First, from a data perspective, the ICT readiness index is available only for a limited number of years (2021-2023), resulting in a small sample size and reduced statistical power. This restricts the ability of the model to detect significant effects, especially in panel regressions with few observations.

Second, regarding measurement and construct validity, the HTNL and UDCN indices may not fully capture the depth or quality of human capital and digital service integration. For instance, the HTNL index emphasises the quantitative availability of staff but may overlook qualitative aspects such as skill relevance, digital competency, or adaptability to technological changes.

Third, in terms of implementation, several digital initiatives in Hau Giang remain underutilised. Preliminary interviews with officials from the Department of Information and Communications revealed that many IT applications in public services are only partially deployed or face limited usage due to low citizen digital literacy or a lack of training at the commune level. This implementation gap likely reduces the measurable impact of UDCN on economic output.

Together, these factors help explain the non-significance of these digital transformation subcomponents in the regression analysis and highlight the need for improved data collection, targeted training programmes, and outcome-based evaluation of digital projects at the provincial level.

4.2.2. Impact of capital and labour

In addition to digital transformation, the regression results show that investment capital (K) has a positive and statistically significant effect on GRDP. This finding is aligned with classical and modern growth theories, particularly those of R.M. Solow (1956) [11] and P.M. Romer (1990) [12], which emphasise the critical role of capital accumulation in driving long-term economic growth. It also echoes the empirical findings by H.T.T. Ngan, et al. (2021) [23], who identified capital investment as a key determinant of economic growth at the provincial level.

Conversely, the labour variable (L) does not exhibit a statistically significant relationship with GRDP in this study. This result mirrors the insignificance of the HTNL, suggesting that existing human capital in Hau Giang Province may not yet be effectively leveraged to stimulate growth. Possible explanations include a mismatch between workforce skills and market demand, or the limited integration of human resources into the digital economy. These limitations indicate a need for greater investment in workforce development and training to fully capitalise on the province's labour potential.

5. Conclusions and policy recommendations

5.1. Conclusions

This study examines the relationship between digital transformation and economic growth in Hau Giang Province from 2015 to 2023, utilising secondary data from provincial statistics and ICT performance reports. The regression analysis was conducted using the OLS model, with diagnostic tests confirming the absence of heteroscedasticity, autocorrelation, and model specification errors, thus ensuring the robustness of the empirical results.

The findings reveal that the HTCN coefficient was positive and marginally significant at the 10% level in the reported specification. Specifically, a 1% increase in HTCN corresponds to approximately a 0.99% rise in GRDP, highlighting the importance of digital infrastructure in driving regional development. In contrast, the ICT, HTNL, and UDCN did not exhibit statistical significance, pointing to limitations in digital adoption and capacity utilisation.

Among traditional factors, investment capital (K) remains a robust and significant determinant of economic growth, consistent with established growth theories. However, labour (L) did not show a statistically significant impact.

Building on the empirical results, this section discusses theoretical and practical implications in comparison with prior studies. The findings contribute to the literature by providing subnational empirical evidence from a rural province in a developing country context. The significance of HTCN aligns with global and regional research emphasising the foundational role of digital infrastructure in enabling economic growth [16, 18].

The non-significance of HTNL and labour reflects similar observations in subnational studies in Vietnam (e.g. H.T.T. Ngan, et al. (2021) [23]) and can be explained by the mismatch between skill supply and the requirements of digital economies. Similarly, the non-significance of UDCN may point to implementation gaps in policy execution and digital services utilisation.

These outcomes underscore the importance of investing not only in infrastructure but also in human capital development and actual technology adoption. Future research should extend the analysis to other provinces, apply longitudinal or mixed-methods approaches, and consider mediating or moderating factors such as governance, FDI, or institutional readiness. These implications underline the need for holistic digital strategies - ones that go beyond infrastructure investment to include workforce upskilling and institutional innovation.

5.2. Policy recommendations

To enhance the economic benefits of digital transformation, Hau Giang Province (before the administrative merger) should pursue a comprehensive digital strategy that targets infrastructure, human capital, governance, and cross-sectoral engagement.

First, expanding IT infrastructure should remain a strategic priority. The significance of HTCN in the regression results aligns with Hau Giang's achievements in ensuring 100% computer usage among civil servants and deploying integrated digital platforms across departments [7]. To sustain and scale this impact, investments should be directed towards broadband expansion, especially in remote communes, and cloud-based data management systems to support digital services.

Second, while the UDCN shows a positive coefficient, its lack of statistical significance reflects an adoption gap at the user level. Despite efforts such as the 2023 Digital Transformation Week, which engaged over 50 businesses and nearly 90 tech booths [47], digital platforms remain underutilised in both public and private sectors. Addressing this requires targeted support for SMEs, including digital skills training, subsidised access to enterprise software, and incentives for process digitisation.

Third, the HTNL index's insignificance points to a structural gap in human capital development. Although the province trained more than 4,000 members of community digital task forces and rolled out awareness programmes in all districts [7], digital skills among local workers and officials remain limited. Strengthening human capital will require public-private partnerships to design industry-relevant training curricula, introduce digital apprenticeships, and create talent retention mechanisms such as scholarships and job guarantees.

Fourth, the ICT readiness index was constrained by limited data availability (2021-2023). Nonetheless, the province has made progress in institutional ICT governance, with all departments maintaining digital transformation units and public-facing portals [35, 45-47]. Further efforts should focus on standardising digital maturity assessments, integrating digital dashboards for performance monitoring, and ensuring data transparency across sectors.

Fifth, promoting public-private partnerships (PPPs) is critical for scaling digital initiatives. The province has involved youth organisations in digital outreach and collaborated with private firms during awareness campaigns [7]. To institutionalise such efforts, Hau Giang should offer tax incentives for tech start-ups, create digital innovation zones, and establish regulatory sandboxes that encourage experimentation with emerging technologies.

Finally, the development of a secure and enabling legal framework is essential. As digital services expand, data protection and cybersecurity policies must evolve accordingly. Hau Giang should align local regulations with national cybersecurity standards, raise public awareness of digital rights and privacy, and develop risk management protocols to ensure resilience in digital projects [45].

In summary, Hau Giang Province has made considerable progress in digital infrastructure and policy orientation. However, to fully harness the economic benefits of digital transformation, a stronger focus on digital workforce development, adoption capacity, and institutional innovation is needed. The policy recommendations presented herein are grounded in empirical evidence and contextualised within the province's digital transformation trajectory. These strategies provide a roadmap for building a resilient, inclusive, and innovation-driven digital economy.

5.3. Limitations and directions for future research

This study contributes to the growing body of literature examining the impact of digital transformation on provincial economic growth in the Vietnamese context. However, several limitations should be acknowledged to enhance the scientific rigour and reliability of the findings.

First, the regression analysis shows that the variables representing HTNL and labour (L) do not exhibit statistical significance. While the paper proposes preliminary explanations, the underlying causes of these insignificant results have not been fully identified. Potential factors include measurement errors, temporal lags in impact, or skill-job mismatches within the local digital economy. Future research should explore these possibilities through

refined variable construction, qualitative methods such as expert interviews or enterprise surveys, and extended datasets to reassess the role of human capital in digital economic growth.

Second, the study relies heavily on secondary data from provincial reports, which may be subject to reporting bias, especially when digital transformation indicators are linked to administrative performance targets. Additionally, the time series is relatively short (2015-2023), limiting the ability to assess long-term trends or lagged policy effects.

Moreover, the model may suffer from omitted variable bias, as it excludes potentially important determinants such as FDI, public governance quality, or sector-specific labour productivity. These factors could serve as mediators or moderators in the relationship between digital transformation and economic performance at the subnational level.

Finally, the sample size remains modest, particularly for digital transformation variables, reducing statistical power and generalisability. Future studies should consider expanding the dataset through a multi-provincial or panel approach and adopt mixed-methods designs to better capture the pathways through which digital transformation influences economic development at the local level.

CRediT author statement

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COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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