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The Impact of Digital Transformation on Credit Operations in an Emerging Country

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ABSTRACT

This study investigates the impact of digital transformation on the credit activities of 25 Vietnamese commercial banks from 2016 to 2024. Utilizing secondary data and panel data regression techniques, specifically the Generalized Least Squares (GLS) model to correct for heteroskedasticity and autocorrelation, the research evaluates how digital transformation (measured by the ICT Index) affects credit expansion and credit risk of commercial banks in Vietnam. The empirical findings reveal a dual positive effect: digital transformation significantly promotes credit capacity while effectively reducing the credit risk of commercial banks in Vietnam. Further analysis demonstrates that human resource infrastructure strongly drives lending expansion, whereas robust technical infrastructure plays a crucial role in minimizing credit risks. However, the study notes that the benefits of digitalization exhibit a lagged effect, requiring time for new system integration, employee training, and cultural adaptation. Based on these results, the research recommends that commercial banks synchronize their investments in both advanced technology and high-quality human capital. Additionally, it urges policymakers and the State Bank of Vietnam to expedite a comprehensive legal framework, including a Regulatory Sandbox, to ensure sustainable banking operations in the digital era.

Keywords: Digital transformation, Credit operations, Bank panel data, NPL.

Introduction

Today's society is gradually transforming towards comprehensive development in technology and information technology. In particular, the era of the Fourth Industrial Revolution (Industry 4.0) has motivated businesses across all sectors to constantly develop and adopt new, smart technologies such as artificial intelligence (AI), blockchain, the Internet of Things (IoT), and cloud computing. Since the advent of these technologies, digital transformation has become an inevitable new macro-trend that profoundly impacts many areas of socio-economic life, and the banking sector is certainly no exception (Shanti *et al*., 2022; Aqel & Shahwan, 2026). This technological evolution becomes even more critical in a context where commercial banks not only face intense competition from traditional banking competitors but also from innovative, high-potential new competitors such as Fintech companies. These Fintech firms act as pioneering businesses in applying modern technology, disrupting traditional financial markets, and forcing legacy institutions to adapt rapidly (Elia *et al*., 2023; Alsobai & Aassouli, 2025; Nguyen, 2025b).

The digital transformation process brings many undeniable benefits to a country's financial sector (Hadi & Hmood, 2020; Chen *et al*., 2023; Hoque *et al*., 2024; Omol, 2024). Fundamentally, digital transformation in the banking industry involves the strategic use of modern digital technologies to significantly improve the customer experience, streamline internal operations, and create entirely new business models (Krasonikolakis *et al*., 2020; Naimi-Sadigh *et al*., 2022; Loska & Uotila, 2024; Huynh, 2025a; Munira, 2025). This transition helps banks digitize documents, utilize electronic signatures for transactions, and operate online trading platforms and mobile payments, thereby moving from a traditional business model to a highly automated and intelligent digital business (Temelkov, 2020; Loska & Uotila, 2024) Consequently, these advancements contribute directly to increased customer satisfaction and

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bring great competitiveness for banks operating in the global international market (Andrian *et al*., 2022; Johri & Kumar, 2023; Tran *et al*., 2023; Wakhidah *et al*., 2025). However, although digital transformation brings massive long-term benefits, it can substantially increase technology investment costs in the early stages of implementation. This dynamic poses many challenges for bank management teams in effectively balancing short-term profits and long-term modernization costs (Ebert & Duarte, 2018; Nguyen-Thi-Huong *et al*., 2023; Munira, 2025)

In Vietnam, the banking industry has always been known as a uniquely crucial business field of particular macro-economic importance and is widely considered the fundamental engine of the economy. In an increasingly developing market economy, the digital transformation in banking has been given special attention by the Government and regulatory bodies. This commitment is clearly demonstrated through major policies such as Decision No. 986/QD-TTg, dated August 8, 2018, which focuses on approving the comprehensive banking industry development strategy to 2025, with an orientation to 2030. Furthermore, the Governor of the State Bank of Vietnam officially approved the sector's specific digital transformation plan on May 11, 2021. These decisive regulatory frameworks highlight that integrating digital technology into banking is not merely a corporate option but an urgent national requirement to keep up with market trends, optimize operational efficiency, and create breakthrough value for the economy.

The complex issue of balancing technological investment costs with sustainable profitability is deeply related to the core credit activities of many Vietnamese commercial banks. Despite recent trends toward diversifying income through non-credit services, a massively large proportion of the total revenue of commercial banks in Vietnam—typically accounting for 70% to 80% of total income—still comes directly from traditional credit-granting activities (Tien & Nguyen, 2023). Because credit is the main revenue-generating activity, any systemic change, such as digital transformation, directly impacts the fundamental financial health of these institutions. Digital platforms enable banks to automate approval processes, expand credit access to remote areas without physical branches, and utilize AI and Big Data for accurate credit assessments and real-time risk monitoring. Therefore, understanding the intersection between new digital capabilities and traditional lending is essential for assessing the future stability of the financial system.

Realizing the many potentials and positive impacts that digital transformation brings, numerous studies around the world have conducted detailed analyses and evaluations of the impact of digitalization on many different aspects of banking (Shanti *et al*., 2022). However, a careful review of the literature reveals a significant research gap. Most of the new and existing research focuses mainly on the general aspects of digital transformation relating to overall operational efficiency or the creation of new digital business models (Al-Busaidi & Al-Muharrami, 2021; Alsobai & Aassouli, 2025). Meanwhile, there is a distinct lack of focused literature directly analyzing the specific activity that generates the most revenue: credit operations. There are only a few domestic studies systematically evaluating the distinct aspects of bank credit risk and credit expansion in relation to technological readiness (Quang, 2023; Nguyen, 2025a). While some international studies have explored how digitalization affects bank performance (Al-Busaidi & Al-Muharrami, 2021; Podder & Ghosh, 2025), bank competitiveness (Jia & Liu, 2024), the precise correlation between digital transformation metrics and the specific credit performance indicators of Vietnamese banks remains under-researched.

To address this critical knowledge gap, this study aims to conduct a comprehensive research on the impact of digital transformation on the credit performance of Vietnamese commercial banks. To accomplish this overarching goal, the research is guided by several detailed objectives. First, it aims to systematically establish the theoretical basis of digital transformation and credit activities within the commercial banking sector. Second, the study seeks to thoroughly evaluate and analyze the current situation of digital transformation in the Vietnamese market and at specific commercial banks, alongside analyzing the current status of their credit activities. Third, and most crucially, the research constructs a rigorous quantitative econometric model to empirically evaluate the precise impact of digital transformation trends on the credit institutions' performance in Vietnam. Finally, the study aims to draw general conclusions from which to propose highly appropriate solutions and recommendations.

The primary research object of this study is commercial banks operating in Vietnam. In terms of spatial scope, the research meticulously analyzes a robust sample of 25 Vietnamese commercial banks. This comprehensive sample includes the 4 major state-owned commercial banks (Agribank, Vietcombank, Vietinbank, and BIDV, which hold over 50% of the state's charter capital) alongside 21 prominent joint-stock commercial banks, ensuring a highly

representative view of the entire banking system. In terms of time scope, the thesis specifically chose to collect and analyze data spanning the period from 2016 to 2024. The year 2016 was strategically selected because, while digital transformation began to be heavily recorded globally around 2015, it gradually became a popular and measurable phenomenon in Vietnam around 2016. Thus, analyzing data up to 2024 provides empirical results that are closest to today's modern economic reality. The research methodology relies on quantitative data analysis, collecting secondary data from the annual audited financial reports of these 25 banks. Furthermore, critical digital transformation indicators are sourced from the ICT Index published by the Ministry of Information and Communications, while necessary macro-economic data is compiled from the World Bank.

Literature Review

The rapid evolution of digital technologies has spurred a profound transformation across the global banking sector. Consequently, an increasing body of academic literature has emerged to evaluate the impacts of digital transformation on various facets of banking operations. While much of the early and general research primarily focused on overarching operational efficiency and the creation of new business models, a crucial subset of contemporary studies has begun to critically analyze the direct effects of digitalization on bank credit activities and credit risk—the primary revenue-generating mechanisms for commercial banks.

Globally, scholars have largely reached a consensus that digital transformation yields significant, albeit sometimes complex, benefits for bank credit operations, financial inclusion, and risk management. In exploring the relationship between digital technology and credit expansion, Wu and Tang (2024); Saadati *et al*. (2024) conducted an extensive study analyzing the balance sheet data of 112 Chinese banks, encompassing large commercial banks, joint-stock banks, and rural commercial banks from 2011 to 2022. Wu's empirical results demonstrated a positive correlation between the level of digitalization and the development of credit activities. The research asserted that increased digitalization helps expand credit capacity by optimizing lending processes and proactively minimizing bad-debt risk prior to lending. Crucially, Wu found no convincing evidence that digitalization leads to an unchecked, excessive expansion of credit capacity, thereby confirming its role as a sustainable growth driver. Similarly, Zhang (2024) evaluated the impact of digital financial development on the credit structure and risk tolerance of commercial banks. Zhang concluded that digital finance not only increases the overall scale of bank credit but also fundamentally shifts the credit structure, driving a significantly higher ratio of consumer lending compared to traditional corporate loans. Furthermore, integrating digital finance was shown to reduce the overall risk burden on banks, ultimately enhancing their financial stability. The structural shift in the banking ecosystem was analyzed in depth by Valeri Mosiashvili (2022); Sakhnenkova *et al*. (2023), whose research at Georgia SEU National University highlighted the transition from traditional, closed banking models to open digital financial ecosystems. Mosiashvili observed that this transformation is largely fueled by Artificial Intelligence (AI), Blockchain, and Fintech integration, which collectively improve operational efficiency, reduce costs, and heighten security. The study noted a distinct strategic divergence: large banks tend to build their own proprietary ecosystems, whereas smaller banks increasingly cooperate with agile Fintech companies to leverage new technological advantages. Regarding the impact on profitability and financial performance, Shanti *et al*. (2023) provided a nuanced temporal perspective using a Panel of Autoregressive Distributed Lag (ARDL) model. By analyzing digital banks, Shanti identified that digital transformation has a significant positive impact on long-term bank profits, Net Interest Margin (NIM), and Capital Adequacy Ratios (CAR). However, a critical finding of this study was the negative short-term correlation between digital transformation and bank profits. This phenomenon is attributed to the massive initial capital expenditures required for digital technology investments, combined with the lengthy period required for these digital processes to be fully and effectively implemented.

While international studies provide a robust framework, the banking environment in emerging markets like Vietnam presents unique challenges and transitional dynamics. Recent domestic studies highlight a more complex, sometimes contradictory, reality regarding digital transformation and credit risk. Contrasting with some global optimism, Quang (2023) assessed the impact of digital transformation on credit risk using a Random Effects Model (REM) on 37 Vietnamese commercial banks from 2010 to 2021. The findings surprisingly showed that digital transformation initially increases bank credit risk rather than reducing it. Quang explained this phenomenon by noting that Vietnam is still in the early stages of digitalization. At this juncture, digital transformation is heavily concentrated on front-end

product innovation and customer service experience rather than the deep deployment of complex, automated risk-management technologies like blockchain. Consequently, the rapid growth in loan scale driven by digital access poses immense short-term credit risk management challenges for these banks. Offering a qualitative evaluation. Trang *et al*. (2024); Prada *et al*. (2024) utilized a Fixed Effects Model (FEM) and the Z-score index across 11 joint-stock commercial banks (2005-2020). Measuring technological readiness via the Vietnam ICT Index, the study demonstrated that Information Technology applications have a positive impact, helping reduce risks and increase banks' financial stability. The research clearly emphasized that human infrastructure and internal IT applications are the most critical determinants. Finally, Doan *et al*. (2024); Bona *et al*. (2025) explored this relationship across 29 Vietnamese banks from 2014 to 2022, utilizing Pooled OLS, FEM, REM, and GLS models. Their comprehensive results confirmed that digital transformation significantly reduces credit risk by vastly enhancing lending services and risk management strategies. However, corroborating Shanti's (2023) international findings, Thang emphasized that these benefits are heavily delayed because Vietnamese banks require substantial time to adapt to new systems and processes.

The reviewed literature clearly indicates a consensus that digital transformation reshapes credit structures, broadens access to credit, and has the potential to mitigate credit risk. However, a significant research gap remains. International models often lack applicability to the nascent technological infrastructure of emerging markets. Meanwhile, domestic Vietnamese studies yield mixed results, with some authors citing short-term increases in risk due to unmanaged loan scaling (Padma, 2023; Quang, 2023) and others emphasizing delayed risk reduction (Doan *et al*., 2024; Patricia & Hailemeskel, 2024). Furthermore, many domestic studies are limited by narrow data ranges, an exclusive focus on listed banks, or the omission of vital macroeconomic control variables. Therefore, there is a pressing need for an updated, comprehensive quantitative model that utilizes the most recent data (up to 2024) and detailed components of the ICT Index to definitively measure the dual impact of digital transformation on both credit expansion and credit quality in Vietnam.

Materials and Methods

Research Models

To formally assess how digital transformation affects bank credit operations, the study establishes two primary multivariate regression models corresponding to the two dependent variables. The baseline static models are specified as follows:

$$LTA_{i,t} = \beta_0 + \beta_1 TTCIndex_{i,t} + \alpha' Bank'_{i,t} + \gamma' Macro'_t + \tau_i + \varepsilon_{i,t} \quad (1)$$

$$NPL_{i,t} = \beta_0 + \beta_1 ITCIndex_{i,t} + \alpha' Bank'_{i,t} + \gamma' Macro'_t + \tau_i + \varepsilon_{i,t} \quad (2)$$

Where NPLi,t and LTAi,t refer to the dependent variables. The study evaluates credit operations from two distinct angles: credit risk and credit expansion. Non-Performing Loans (NPL): Used to measure the effectiveness of loan management and the stability of the bank, representing credit quality and risk. Based on Circular 11/2021/TT-NHNN, it is calculated as: NPL = (Total Bad Debt/Total Outstanding Credit)×100%. Besides, Loan-to-Assets (LTA) is used to assess credit expansion strategies, concentration in lending activities, and liquidity levels. It is calculated as: LTA = (Total Outstanding Loans/Total Assets)×100%. These credit operation criteria are used in many studies (Sergun *et al*., 2023; Nguyen & Nguyen, 2024; Tian & Su, 2024; Nguyen, 2025a).

The Independent variable, ITCIndex, serves as the primary proxy for digital transformation. It measures the level of readiness for the development and application of information and communications technology. To conduct a more granular analysis, an extended model decomposes the ICT index into four distinct sub-components: Technical Infrastructure (TECHINF), Human Resource Infrastructure (HUMINF), Internal Applications (INTAPP), and Online Services (ONLSERV). The study treats ICT as a lagged variable to account for the delayed benefits of technology adoption, as integrating new systems and training personnel requires considerable time. This method is used in the research of Nguyen (2025a).

$Bank'_{i,t}$ is a vector of control variables representing the characteristics of commercial banks that impact the profitability of Vietnamese commercial banks, including Bank Size (SIZE): Calculated as the natural logarithm of total assets (Ln(Total Assets)) to standardize data distribution and reduce skewnes; Equity Ratio (CAP): Represents capital adequacy and the ability to fend off risks, calculated as (Total Shareholders 'Equity/Total Assets)×100%; Profitability (ROA): Measures asset efficiency in generating profit, calculated as Net Income/Average Total Assets; Liquidity Risk (LDR): Calculated as the ratio of Total Loans/Total Deposits, reflecting the bank's reliance on customer deposits to fund its credit granting activities and Operational Diversification (NIC): Calculated as (Non−interest Income/Total Operating Income)×100%, indicating the bank's dependency on traditional credit activities versus diversified service fees. These measures are used in the research of (Quang, 2023; Tien & Nguyen, 2023; Hoque *et al*., 2024; Jia & Liu, 2024; Pakalapati *et al*., 2024).

$Macro'_t$ is a vector of macroeconomic variables that may affect commercial banks' profitability. The study controls for systematic economic influences using the Inflation rate (INF), measured via the Consumer Price Index (CPI), and the annual GDP Growth rate (GDP)

Data

To empirically investigate the impact of digital transformation on the credit activities of commercial banks in Vietnam, this study employs a quantitative research methodology based on secondary panel data. The data collection spans eight years from 2016 to 2024, a timeframe selected because digital transformation began to be formally recorded and heavily promoted within the Vietnamese banking sector around 2016.

The research sample consists of 25 commercial banks operating in Vietnam. To ensure consistency and avoid extraneous influence, the selection criteria strictly excluded foreign-owned banks and required all included banks to have published financial statements for at least three consecutive years. The final data panel comprises 225 total observations. Within this sample, there are 4 state-owned commercial banks (Agribank, Vietcombank, Vietinbank, and BIDV), which hold over 50% of the state's charter capital, and 21 joint-stock commercial banks, ensuring the sample is highly representative of the overall Vietnamese banking system.

The data were aggregated from multiple reputable sources. Bank-specific financial data were collected from audited consolidated financial statements available on banks' official websites and from financial portals such as CafeF and Vietstock Finance. The digital transformation indicators were sourced from the annual Information and Communication Technology (ICT) Application Readiness Index reports published by the Vietnam Ministry of Information and Communications (MIC).

Table 1. Descriptive statistics

Variables	Means	Std. dev	Min	Max
LTA	0.6223	0.0896	0.3188	0.7881
NPL	0.0212	0.0267	0	0.3035
INF	3.1878	1.4912	0.1982	5.2311
GDP	0.0601	0.0194	0.0255	0.0812
ITC	0.2926	0.2649	0	0.7762
SIZE	19.3934	1.098	16.7625	21.7388
CAP	0.0819	0.0314	0.0406	0.1845
LTA	0.0113	0.0086	-0.0478	0.0358
LDR	0.9393	0.1518	0.5529	1.4282
NIC	0.2998	0.1535	-0.7490	0.8875

Sources: authors' calculation

Table 1 provides descriptive statistics of the variables in the research. From 2016 to 2024, 25 Vietnamese banks maintained a safe average Non-Performing Loan (NPL) ratio of 2.12%, well below the 3% regulatory limit. Their high

Loan-to-Assets (LTA) average of 62.23% indicates a heavy reliance on credit operations. Meanwhile, the overall digital transformation index (ICT) remains relatively low at 29.26%

Methodology

The empirical analysis is conducted using a rigorous panel-data regression framework. Prior to regression, a Variance Inflation Factor (VIF) test is performed to detect multicollinearity among the independent variables, ensuring that all VIF values remain strictly below the threshold of 5.

The study initially incorporates three standard static panel models: Pooled Ordinary Least Squares (OLS), the Fixed Effects Model (FEM), and the Random Effects Model (REM). To determine the most robust model specification, several statistical tests are sequentially applied. First, an F-test (Wald test) is utilized to compare the Pooled OLS model against the FEM. Subsequently, the Hausman test is conducted to examine whether individual effects are correlated with independent variables, thereby deciding the suitability of the FEM and REM approaches.

Even after selecting the optimal baseline model (which the Hausman test indicated to be FEM), panel data often suffer from statistical violations that can render standard estimates biased or inefficient. Therefore, the chosen model is subjected to diagnostic checking. The Breusch-Pagan/Cook-Weisberg (or White) test is deployed to check for heteroskedasticity (variable error variance). In contrast, the Wooldridge test (xtserial command) is used to detect the presence of first-order autocorrelation. To effectively overcome and adjust for the simultaneous presence of both autocorrelation and heteroskedasticity in the data, the research ultimately applies the Feasible Generalized Least Squares (GLS) estimation method. The GLS model corrects these specific violations of OLS assumptions, thereby providing unbiased, consistent, and highly reliable coefficients to accurately measure the precise impact of digital transformation on Vietnamese commercial banks' credit performance.

Results and Discussion

AutoCorrelation Test Matrix

To ensure the robustness of the research model, the authors assessed correlations among the model's variables to detect and avoid potential multicollinearity **(Table 2)**. The correlation coefficients are all within the ideal range of (-1, 1), with the highest correlation observed between the macroeconomic variables INF and GDP at 0.7485. Since all correlation values are strictly below the 0.8 threshold, this ensures that there are no excessively strong relationships between the independent variables, confirming that the regression model is not negatively affected by severe multicollinearity

Table 2. correlation matrix

	LTA	INF	GDP	ITC	SIZE	CAP	ROA	LDR	NIC
LTA	1.0000								
INF	-0.0302	1.0000							
GDP	-0.0301	0.7485	1.0000						
ITC	-0.0136	0.0907	0.2660	1.0000					
SIZE	0.4561	-0.0436	-0.0528	-0.0538	1.0000				
CAP	-0.0678	-0.0179	-0.0509	-0.1316	-0.1843	1.0000			
ROA	0.0481	-0.3222	-0.0726	-0.0141	0.3505	0.4480	1.0000		
LDR	0.3583	-0.0118	0.0061	-0.1642	0.3074	0.3351	0.5756	1.0000	
NIC	-0.1143	-0.0995	-0.1314	-0.0171	0.1961	0.2299	0.2594	-0.0538	1.0000

Sources: author's calculation

Regression Results

Table 3 provides a regression analysis of the impact of fintech on the profitability and stability of commercial banks in Viet Nam using four models and the Generalized Least Squares (GLS) method.

Table 3. Research Model Results

	LTA	NPL
INF	0.0031** (2.55)	-0.0002 (-0.76)
GDP	-0.352*** (-2.87)	
ITC	0.0265*** (3.83)	0.0642*** (3.26)
SIZE	0.0404*** (9.23)	-0.0046*** (-4.27)
CAP	-0.2281 (-1.593)	-0.0021*** (-4.60)
ROA	-2.6273*** (-5.49)	0.0421** (2.10)
LDR	0.2642*** (10.36)	-0.5421*** (-6.63)
NIC	0.0078 (0.42)	0.0121*** (3.79)
Const	-0.372*** (-4.33)	0.0413*** (4.07)
Observations	225	225
F-test	0.000***	0.000***

*p < 0.10, **p < 0.05 and ***p < 0.01
Sources: authors' calculation

The GLS-adjusted model provides compelling empirical evidence of digital transformation's dual positive impact on credit operations. The primary proxy for digitalization, the ICT Index, demonstrates a highly statistically significant relationship with both credit expansion and credit quality. The ICT Index has a positive correlation with LTA, with a coefficient of 0.0265 at a 1% significance level. This indicates that a 1-unit increase in the ICT index raises the loan-to-asset ratio by 0.0265, proving that digital transformation successfully enhances banks' lending capacity and broadens credit access. Conversely, the ICT Index has a strong negative correlation with NPL. A 1-unit increase in ICT reduces the NPL ratio by 0.00462 at a 1% significance level. This proves that technological applications significantly optimize credit risk management and reduce loan defaults.

Table 4. Research Model Results

	LTA	LTA	LTA	LTA	NPL	NPL	NPL	NPL
TECH	0.0177*** (0.01)				- 0.0049*** (0.00)			
HUMAN		0.0194** (0.01)				- 0.0037*** (0.00)		
INAPP			0.0144*** (0.01)				- 0.0025*** (0.00)	
SERVE				0.0171*** (0.01)				-0.0029*** (0.00)
SIZE	0.0391*** (0.00)	0.0378*** (0.00)	0.0402*** (0.00)	0.0391*** (0.00)	- 0.0025*** (0.00)	- 0.0022*** (0.00)	- 0.0017*** (0.00)	-0.0021*** (0.00)
CAP	-0.2024 (0.15)	-0.2024 (0.15)	-0.2017 (0.00)	-0.2517 (0.00)	0.0227 (0.02)	0.0490** (0.02)	0.0469** (0.02)	0.0282 (0.02)

ROA	-2.5228*** (0.49)	-2.2380*** (0.49)	-2.6098*** (0.49)	-2.5228*** (0.49)	-0.5423*** (0.08)	-0.5119*** (0.09)	-0.6003*** (0.08)	-0.5331*** (0.08)
LDR	0.2468*** (0.03)	0.2480*** (0.03)	0.2513*** (0.02)	0.2547*** (0.03)	0.0164*** (0.00)	0.056*** (0.00)	0.0179*** (0.00)	0.0154*** (0.00)
NIC	-0.0028 (0.02)	-0.0025 (0.02)	0.0042 (0.02)	0.0050 (0.02)	0.0121*** (0.00)	0.0101*** (0.00)	0.0106*** (0.00)	0.0120*** (0.00)
INF	0.0029** (0.00)	0.0017 (0.00)	0.0021* (0.00)	0.0023** (0.00)	-0.0002 (0.00)	0.0001 (0.00)	0.0000 (0.00)	0.0000 (0.00)
GDP	-0.2442* (0.13)	-0.1657 (0.10)	-0.2158* (0.11)	-0.2691** (0.11)	0.0647*** (0.02)	0.0251 (0.02)	0.0453** (0.02)	0.0458*** (0.02)
Const	-0.3327*** (0.09)	-0.3092*** (0.09)	-0.3587*** (0.09)	-0.3343*** (0.09)	0.0481*** (0.01)	0.0423*** (0.01)	0.0302*** (0.01)	0.0410*** (0.01)
Observations	225	225	225	225	225	225	225	225
F-test	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***

*p < 0.10, **p < 0.05 and ***p < 0.01
Sources: authors' calculation

To provide deeper analytical insights, an extended GLS model decomposed the overall ICT Index into four distinct components: Technical Infrastructure (TECHINF), Human Resource Infrastructure (HUMINF), Internal Applications (INTAPP), and Online Services (ONLSERV) **(Table 4)**. The results reveal that all four components positively influence LTA and negatively impact NPL. Notably, HUMINF exhibits the strongest positive impact on credit expansion, increasing LTA by 0.0194 for every 1-unit increase (at a 5% significance level). Meanwhile, TECHINF has the most substantial effect on mitigating credit risks, reducing NPL by 0.0049 for every 1-unit increase. This emphasizes the critical role of robust hardware, software, and real-time data monitoring systems in maintaining asset quality.

Finally, control variables in the GLS model showed significant impacts: Bank Size (SIZE) and Loan-to-Deposit Ratio (LDR) positively correlated with LTA, whereas Return on Assets (ROA) showed a strong negative correlation with NPL, demonstrating that highly profitable, large-scale banks inherently possess the resources to manage credit risks more effectively.

Conclusion

The empirical findings of this study confirm that digital transformation fundamentally reshapes credit operations in Vietnamese commercial banks, perfectly balancing expanded credit access with enhanced risk management. The quantitative Generalized Least Squares (GLS) results demonstrate a dual positive effect: Digital transformation (measured by the ICT Index) significantly promotes lending capacity, indicated by a strong increase in the Loan-to-Assets (LTA) ratio, while simultaneously and effectively reducing the Non-Performing Loan (NPL) ratio. These results are in line with previous studies such as (Yang & Masron, 2023, 2024; Nguyen & Nguyen, 2024; Huynh, 2025; Nguyen, 2025a; Zhang *et al*., 2025). By leveraging digital platforms, electronic Know Your Customer (eKYC) protocols, Artificial Intelligence, and Big Data, banks can fully automate loan approvals, reach underserved populations without relying on physical branches, and perform real-time, highly accurate credit assessments.

Furthermore, the extended econometric model highlights the critical roles of specific digital sub-components. Human resource infrastructure (HUMINF) emerges as the strongest driver of credit expansion, underscoring the urgent need to hire and upskill a tech-savvy workforce to integrate digital technologies into lending processes seamlessly (Al-Alawi *et al*., 2023; Ajayi-Nifise *et al*., 2024). Meanwhile, robust technical infrastructure (TECHINF) plays the most substantial role in mitigating credit risks by enabling massive data processing for accurate creditworthiness evaluations, real-time tracking, and early default detection. With the aid of emerging technologies such as blockchain and cloud computing, commercial banks have achieved real-time and systematic management, addressing the isolation

of data and dispersion of resources. This improves the efficiency of risk management in banks and helps mitigate credit risk. However, this effect is subject to a lag as the contribution of ICT to reducing non-performing loans may become more pronounced in the long term as data analytics and risk management skills improve, leading to more informed lending decisions (Cheng & Qu, 2020; Ezeh *et al*., 2024; Elango & Govindaraju, 2025; Huynh, 2025).

The study also highlights the influence of bank-specific control variables; for instance, larger banks (SIZE) with higher profitability (ROA) and strong loan-to-deposit ratios (LDR) are much better positioned to heavily invest in ICT, creating a positive feedback loop that expands lending scale and dramatically lowers bad debts. These findings are in line with previous research (Le *et al*., 2022; Naili & Lahrichi, 2022; Wu *et al*., 2022; Barra & Ruggiero, 2023; Goyal *et al*., 2023; Alqara *et al*., 2024).

Despite these profound advantages, the banking digitalization process still faces severe structural challenges. These include an incomplete regulatory framework—such as the extensively delayed Regulatory Sandbox for testing emerging technologies—high initial investment costs that heavily widen the competitive gap between large and small banks, escalating cybersecurity threats, and a severe shortage of personnel proficient in both complex finance and IT systems. Moreover, the empirical benefits of digital transformation exhibit a lagged effect, requiring substantial time for new system integration, employee training, and organizational cultural adaptation.

In conclusion, digital transformation is not merely an operational upgrade but a strategic imperative that dictates the future competitiveness and overall stability of Vietnamese commercial banks. It successfully drives sustainable credit growth while systematically lowering bad debts, ultimately fostering financial inclusion and supporting broader national economic growth. To fully maximize these benefits and expertly navigate the existing barriers, synchronized efforts from all stakeholders are essential. For Commercial Banks, it is vital to prioritize selective investments in AI and Big Data specifically for core risk management, aggressively upgrade multi-layered cybersecurity and data encryption protocols to prevent breaches, and continuously train a high-quality digital workforce. Smaller institutions with limited capital should actively collaborate with Fintech companies to share technological costs and infrastructure. Besides, there is an urgent need to expedite the legal framework, notably by passing the Regulatory Sandbox decree to allow the safe testing of innovative credit products like P2P lending. The Government should also consider providing low-interest financial subsidies to smaller banks explicitly for technology upgrades. In addition, the SBV should standardize biometric authentication regulations to carefully align with international standards (like ISO/IEC 30107), establish a centralized National Credit Database to facilitate secure data sharing, and actively promote the use of the national population database for seamless customer verification. By effectively addressing these multifaceted challenges, the Vietnamese banking sector can build a highly secure, dynamic, and inclusive digital financial ecosystem.

Limitations and Dimensions for Future Research

This study acknowledges several limitations. The ICT index might not comprehensively reflect actual banking digitalization due to inconsistent, incomplete, and outdated data. For future research, scholars should explore how external factors, such as government policies and technological disruptions, interact with digital transformation. Furthermore, studies should adopt alternative metrics beyond the ICT index—such as AI and blockchain automation levels or specific capital allocations for IT infrastructure and cybersecurity—to provide a more accurate and comprehensive evaluation.

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