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Information and communication technology as a catalyst for bank efficiency: Empirical evidence from Vietnam

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ABSTRACT

The swift progression of the digital economy and the Fourth Industrial Revolution highlights the essential function of Information and Communication Technology (ICT) in the transformation of the banking sector. In emerging markets such as Vietnam, the rapid growth of digital financial services necessitates an understanding of the relationship between ICT and bank performance. This research examines the influence of ICT on the operational efficiency and profitability of 24 commercial banks in Vietnam over the period from 2011 to 2022. This study assesses the impact of ICT and its components—Information Technology Infrastructure (ITI) and Information Technology Applications (ITA)—on essential financial metrics: Return on Assets (ROA), Return on Equity (ROE), and Net Interest Margin (NIM). The methodology employs panel data regression techniques such as Pooled OLS, Fixed and Random Effects Models, Feasible Generalized Least Squares (FGLS), and the Generalized Method of Moments (GMM) to ensure robustness and address endogeneity concerns. The findings indicate that ITI has a significantly positive impact on ROA and ROE; however, the overall ICT index does not demonstrate a consistent positive relationship across models, suggesting a profitability paradox. Online payment systems enhance return on assets (ROA) while adversely impacting ROE and NIM as a result of implementation expenses and operational risks. It concludes that ICT investment can improve efficiency, but its advantages are contingent upon strategic alignment, employee readiness, and regulatory support. Policymakers and bank managers must emphasize IT infrastructure, staff training, and risk management to optimize returns from digital transformation.

1. Introduction

Digital transformation has become a fundamental aspect of institutional growth, competitiveness, and resilience in the rapidly changing global economy. Financial institutions are experiencing a significant transformation due to technological innovation, which is altering business models and redefining interactions with customers, regulators, and markets. The [International Data Corporation \(2022\)](#) reports that global expenditure on digital transformation in the banking sector surpassed USD 600 billion and is projected to increase at a compound annual growth rate of 16.5 % until 2026. According to [Demirgüç-Kunt et al. \(2022\)](#) indicates that >70 % of adults in developing countries possess access to a financial account, primarily facilitated by mobile banking and digital platforms. The data highlight the critical role of ICT in enhancing financial inclusion and optimizing banking sector performance. Within the framework of the Fourth Industrial Revolution, the

growth of ICT has reached remarkable levels, highlighting the transformative influence of emerging technologies and their diverse applications across multiple sectors. ICT acts as a vital driver in enhancing development processes, offering a significant means to boost efficiency and productivity. ICT can be defined as a comprehensive system involving the collection, storage, manipulation, and transmission of information via electronic channels ([Laudon and Laudon, 2001](#)), encompassing a wide range of digital tools such as devices, applications, intranets, data storage, and cybersecurity ([Mahboub, 2018](#)), while also enabling the integration of data, audio, and video through high-speed communication networks ([Alabi, 2005](#)).

Innovative business models, driven by contemporary technology, are transforming operational frameworks within financial institutions ([Schueffel, 2016](#)). Alongside the swift advancement of the digital economy, innovation, and integration, banking sector has also been experiencing considerable change ([Mention, 2021](#)). Investment in ICT

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has significantly improved bank performance in multiple areas, such as operational efficiency, profitability, and customer happiness. [Yongjie & Jin \(2023\)](#) demonstrate that banking institutions enhance efficiency and agility through digital transformation efforts, which are essential for maintaining competitiveness in the financial industry. Moreover, the implementation of cutting-edge technologies improves interactions between banks and their clients, consequently augmenting service delivery and customer experience ([Del Gaudio et al., 2021](#); [Galazova and MaroMaeba, 2019](#)). Furthermore, empirical research has shown a positive association between ICT investments and profitability indicators in diverse banking environments ([Del Gaudio et al., 2021](#); [Leckey et al., 2011](#); [Obasa, 2023](#)). Besides operational efficiency and profitability, ICT investments are crucial for improving customer trust and happiness. The digital transformation of financial services has reduced operating expenses, enhanced client engagement through accessible and user-friendly platforms, met evolving customer expectations, and fostered loyalty—key factors for sustained success in the banking industry ([Pristiyono et al., 2022](#)). The incorporation of digital technologies enables banks to deliver tailored services that enhance client satisfaction and retention, while investments in ICT improve decision-making and management efficacy, both of which are crucial for navigating the complexities of the modern banking landscape ([Matthew and Ibikunle, 2012](#)). The strategic implementation of digital tools empowers banks to continuously innovate, enabling them to adapt to regulatory changes and evolving market trends, thereby ensuring sustained growth, competitiveness, and resilience ([Liu et al., 2011](#); [Jia, 2024](#)).

However, the relationship between ICT investments and bank performance is multifaceted and occasionally inconsistent, as various factors can mediate or even hinder the expected benefits. [Alt et al. \(2018\)](#) and [Pierri & Timmer \(2022\)](#) highlight that while ICT holds the potential to enhance operational efficiency, customer service, and overall competitiveness, substantial implementation and maintenance costs can place significant financial strain on banks, particularly smaller institutions. Similarly, [Brynjolfsson & Hitt \(2000\)](#) emphasize that realizing the full value of ICT investments requires complementary organizational changes, which can be both time-consuming and costly. Furthermore, the growing prevalence of cybersecurity threats poses a critical challenge, as breaches can lead to reputational damage, regulatory penalties, and loss of customer trust ([von Solms and van Niekerk, 2013](#)). These complexities suggest that the effectiveness of ICT investments depends not only on the technology itself but also on strategic planning, robust risk management, and the ability to balance cost-benefit dynamics within a rapidly changing digital environment.

In recent years, Vietnam has undergone notable technical progress, marked by the extensive proliferation of smartphones, enhanced internet accessibility, and the emergence of digital financial services, all of which have profoundly influenced the banking sector ([Pham et al., 2023](#)). Vietnam's digital economy has developed rapidly, with an average growth rate of 20 % per year, three times the country's GDP growth rate. It is expected that the digital economy will contribute approximately 18.3 % to the national GDP in 2024 and will account for 20 % of GDP by 2030. Among them, three sectors are expected to have a significant impact on the development of the digital economy: e-commerce, digital content, and finance and banking. In 2019, the State Bank of Vietnam signed Decision No. 2655, emphasizing that the application of ICT must become a critical foundation to actively support the development strategy of the banking sector by 2030 ([State Bank of Vietnam, 2019](#)). Thus, Vietnamese banks are prioritizing the modernization of their ICT infrastructure, integrating digital technologies into both internal operations and business processes, and enhancing customer experiences through innovative solutions. As a result, the number of customers engaging in mobile payment transactions has grown significantly, with transaction volume increasing by an average of 87 % per year and transaction value growing by 140 % annually from 2015 to 2021. By 2024, Vietnam's online payment scale is expected to reach approximately 87 %, surpassing the government's target of 80 % by

2025. Therefore, exploring the relationship between ICT investment and banking performance is becoming increasingly important in this emerging market ([Pham and Nguyen, 2022](#)).

This study offers a new perspective on the impact of ICT on the performance of commercial banks in Vietnam, using a dataset of 24 banks from 2011 to 2022. To strengthen the robustness of the findings, the authors supplemented the ICT index as the primary measure of impact by incorporating Information Technology Infrastructure (ITI) and Information Technology Application (ITA) as alternative proxies for the ICT index. ITI encompasses the hardware, software, networks, data management, and services crucial for IT service delivery in an organization. It includes both physical and virtual assets like servers and networking equipment, supporting operations, business processes, and communication. ITI forms the foundation for ICT, incorporating internet and mobile technologies to boost efficiency, customer engagement, and innovation ([Peace et al., 2018](#); [Zhang et al., 2022](#)). Meanwhile, ITA means utilizing IT tools to tackle challenges, enhance productivity, and improve efficiency in business. It includes software, systems, and processes that manage and share information to aid decision-making and foster innovation, all within the ICT framework. This study employs three theoretical frameworks to explain ICT's impact on bank performance. Endogenous Growth Theory emphasizes technology's role in boosting productivity and innovation. Resource-Based View considers ICT a strategic asset that can generate sustained competitive advantage when effectively utilized. Transaction Cost Theory highlights ICT's ability to reduce coordination and information costs, thereby improving decision-making efficiency ([Williamson, 1981](#)). Collectively, these perspectives provide a comprehensive understanding of ICT's context-dependent effects on banking performance.

This research adds to the current body of knowledge in multiple aspects. Initially, it enhances the comprehension of the influence of ICT on the performance of commercial banks, expanding upon the foundational research conducted by [Thalassinou et al. \(2012\)](#). Secondly, the authors identified a gap in the literature regarding the impact of ICT on the performance of commercial banks in Vietnam, as most studies focus on specific factors like ATM, POS, and mobile banking as proxies for ICT. To address this gap, the authors opted to use a composite index as a proxy for ICT adoption in Vietnamese commercial banks. We also added IT Infrastructure (ITI) and IT Application (ITA) as alternative proxies alongside the ICT index to enhance the robustness of the results. Thirdly, in addition to the commonly used panel data regression techniques such as Pooled OLS, FEM, REM, and FGLS in studies on this topic, this paper employs the Generalized Method of Moments (GMM) to address endogeneity, thereby enhancing the reliability of the research findings, as recommended by [Sani et al. \(2019\)](#) and [Agu & Aguegbah \(2020\)](#). Lastly, the findings offer valuable insights for policymakers and regulators to develop ICT strategies and regulatory frameworks that enhance IT infrastructure and applications, fostering sustainable, technology-driven performance improvements in the Vietnamese banking sector.

The remainder of this study is organized as follows: [Section 2](#) includes a review of the literature. [Section 3](#) highlights the methodology adopted for the study. Further, [Section 4](#) summarizes the primary findings and results. Finally, conclusions and recommendations are discussed in [Section 5](#).

2. Literature review and hypothesis development

2.1. Theoretical background

This study examines the impact of ICT on bank performance through three complementary theoretical frameworks: Endogenous Growth Theory ([Solow, 1956](#); [Romer, 1990](#)), Transaction Cost Theory ([Williamson, 1981](#)), and the Resource-Based View ([Barney, 1991](#)). Each theory offers a distinct perspective for analyzing the impact of technological investment on firm performance, particularly in the banking sector of transitional economies.

The Endogenous Growth Theory enhances neoclassical models by identifying technology as an intrinsic factor influencing economic growth. [Romer \(1990\)](#) highlighted that investments in knowledge, innovation, and human capital lead to productivity improvements over time. In the banking sector, investments in ICT improve efficiency through process automation, facilitate data-driven decision-making, and broaden access to financial services ([Acemoglu et al., 2014](#)). Recent literature supports this notion, demonstrating that ICT enhances financial performance through increased economies of scale, decreased marginal costs, and improved service delivery ([Nguyen et al., 2023](#); [Obasa, 2023](#)).

The Transaction Cost Theory, proposed by Williamson in 1981, elucidates the role of ICT in diminishing transaction costs via enhanced coordination, transparency, and information processing. Digitizing operational processes enables banks to reduce the costs associated with information asymmetry and agency problems ([Alt et al., 2018](#)). In developing economies characterized by fragmented banking infrastructure, ICT applications, including mobile banking, CRM software, and online payments, contribute to lowering customer acquisition costs and enhancing outreach ([Tega and David, 2021](#); [Wang, 2022](#)).

The Resource-Based View posits that ICT functions as a strategic and unique resource that can yield competitive advantage, provided it meets the criteria of being valuable, rare, inimitable, and non-substitutable ([Barney, 1991](#)). The effective deployment of ICT, including robust IT infrastructure and tailored software applications, enhances service differentiation, improves customer loyalty, and supports innovation ([Galazova and Magomaeva, 2019](#); [Mahboub, 2018](#)). In Vietnam, banks are competing to provide differentiated digital services, with ICT serving as a fundamental capability that enhances sustainable performance ([Doan et al., 2022](#)).

Together, the three theories support the study's framework and the empirical results also demonstrate their applicability. Indeed, the positive impact of ITI on ROA and ROE aligns with both the Resource-Based View and the Endogenous Growth Theory: ITI serves as a valuable strategic resource that promotes sustained competitiveness (RBV) while also increasing productivity through automation and efficiency gains (EGT). Next, the Transaction Cost Theory can be used to analyze the inconsistent and occasionally adverse effects of OP and the composite ICT index. According to the theory, efficiency advantages are outweighed by high implementation costs, integration difficulties, and operational risks in Vietnam's transitional banking environment. The results indicate that different ICT dimensions may function through different mechanisms, even though it is difficult to empirically separate the magnitude of each theoretical channel.

2.2. Information and communication technology and bank performance

ICT includes a wide range of technologies, such as software, hardware, data systems, and communication networks. In banking, ICT enhances service delivery efficiency, enables real-time data access, fosters customer engagement, and ensures compliance with regulatory requirements ([Laudon and Laudon, 2001](#); [Alabi, 2005](#)). ICT serves as an innovation input that enhances productivity ([Romer, 1990](#)), lowers transaction costs ([Williamson, 1981](#)), and strengthens firm capabilities ([Barney, 1991](#)).

Empirical research has demonstrated the beneficial impact of ICT on banking performance. [Gupta et al. \(2018\)](#) demonstrated that the adoption of ICT enhances operational efficiency and profitability in Indian banks. [Del Gaudio and Tommaso \(2021\)](#) demonstrated that ICT enhances customer satisfaction and financial returns in European banks. [Obasa \(2023\)](#) demonstrated a significant correlation between ICT investments and bank profitability in Nigeria within developing markets.

Nonetheless, additional research indicates varied results. [Ho and Mallick \(2010\)](#) identified a "profitability paradox," wherein substantial IT investments did not yield increased profits, attributed to elevated implementation costs, insufficient employee training, or cybersecurity

vulnerabilities. [Pierri and Timmer \(2022\)](#) observed that although ICT enhances efficiency, its influence on performance is moderated by factors specific to the firm. The mixed results in Vietnam can be attributed to the varying levels of ICT maturity among banks and differing degrees of alignment with strategic objectives ([Pham and Nguyen, 2023](#)).

[Table 1](#) offers a structured overview of the most important research on ICT and bank performance to help readers better grasp the global data. The various proxies used to measure ICT (from ATM/POS networks to composite ICT indices), the financial and non-financial performance indicators (ROA, ROE, NIM, efficiency, and customer satisfaction), and the methodological approaches used in different contexts are all highlighted in this synthesis.

The comparison shows that although the majority of research supports ICT's beneficial impact on productivity and profitability, findings differ according on sample size, cost structures, and nation-specific variables. For instance, research in emerging economies like Nigeria and India highlights the profitability effects of ICT adoption, whereas studies in industrialized markets frequently discover significant efficiency improvements. However, [Ho and Mallick's \(2010\)](#) "profitability paradox" emphasizes that large ICT expenditures do not always result in instant profits. These revelations highlight how crucial it is to look at Vietnam's particular situation, where banks are embracing digital tools at a quick pace despite significant implementation costs and capacity limitations.

Vietnam's swift digital advancement and government-supported ICT initiatives foster an environment that enables banks to utilize technology for improved performance. Disparities in infrastructure and staff capability may influence these effects.

Hypothesis 1. *The ICT index has a positive impact on the performance of commercial banks in Vietnam.*

2.3. Information technology infrastructure and bank performance

ITI denotes the essential systems—hardware, software, databases, servers, and communication networks—that underpin IT services within an organization. In banking, ITI is essential for facilitating transaction processing, inter-branch communication, cybersecurity, and digital service platforms ([Jarrah et al., 2023](#); [Zhang et al., 2022](#)).

The Resource-Based View posits that a robust IT infrastructure serves as a distinctive organizational capability that is difficult to imitate and can yield enduring performance benefits ([Melville et al., 2004](#)). [Hasan et al. \(2011\)](#) established a direct correlation between payment infrastructure and banking revenue, especially within the retail banking sector. [Wambui \(2023\)](#) noted that properly aligned IT infrastructure improves operational efficiency in microfinance institutions, particularly in resource-constrained settings. Furthermore, research conducted by [Peace et al. \(2018\)](#) and [Liu \(2022\)](#) indicates that contemporary infrastructure minimizes downtime, enhances security, and facilitates service innovation.

Amid Vietnam's vigorous advancement and investment in ITI, banks will have increased chances to improve access to and innovation in technology. The expansion of ITI has markedly enhanced banking operations, promoting efficiency and encouraging innovation. The authors assert that enhancing IT infrastructure is crucial for Vietnamese banks seeking to improve operational efficiency and market competitiveness.

Hypothesis 2. *ITI has a positive impact on the performance of commercial banks in Vietnam*

2.4. Information technology application and bank performance

ITA encompasses the deployment and utilization of IT tools, including CRM software, mobile banking applications, and online payment platforms, aimed at enhancing business processes, decision-making, and customer service. The Transaction Cost Theory posits that ITA diminishes communication, coordination, and information

Table 1
Comparative literature on ICT and bank performance.

Study	Country / Region	Sample & Period	ICT Measure(s)	Performance Measure(s)	Methodology	Key Findings
Gupta et al. (2018)	India	20 commercial banks, 2000–2015	ICT index (ATM density, mobile banking adoption)	ROA, ROE	Panel regression (OLS, FEM/REM)	ICT adoption improves profitability and efficiency
Del Gaudio & Tommaso (2021)	Europe	50 banks, 2005–2015	ICT spending and digital service indicators	Customer satisfaction, ROA	FEM with robustness checks	ICT enhances customer experience and returns
Ho & Mallick (2010)	Developed & Emerging Markets	80 banks, 1995–2006	IT expenditure (as % of assets)	ROA, ROE, efficiency scores	Dynamic panel regression	Found “profitability paradox”: ICT raises efficiency but not profits
Obasa (2023)	Nigeria	15 banks, 2006–2019	ICT investment index	ROA, ROE	GMM	Significant positive impact of ICT on profitability
Hasan et al. (2011)	Europe (retail banks)	30 banks, 1999–2009	Payment infrastructure (ATMs, POS systems)	Banking revenue	Cross-country regression	Strong link between payment infrastructure and income
Wambui (2023)	Kenya (MFIs)	25 MFIs, 2010–2020	IT infrastructure (servers, networks)	Operational efficiency	OLS and FEM	ITI improves efficiency in resource-constrained institutions
Pierrri & Timmer (2022)	Europe	90 banks, 2008–2018	Digital technology adoption index	Efficiency ratio, ROA	Panel regressions	ICT improves efficiency; profitability depends on cost structures
Thalassinos et al. (2012)	Global	100+ banks, 2000–2010	ICT proxies (ATM, POS, internet banking)	ROA, ROE	Cross-country regression	ICT adoption positively associated with profitability
Current study (2024)	Vietnam	24 banks, 2011–2022	ICT index, IT infrastructure (ITI), IT applications (OP)	ROA, ROE, NIM	OLS, FEM/REM, FGLS, GMM	ITI improves ROA/ROE; ICT index shows paradox; OP has mixed effects

retrieval costs, consequently enhancing organizational efficiency (Williamson, 1981).

Empirical studies present inconclusive findings. Al-Mamary et al. (2022) showed that smartphone banking applications markedly improved customer satisfaction and marketing effectiveness in Jordan. Valahzaghard & Shakourloo (2013) similarly found that CRM-based IT applications enhance customer retention, which is a crucial factor for long-term profitability. Conversely, Oye (2020) warned that ITA presents operational risks, including system failures and cyberattacks, which may compromise profitability. Sabari and Kamesh (2019) observed that techno-stress arising from unfamiliar or rapidly evolving technologies can diminish employee efficiency and morale.

As Vietnam persists in investing in and advancing information technology applications, banks will encounter augmented prospects to improve technological accessibility and stimulate innovation. In light of these observations, the authors propose that the effective application of IT tools will continue to have a positive impact on Vietnamese banks' efficiency and customer service standards.

Hypothesis 3. *ITA has a positive impact on the performance of commercial banks in Vietnam*

3. Methodology

3.1. Model specification and estimation method

To examine the impact of technological innovation on performance of bank i for a period t , this study employs a standard regression models as follows:

$$ROA_{i,t} = \alpha + \beta_1 ICT_{i,t} + \beta_2 ITI_{i,t} + \beta_3 OP_{i,t} + \beta_4 SIZE_{i,t} + \beta_5 CAR_{i,t} + \beta_6 LDR_{i,t} + \varepsilon \quad (1)$$

$$ROE_{i,t} = \alpha + \beta_1 ICT_{i,t} + \beta_2 ITI_{i,t} + \beta_3 OP_{i,t} + \beta_4 SIZE_{i,t} + \beta_5 CAR_{i,t} + \beta_6 LDR_{i,t} + \varepsilon \quad (2)$$

$$NIM_{i,t} = \alpha + \beta_1 ICT_{i,t} + \beta_2 ITI_{i,t} + \beta_3 OP_{i,t} + \beta_4 SIZE_{i,t} + \beta_5 CAR_{i,t} + \beta_6 LDR_{i,t} + \varepsilon \quad (3)$$

The research opts for ROA, ROE and NIM as the dependent variables. These selections are based on previous research examining the impact of IT development on bank profitability (Aliyu and Tasmin, 2012). Hughes and Mester (2008) proposed that bank performance can be measured using structural approach such as ROA and ROE. These are also widely used profitability indicators in previous studies both globally and in Vietnam (Buallay et al., 2020; Chowdhury et al., 2017; Esteban-Sanchez et al., 2017; Batten and Vo, 2016; Pham and Nguyen, 2023). At the same time, to establish a specific performance measure for the banking sector, we introduce the variable NIM, as recommended by Saksonova (2014).

For the independent variables, we employ the ICT, ITI (IT infrastructure) and ITA (IT application) indices into the models. All of them are measured and calculated independently based on statistics from the Ministry of Information and Communication. According to this calculation method, the ICT index consists of four elements: (i) technical infrastructure (ITI), (ii) human resource infrastructure, (iii) application of internal IT, and (iv) online banking services. The ITI index constitutes a comprehensive assessment of a commercial bank's information technology capabilities and the efficacy of its digital applications in underpinning core business functions. It includes five indicators: (i) server and workstation infrastructure, (ii) communication infrastructure, (iii) ATM and POS infrastructure, (iv) information security and data safety solutions, and (v) data centers and disaster backup centers. Simultaneously, to assess the level of ITA, we use online payment (OP) as a representative. This index assesses the level of implementation of electronic payment systems by banks. Details of the measurement and formula of calculating ICT and its components are shown in the Appendix 7 and Appendix 8.

This analysis incorporates control variables such as bank size (SIZE), capital adequacy ratio (CAR), and loan-to-deposit ratio (LDR). Empirical studies have established a positive association between bank size and profitability, with larger banks benefiting from economies of scale, which subsequently enhance their financial performance (Rosalina and Nugraha, 2019; Hadad et al., 2012; Teshome et al., 2018). The relationship between CAR and profitability is nuanced, with some studies indicating a positive correlation (Hamid et al., 2017; Jadhav et al., 2021), while others suggest a negative association (Karki, 2019; Balami, 2023) or the degree of influence of capital on other factors also differs according to the bank's conditions (Barrios & Blanco, 2000). The LDR, which serves as a measure of liquidity, has the potential to increase profitability when loans are effectively managed (Murtiningrum, 2024; Pratiwi, 2023). However, excessively high LDRs may expose banks to

liquidity risks, which can negatively impact profitability (Rachmawati, 2024; Akbar, 2023). The description of these variables has been demonstrated as in Table 2.

We use difference panel data regression techniques which are widely applied in banking studies to analyze business performance (Buallay et al., 2020; Esteban-Sanchez et al., 2017). This study tests the pooled OLS, fixed effects model (FEM), and random effects model (REM) to identify the most suitable model. The F-test compares OLS and FEM, the Breusch-Pagan Lagrange Multiplier test evaluates REM against OLS, and the Hausman test contrasts FEM with REM. To reduce model bias, additional tests include the Wald test for heteroscedasticity and robustness checks. The Feasible Generalized Least Squares (FGLS) method provides valuable insights into the determinants of bank performance by addressing econometric challenges such as heteroscedasticity and serial correlation, where traditional techniques like

Table 2
Description of variables.

Variables	Types	Definition	Sources
ROE	Dependent	<i>Return on Equity</i> The ratio of a bank's net income to its average shareholder equity.	Financial Statements of 24 banks
ROA	Dependent	<i>Return on Asset</i> The ratio of a bank's net income to its average total assets.	Financial Statements of 24 banks
NIM	Dependent	<i>Net Interest Margin</i> NIM is simply understood as the difference between the organization's net interest income and the budget that financial institution (bank) must pay. NIM signifies a financial institution's ability to generate profits from the interest it earns from credit and investment activities.	Financial Statements of 24 banks
ICT	Independent	<i>Information and communication technology index</i> ICT is a term associated with the development of information technology in the current era. It plays an important role in innovation and development in bank industry	ICT Index Report from 2011 to 2022
ITI	Independent	<i>Information technology infrastructure index</i> This index is often used to evaluate banks' competitiveness in the market, and is an important indicator in the development of online banking services and digital products.	ICT Index Report from 2011 to 2022
OP	Independent	<i>Online payment</i> This index evaluates the level of implementation of electronic payment systems by banks.	ICT Index Report from 2011 to 2022
SIZE	Bank-specific control variables	<i>Bank size</i> The aggregate assets calculated using logarithms	Financial Statements of 24 banks
CAR	Bank-specific control variables	<i>Capital Adequacy Ratio</i> This statistic is used to evaluate the capital or solvency of banks. The percentage of total assets that equity represents determines the bank's capital size.	Financial Statements of 24 banks
LDR	Bank-specific control variables	<i>Loans to Deposits Ratio</i> The ratio of loans funded by deposits	Financial Statements of 24 banks

OLS, FEM, and REM often fall short. Greene (2012) and Wooldridge (2010) highlight FGLS's ability to deliver more reliable parameter estimates in panel data analysis by mitigating these issues. To mitigate this concern of endogeneity, GMM estimation is used to increase accuracy, consistency and unbiasedness of the model. This estimation consists of Hansen test that assesses over-determined restriction and validity by analyzing the same sample under time conditions and Arellano-Bond Test that checks for existence of autocorrelation in error terms (Arellano and Bond, 1991).

3.2. Data

The dataset consists of 288 observations from 24 commercial banks between 2011 and 2022, with bank names listed in Appendix 1. Performance metrics and control variables come from annual reports and the Bankscope database. ICT data, sourced from the Vietnam ICT Index Report, is collected from the Vietnam Information Technology Association (from 2009 to 2012, published at vaip.org.vn) and the Ministry of Information and Communications (from 2013 to 2022, published at mic.gov.vn). The ICT application and development reports are comprehensive rankings covering various sectors, including ministries, localities, organizations, businesses in general, and commercial banks in particular.

The study focuses on the period from 2011 to 2022, primarily due to data availability, as ICT index data for commercial banks in Vietnam has only been consistently published since 2011. Additionally, this time-frame marks the beginning of a significant shift in the Vietnamese banking sector, during which many banks actively accelerated their digital transformation process. During the study period, a total of 49 banks were operating in Vietnam. However, this research focuses exclusively on Vietnamese commercial banks; thus, foreign banks, joint-venture banks, and policy banks were excluded from the sample. Among the 35 domestic commercial banks that operated continuously from 2011 to 2022, additional exclusions were made for banks that underwent mandatory restructuring, were placed under state control, or lacked available ICT index data. As a result, the final sample comprises 24 Vietnamese commercial banks over the period 2011–2022.

4. Results and discussions

4.1. Descriptive statistics

Table 3 summarizes the descriptive statistics of the model variables. The ROA is relatively low but exhibits moderate variability, while the ROE demonstrates significant fluctuations, suggesting potential instability in shareholder returns. Investments in ICT and ITI show considerable allocations, though with notable variability. Other variables such as OP, SIZE, CAR, and LDR exhibit varying degrees of consistency and dispersion, reflecting differences in performance and practices among institutions.

Table 4 presents the correlation matrix for the variables in the model. This matrix shows the relationships between the different variables, highlighting how they are interconnected. The correlation matrix results

Table 3
Data description.

Variable	Obs	Mean	Std. Dev	Min	Max
ROA	288	0.0096	0.0095	−0.0551	0.0538
ROE	288	0.1109	0.1083	−0.8200	0.6592
NIM	288	0.0350	0.0131	0.0057	0.0953
ICT	288	0.3950	0.2473	0	0.8114
ITI	288	0.3338	0.2447	0	0.8561
OP	288	2.05	1.5130	0	4
SIZE	288	32.4725	2.3123	0	35.2905
CAR	288	12.2769	3.8965	4.2322	24.7618
LDR	288	0.8867	0.1594	0.3633	1.4282

Table 4
Correlation matrix.

	ROA	ROE	NIM	ICT	ITI	OP	SIZE	CAR	LDR
ROA	1.0000								
ROE	0.8169	1.0000							
	0.0000								
NIM	0.5427	0.4354	1.0000						
	0.0000	0.0000							
ICT	0.0721	0.1294	0.0453	1.0000					
	0.2226	0.0281	0.4439						
ITI	0.1219	0.1962	0.0897	0.8155	1.0000				
	0.0388	0.0008	0.1290	0.0000					
OP	0.0569	0.1527	0.0741	0.6992	0.8193	1.0000			
	0.3359	0.0094	0.2101	0.0000	0.0000				
SIZE	0.1389	0.3048	0.0672	0.1463	0.1467	0.1047	1.0000		
	0.0184	0.0000	0.2554	0.0130	0.0127	0.0760			
CAR	−0.3921	−0.2204	−0.4747	0.1430	0.1640	0.1332	0.1181	1.0000	
	0.0000	0.0002	0.0000	0.0151	0.0053	0.0238	0.0453		
LDR	0.3304	0.2812	0.4810	−0.0046	0.1338	0.1734	0.0303	−0.1675	1.0000
	0.0000	0.0000	0.0000	0.9374	0.0232	0.0032	0.6090	−0.0044	

indicate that the correlation coefficients between the independent variables are all below 0.8. This suggests that the independent variables exhibit low multicollinearity, making them appropriate for inclusion in regression analysis.

4.2. Regression results and discussion

4.2.1. Discussion of OLS, FEM and REM regression results

The regression results for ROA, ROE, and NIM utilising Ordinary Least Squares (OLS), Fixed Effects Model (FEM), and Random Effects Model (REM) yield important insights regarding the influence of ICT factors. Prior to coming up with results, some model validation technique has been performed to deem a model appropriate such as VIF test for multicollinearity, Breusch-Pagan test for heteroscedasticity and Hausman test to compare between FEM and REM. In particular, the mean VIF value of 2.39 as in [Appendix 2](#) indicates a moderate correlation among the independent variables, remaining within an acceptable range, which suggests that the regression results are robust and interpretable. Moreover, Hausman test indicates that REM is favoured for the ROA and NIM models, while FEM is more suitable for the ROE model, addressing the heterogeneity and structure of the panel data. The White test indicates the presence of heteroscedasticity in the models. Thus, we applied robust standard errors to address this issue. Additionally, the Wooldridge test reveals evidence of autocorrelation, suggesting that the use of the Generalized Method of Moments (GMM) would enhance the reliability of the model estimates.

The findings demonstrate that the ICT index lacks a statistically significant impact on the principal banking performance indicators (ROA, ROE, and NIM) in the OLS, FEM, and REM models. It aligns with the research conducted by [Ho and Mallick \(2010\)](#) and [Alt et al. \(2018\)](#), which emphasised the "profitability paradox," indicating that heightened IT investment does not invariably result in prompt financial returns due to substantial implementation costs, ongoing maintenance expenses, and obstacles such as competitive pressures and cybersecurity threats. This indicates that direct expenditures in ICT may not improve profitability without supplementary elements like efficient management practices, employee training, and strategic alignment, as highlighted by [Del Gaudio et al. \(2021\)](#). These variables are crucial for maximising the advantages of ICT infrastructure to achieve quantifiable financial results in the short term.

Investment in technological infrastructure (ITI) exhibits a statistically significant beneficial impact on both ROA and ROE across multiple models. ITI positively influences ROA in both OLS and REM, as well as ROE in OLS and REM. These results corroborate the findings of [Hasan et al. \(2011\)](#) and [Wambui \(2023\)](#), who noted that properly aligned ITI investments markedly improve operational efficiency and financial

performance in banking. These findings also support the Endogenous Growth Theory ([Solow, 1956](#); [Romer, 1990](#)), which views technological advancement as a key driver of productivity and long-term economic growth. Furthermore, the results resonate with the Resource-Based View ([Barney, 1991](#)), which emphasizes that IT infrastructure, when aligned with organizational strategy and effectively managed, can serve as a unique, valuable resource that generates sustained competitive advantage. The correlation between Online Payment (OP) and ROA is negative in all models, with coefficients that are statistically significant at the 5 % level. This indicates that the heightened use of online payment systems may include short-term expenses or difficulties that affect profitability, in accordance with [Alt et al. \(2018\)](#) and [Oye \(2020\)](#), who emphasised the significant implementation costs and operational risks associated with online payment adoption.

The variable SIZE exhibits a substantial positive impact on both ROA and ROE in the OLS model, achieving significance at the 1 % level, corroborating the conclusions of [Rosalina & Nugraha \(2019\)](#) and [Teshome et al. \(2018\)](#), which indicate that larger banks gain from economies of scale. Nonetheless, its importance wanes in FEM and REM models, chiefly affecting ROE. The CAR has a negative and significant correlation with both ROA and NIM in all models, underscoring the trade-off between financial stability and profitability, as noted by [Karki \(2019\)](#) and [Balami \(2023\)](#). This indicates that elevated capital adequacy levels, although crucial for financial stability, may limit profitability. The LDR exhibits a strong, positive, and statistically significant association with all performance measures, highlighting the essential significance of effective loan utilisation in enhancing financial outcomes, in accordance with the findings of [Murtiningrum \(2024\)](#) and [Pratiwi \(2023\)](#). The estimation results of the models have been indicated in [Table 5](#).

4.2.2. Discussion of FGLS & GMM regression results

The results of the FGLS model are relatively consistent with the findings from the pooled OLS, FEM, and REM analyses. In the ROA model, ICT investment has a significant negative impact, suggesting potential costs of technology implementation on asset returns. This finding can be interpreted through the lens of the Transaction Cost Theory ([Williamson, 1981](#)), which suggests that technology, while potentially reducing long-term coordination and information costs, may initially increase internal complexity, adjustment costs, and risk exposure. ITI positively affects ROA enhancing asset efficiency. SIZE and LDR also positively impact ROA, while CAR has a significant negative effect, indicating profitability constraints from high capital reserves. For the ROE model, SIZE and LDR show significant positive effects, implying larger institutions and higher loan-to-deposit ratios yield better equity returns, while ICT, ITI, and CAR are insignificant. The variable OP does

Table 5

Estimation results for OLS, FEM, and REM models.

	OLS			FEM			REM		
	ROA	ROE	NIM	ROA	ROE	NIM	ROA	ROE	NIM
ICT	0.000787 [0.23]	−0.0148 [−0.37]	0.00355 [0.83]	0.00111 [0.37]	−0.0207 [−0.55]	0.00234 [0.72]	0.000850 [0.29]	−0.0206 [−0.55]	0.00227 [0.71]
ITI	0.00991** [2.31]	0.102** [2.03]	0.00560 [1.04]	0.00756** [2.15]	0.0691 [1.55]	0.00154 [0.40]	0.00798** [2.29]	0.0808* [1.78]	0.00194 [0.51]
OP	−0.00110** [−1.97]	−0.00344 [−0.52]	−0.000697 [−1.00]	−0.000971** [−2.05]	−0.00292 [−0.49]	−0.0000353 [−0.07]	−0.00097** [−2.08]	−0.00289 [−0.48]	−0.0000761 [−0.15]
SIZE	0.00063*** [3.01]	0.0142*** [5.74]	0.000506* [1.92]	0.000303 [1.55]	0.00500** [2.01]	0.0000526 [0.25]	0.000310 [1.61]	0.0078*** [3.25]	0.0000886 [0.42]
CAR	−0.00094*** [−7.40]	−0.00690*** [−4.59]	−0.00146*** [−9.13]	−0.000488*** [−3.39]	−0.00258 [−1.41]	0.00093*** [−5.94]	−0.00052*** [−3.82]	−0.00406** [−2.45]	−0.0009*** [−6.55]
LDR	0.0153*** [4.79]	0.141*** [3.76]	0.0334*** [8.28]	0.0190*** [6.09]	0.227*** [5.76]	0.0287*** [8.46]	0.0180*** [5.96]	0.194*** [5.12]	0.0289*** [8.68]
_cons	−0.0143* [−1.94]	−0.413*** [−4.77]	0.00501 [0.55]	−0.0121* [−1.68]	−0.230** [−2.52]	0.0179** [2.29]	−0.0105* [−1.47]	−0.279*** [−3.20]	0.0174** [2.22]

Note: ***, **, * depict the statically significance at 1 %, 5 %, 10 %, respectively, t-statistics given in parentheses.

not exhibit a statistically significant impact across all three models. These results highlight distinct effects of technology, bank size, capital structure, and loan strategies across performance metrics.

The GMM model employs 24 instruments with 216 observations, maintaining a suitable instrument-to-observation ratio. This balance confirms the appropriateness of the instrument count, ensuring robust results and addressing endogeneity issues. The Arellano-Bond test indicates significant first-order autocorrelation (AR (1)) and non-significant second-order autocorrelation (AR (2)), supporting the reliability of the instruments and GMM estimators. The J-statistic (also known as the Hansen J test) in the Generalized Method of Moments (GMM) is a test statistic used to assess the validity of the moment conditions—specifically, to determine whether the instruments are truly exogenous. The tests reported in [Appendix 6](#) yield p-values greater than 0.05, indicating no evidence against the validity of the instruments. The results from the GMM model further reinforce the findings of this study. ICT negatively impacts ROA, reflecting the costs of implementation, while ITI has a marginally significant positive effect. This result is relatively consistent with the findings from the FEM, REM, and OLS models discussed earlier. Meanwhile, both ICT and ITI contribute to improving ROE. These findings are aligned with the studies of [Hasan et al. \(2011\)](#) and [Wambui \(2023\)](#), who emphasized that properly ICT and IT infrastructure investments significantly enhance operational efficiency and financial performance in the banking sector. The variable OP demonstrates a positive impact on ROA but exhibits a negative effect on both ROE and NIM ([Table 7](#)).

In order to drill down the extent of these relationships, we also calculated the elasticity of the effects at the sample mean to better show the size of these correlations. Elasticities were calculated using $E = \beta \times (X^- / Y^-)$ based on the GMM coefficients and descriptive statistics in [Table 3](#). According to the findings, a 1 % increase in the ICT index results

in an estimated 0.47 % drop in ROA, whereas a 1 % increase in online payment (OP) and IT infrastructure (ITI) usage increases ROA by roughly 0.25 % and 0.26 %, respectively ([Table 6](#)).

5. Conclusion

5.1. Key findings

This study highlights the significant but nuanced role of ICT in enhancing the performance of Vietnamese commercial banks, with effects that vary across financial metrics. Consistent with studies such as [Wambui \(2023\)](#) and [Hasan et al. \(2011\)](#), our findings suggest that investments in ITI positively impact bank performance, particularly ROA. However, the negative impact of ICT on ROA contrasts with the broader positive findings ([Gupta et al., 2018](#); [Del Gaudio et al., 2021](#); [Pierri and Timmer, 2022](#)), which highlighted ICT's role in enhancing profitability through operational efficiency. This discrepancy could stem from differences in market maturity, suggesting that Vietnamese banks are still grappling with the high implementation and maintenance costs associated with ICT integration. The adoption of online payment systems presents a similarly complex scenario. While operational efficiencies are evident, as seen in the positive correlation with ROA, the negative effects on ROE and NIM echo the findings of [Alt et al. \(2018\)](#), who highlighted the cost burdens and competitive pressures linked to digital banking innovations. Unlike studies in more developed markets where OP systems significantly enhance customer retention and profitability, the Vietnamese banking sector may still be in a transitional phase where benefits are offset by high development costs and cybersecurity risks. All things considered, these results are consistent with various theoretical viewpoints. Both the Resource-Based View and the Endogenous Growth Theory are supported by the notable and favorable impact of ITI on ROA and ROE, which emphasizes how technical capital boosts productivity and acts as a strategic competency. On the other hand, the Transaction Cost Theory, which highlights the coordination difficulties and transitional adjustment costs that may initially balance efficiency gains, is consistent with the short-term negative or mixed effects of overall ICT and OP. The findings collectively imply that ICT affects bank performance through three complimentary but separate channels: cost-reduction dynamics, strategic resource generation, and productivity enhancement. The relative potencies of these channels vary depending on the digital maturity of each bank.

5.2. Implications

The results have significant ramifications for regulators, bank executives, and policymakers in developing nations going through digital transformation. In order to encourage ICT investment in the banking

Table 6

Estimated elasticities at the sample mean (GMM Model).

Independent Variable	Dependent Variable	Elasticity at Mean	Interpretation
ICT	ROA	−0.47	A 1 % increase in ICT index leads to a 0.47 % decrease in ROA (short-term implementation and adjustment costs).
ITI	ROA	+0.25	A 1 % increase in IT infrastructure raises ROA by 0.25 %, confirming the productivity-enhancing role of IT assets.
OP	ROA	+0.26	A 1 % increase in online payment usage raises ROA by 0.26 %, reflecting efficiency gains from digital transactions.

Table 7
FGLS and GMM regression results.

FGLS regression results				GMM regression results			
	ROA	ROE	NIM		ROA	ROE	NIM
Variables				Variables			
_cons	−0.00628 0.049	−0.210*** 0.000	0.0297*** 0.000	ROA(−1)	0.374309** 0.0458		
				ROA(−2)	−0.051088* 0.0713		
				ROE(−1)		0.472106*** 0.0000	
				NIM(−1)			0.371728*** 0.0067
ICT	−0.00287** 0.03	−0.0269 0.102	−0.00021 0.928	ICT	−0.015612*** 0.0052	0.165738*** 0.0039	0.00272 0.6900
ITI	0.00309** 0.036	0.0242 0.182	0.00102 0.688	ITI	0.007091* 0.1000	0.149385*** 0.0003	0.001083 0.8491
OP	0.0000131 0.954	0.000837 0.769	0.0000668 0.863	OP	0.001237*** 0.0009	−0.006580** 0.0352	−0.000997** 0.0472
SIZE	0.000294** 0.017	0.00734*** 0.000	0.0000707 0.713	SIZE	−0.000566 0.642	−0.000073 0.9272	0.000235 0.7347
CAR	−0.000381*** 0.000	−0.00073 0.413	−0.00105*** 0.000	CAR	−0.001786*** 0.0084	−0.002146 0.4048	0.000570* 0.0802
LDR	0.0115*** 0.000	0.0933*** 0.000	0.0162*** 0.000	LDR	0.007847 0.2478	0.225059*** 0.0000	0.050714*** 0.0000

Note: ***, **, * depict the statically significance at 1 %, 5 %, 10 %, respectively, p-value given in parentheses.

industry, governments should first concentrate on establishing an enabling environment. This entails boosting cybersecurity procedures, granting incentives for modernizing infrastructure, and clarifying regulations for online transactions. Second, public-private partnerships should promote digital financial inclusion measures to provide access to dependable internet and mobile infrastructure, especially in rural areas. Third, bank management should recognize that ICT investments alone are insufficient to improve financial performance. To achieve long-term benefits, complementary programs including consumer education, staff training, and the smart use of digital resources are essential.

Our findings align with [Owusu-Ansah et al. \(2016\)](#), who observed that techno-stress among employees limits the gains from ICT investments. As such, Vietnamese banks should invest in comprehensive training programs to equip staff with the skills to leverage ICT effectively, a recommendation supported by both domestic and international studies on the interplay between human capital and technology integration. Besides, regulatory support and policy interventions are also essential resonating with the observations of [Thalassinos et al. \(2012\)](#) and [Zhang et al. \(2022\)](#), which stress the importance of regulatory frameworks in driving successful ICT adoption. Policymakers in Vietnam should introduce financial incentives for technology adoption, enforce robust cybersecurity standards, and ensure system interoperability to facilitate seamless integration of ICT systems across banks. Furthermore, in line with [Buallay et al. \(2020\)](#) and [Rachmawati \(2024\)](#), our findings emphasize the importance of optimizing loan management practices. The positive impact of a higher LDR ratio on performance metrics underscores the need for efficient deposit utilization. However, the observed negative relationship between the CAR and profitability aligns with [Karki \(2019\)](#), highlighting the trade-offs between financial stability and operational efficiency. Vietnamese banks must strike a balance between maintaining regulatory capital requirements and pursuing profitability-enhancing strategies.

5.3. Limitations and future research

Despite being thorough, this study has certain drawbacks. First, the analysis is restricted to Vietnamese commercial banks, which would limit the findings' applicability to other financial systems or developing nations with distinct regulatory frameworks and levels of technical preparedness. Second, despite efforts to employ comprehensive indicators, data limitations prevented the capturing of some qualitative

components of ICT effectiveness, including cybersecurity readiness, digital literacy, and customer happiness. Third, the study makes use of annual data, which might not accurately represent current technical advancements or short-term variations.

Future research should build upon these findings by utilizing a more extensive dataset that includes all Vietnamese commercial banks, particularly those in the process of restructuring. This would enable a more thorough examination of risk tolerance and the overall economic effects of ICT investments. Besides, subsequent research may explore the varying effects of ICT adoption among different banking groups, considering variables such as bank size, ownership structure, and market segment. Moreover, it should also investigate the long-term impact of ICT investment on risk management and customer retention, to provide further guidance for the sector's digital transformation. Future research may even further break down ICT investment by looking at the impacts of certain technologies like block chain, mobile banking, or AI-enabled products. Assessing the findings' cross-country relevance might also be aided by comparative studies conducted among ASEAN or South Asian nations. Last but not least, adding qualitative information via case studies or executive interviews with banks may enhance comprehension of the organizational dynamics behind digital transformation.

CRedit authorship contribution statement

Nham Linh Vuong: Visualization, Validation, Project administration, Funding acquisition, Conceptualization. **Hung Manh Pham:** Supervision, Software, Methodology, Investigation, Formal analysis. **Trung Tien Le:** Writing – review & editing, Validation, Data curation. **Van Chi Nguyen:** Writing – original draft, Methodology, Formal analysis, Data curation. **Thu Hoai Thi Nguyen:** Writing – review & editing, Validation, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX*Appendix 1. List of commercial banks in the sample*

No	Commercial Bank Name	Stock codes on exchanges
1	Bank For Investment and Development of Vietnam	BID
2	Bank for Foreign Trade of Vietnam	VCB
3	Vietnam Joint Stock Commercial Bank for Industry and Trade	CTG
4	Vietnam Prosperity Joint Stock Commercial Bank	VPB
5	Kien Long Commercial Joint Stock Bank	KLB
6	Ho Chi Minh Development Joint Stock Commercial Bank	HDB
7	Military Commercial Joint Stock Bank	MBB
8	Tien Phong Commercial Joint Stock Bank	TPB
9	Sai Gon Thuong Tin Commercial Joint Stock Bank	STB
10	An Binh Commercial Joint Stock Bank	ABB
11	Saigon Commercial Joint Stock Bank	SCB
12	Vietnam Bank for Agriculture and Rural Development	ARG
13	Vietnam Commercial Joint Stock Export Import Bank	EIB
14	Nam A Commercial Joint Stock Bank	NAB
15	Ban Viet Commercial Joint Stock Bank	BVH
16	Viet Capital Commercial Joint Stock Bank	BVB
17	Saigon Hanoi Commercial Joint Stock Bank	SHB
18	Orient Commercial Joint Stock Bank	OCB
19	Vietnam Asia Commercial Joint Stock Bank	VAB
20	Vietnam International Commercial Joint Stock Bank	VIB
21	Asia Commercial Joint Stock Bank	ACB
22	Vietnam Technological and Commercial Joint Stock Bank	TCB
23	Southeast Asia Commercial Joint Stock Bank	SSB
24	Saigon Bank for Industry and Trade	SGB

Appendix 2. VIF test for multicollinearity

Variable	VIF	1/VIF
ITI	4.80	0.208503
ICT	3.16	0.315958
OP	3.13	0.319456
LDR	1.12	0.889254
CAR	1.08	0.925716
SIZE	1.04	0.964518
Mean VIF	2.39	

Appendix 3. Breusch-Pagan Lagrangian and Hausman tests

	Testing	P-value	Conclude
ROA model	Breusch-Pagan Lagrangian	0.0000	The Pooled OLS is not suitable
	Hausman	0.8669	The REM model is more suitable than the FEM model
ROE model	Breusch-Pagan Lagrangian	0.0000	The Pooled OLS is not suitable
	Hausman	0.0000	The FEM model is more suitable than the REM model
NIM model	Breusch-Pagan Lagrangian	0.0000	The Pooled OLS is not suitable
	Hausman	0.0759	The REM model is more suitable than the FEM model

Appendix 4. Arellano bond test

		m-Statistic	P-value
ROA model	AR(1)	-1.725264	0.0845
	AR(2)	0.059838	0.9523
ROE model	AR(1)	-2.377357	0.0174
	AR(2)	0.398072	0.6906
NIM model	AR(1)	-3.023309	0.0025
	AR(2)	0.340471	0.7335

Appendix 5. Testing reasonable instrument variables

	Cross-sections included	Instrument rank
ROA model	24	18
ROE model	24	21
NIM model	24	21

Appendix 6. J-statistic test

	P-value
ROA model	0.461020
ROE model	0.354942
NIM model	0.365861

Appendix 7. Details and formulas of elements of ICT factor

Elements	Indicators	Details and formulas
(i) Technical infrastructure	Server and workstation infrastructure	- Ratio of Virtual Servers/Total Servers (Physical Servers + Virtualized Servers): $\frac{\sum \text{Virtual Servers}}{\sum \text{Servers}}$ - Workstation ratio (PC/Laptop) within the last 3 years / Total workstations: $\frac{\sum \text{Workstations equipped in the last 3 years}}{\sum \text{Workstations}}$
	Communication infrastructure	- Percentage of workstations running licensed and manufacturer-supported operating systems: $\frac{\sum \text{Workstations running licensed and manufacturer – supported operating systems}}{\sum \text{Workstations}}$ - Internet Bandwidth Ratio for Internet Banking Services/Total Internet Banking Customers: $\frac{\sum \text{Internet Banking connection bandwidth}}{\sum \text{Internet Banking Customers}}$ - Percentage of Internet bandwidth provided to internal users/Total number of computers connected to the Internet: $\frac{\sum \text{Connection bandwidth for internal users}}{\sum \text{Number of computers connected to the Internet}}$ - Broadband Ratio/Total Terminals: $\frac{\sum \text{Bandwidth of a wide area network}}{\sum \text{Terminals}}$
	ATM and POS infrastructure	- ATM Ratio/Total Payment Cards: $\frac{\sum \text{Number of ATMs}}{\sum \text{Payment Cards}}$ - Chip card acceptance rate/Total number of ATMs $\frac{\sum \text{ATMs that accept chip cards}}{\sum \text{Number of ATMs}}$ - Ratio of ATMs with recharge function/ Total number of ATMs: $\frac{\sum \text{The ATM has a deposit function}}{\sum \text{Number of ATMs}}$ - Ratio (mPOS+ Wireless POS)/Total POS: $\frac{\sum \text{mPOS} + \sum \text{PWireless POS}}{\sum \text{Number of POS}}$
	Implement information security and data safety solutions	- Anti-virus software installation rate + Information security + Data safety: $\frac{\sum \text{Computer with antivirus software installed}}{\sum \text{Number of computers}}$ Information security = $(\sum \text{Affiliated units deploy firewalls}) \times 5 + \sum \text{Affiliated units deploy spam filtering software} + \sum \text{Affiliated units deploy anti-virus software} + \sum \text{Affiliated units deploy access warning software} + (\sum \text{Affiliated units deploy the solution other information security}) \times 0,5) / (\sum \text{Affiliated units})$ Data safety = $(\sum \text{Affiliated units install magnetic tape} + \sum \text{Affiliated units install disk cabinets} + (\sum \text{Affiliated units installation SAN}) \times 5 + (\sum \text{Affiliated units installation NAS}) \times 4 + (\sum \text{Affiliated units installation DAS}) \times 3 + (\sum \text{Affiliated units' installation other storage devices}) \times 0,5) / (\sum \text{Affiliated units})$
	Data centers and disaster backup centers	Data centers and disaster backup centers are built to ensure stable operations and avoid risks when an incident occurs. A data center helps banks store and manage data efficiently, while a disaster backup center helps minimize damage when something goes wrong.
(ii) Human resource infrastructure	The proportion of full-time staff in information technology	This index measures the proportion of officials in the total number of employees of the bank with expertise in information technology. This is an important indicator to ensure that the bank has enough human resources to develop and maintain information technology systems. $\frac{\sum \text{Officer in charge of IT}}{\sum \text{Staff officers}}$
	The proportion of full-time staff in charge of information security	This index measures the proportion of full-time officers in charge of information security in the total number of employees of the bank. This is an important indicator to ensure that the bank has enough

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(continued)

Elements	Indicators	Details and formulas
		manpower to protect customer information and prevent cyberattacks. $\frac{\sum \text{Officer in charge of Information security}}{\sum \text{Staff officers}}$
	The ratio of full-time information technology officers with international certificates in information technology/total number of full-time information technology officers	This index measures the proportion of full-time information technology officers with international certificates in information technology in the total number of full-time information technology officers of the bank. This is an important indicator to ensure that the bank's IT staff is qualified and professional enough to meet the needs of the job. $\frac{\sum \text{IT officers have international certificates specializing in IT}}{\sum \text{Officer in charge of IT}}$
(iii) Application of internal IT	Implement core banking	Core Banking is the bank's core financial and transaction management system, including customer account management, transfers, borrowing, payments and other financial services. This index assesses the level of implementation of the bank's Core Banking system. Formula: Total number of deployed Core bank Modules + Total number of connections to Core bank and other systems (ERP, ATM/POS, Internet Banking, SWIFT, CITAD, Reporting Systems...) + Connection methods between Core bank and other systems (1: file interface, 2: Database, 3: Message Queue, 4: ESB integration axis, 5: Other forms) + Level of automation when processing transactions between Core bank system and other systems (0: not automatic, 1: semi-automatic, 2: automatic) + Handling data reconciliation between Core Bank and other systems (0: no reconciliation, 1: manual reconciliation, 2: with partial automatic collation, 3 with full automatic collation)
	Implement basic applications	Including basic applications such as account management software, customer management software, transaction management software, risk management software, and human resource management software. This index assesses the level of implementation of basic applications of banks. Formula: Basic IT applications + 0,2 x others
	Implement electronic payments	Including online payment and mobile payment applications, helping customers make transactions quickly and conveniently. This index assesses the level of implementation of electronic payment systems of banks. Formula: Interbank electronic payment + SWIFT + Other (Bilateral payment)
(iv) Online Banking Services	The bank's website	This index measures the attractiveness and convenience of the bank's website. It can include factors such as design, page load speed, informative content, search features, and customer engagement. Formula: Total number of existing main news items (listed in the survey) + 0.2 x Total number of other news items (if any) + frequency of website updates
	Internet Banking for individual customers	This indicator measures the completeness and convenience of online banking services offered to individual customers, including functions such as viewing account balances, transfers, paying bills, opening new accounts, and managing accounts. Formula: Total number of available main items (listed in the questionnaire) + 0.1 x Total number of other items (if any)
	Internet Banking for business customers	This index measures the completeness and convenience of online banking services provided to business customers, including functions such as viewing account balances, transfers, paying bills, managing accounts, and making money delivery transactions. Formula: Total number of available main items (listed in the questionnaire) + 0.1 x Total number of other items (if any)
	Other e-banking services	This index measures the completeness and convenience of other services such as SMS Banking, Mobile Banking, online appointment booking, online financial advice and more. Formula: Total number of available main items (listed in the questionnaire) + 0.1 x Total number of other items (if any)

Appendix 8. Measurement method of ICT and component indices

Standardize data	Each T indicator, before being used to calculate the component index, will be standardized according to the Z-Score method as follows: $T^n = \frac{T - \mu}{\sigma}$ Where: ' T^n ' is a value that has been standardized by the Z-Score method of the index T, ' μ ' is the average value of the values of the indicator T, and ' σ ' is the standard deviation of the indicator T.
Calculate component indices	The component indices of indicator group j are determined according to the following formula: $T_k^j = \frac{1}{m} \sum_{i=1}^m T_i^j$ Where: m is the total number of sub-indicators in group j; T_i^j is the value of a criterion T in group j has been normalized according to Z-Score. Then the component index T is normalized according to the Min-Max method to bring it to the value range [0–1] $T^n = \frac{T - T^{\min}}{T^{\max} - T^{\min}}$ Where: ' T^n ' is the normalized value of the component index T; ' $T^{\max}$ ' and ' $T^{\min}$ ' are the maximum and minimum value of the component index T.
Calculate main index	The ICT index system of commercial banks includes technical infrastructure, human resource infrastructure, internal banking applications, and online services of banks. The research team uses the results of the indicators in the ICT Index report over the years to calculate and apply to the model. The ICT index system of commercial banks is measured and calculated independently based on statistics from the Ministry of Information and Communications. The component indicators have a reciprocal relationship, which is the basis for calculating the results of ICT indicators. The calculation formula is shown as follows (calculation formula according to the Ministry of Information and Communications): $I = (I1 + I2 + I3 + I4)$ Where: 'I1' is the technical infrastructure index, 'I2' is the human infrastructure index, 'I3' is the bank's internal application index, and 'I4' is the bank's online service index. The resulting index data are shown in the ICT Index report, calculated by researchers based on the Z-Score method.

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