

# Nonlinear Dynamics of Information and Communication Technology, Income Diversification, and Competitiveness in Emerging Banking Markets: Evidence from Vietnam

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**Abstract:** This study examines the effects of information and communication technology (ICT) adoption and income diversification (IDI) on bank competitiveness in emerging economies, with evidence from Vietnam. Both ICT and IDI serve as strategic drivers of performance, yet their joint and nonlinear impacts remain underexplored in developing financial systems undergoing digital transformation. Using a dynamic panel of 29 Vietnamese commercial banks from 2010 to 2022, the study employs the system generalized method of moments (S-GMM) estimator to address endogeneity and capture nonlinear and interaction effects. Bank competitiveness is measured by the Lerner index, with controls for bank-specific and macroeconomic factors, including the COVID-19 shock. The results indicate inverted U-shaped relationships between ICT, IDI and competitiveness, implying diminishing returns beyond optimal thresholds. The negative interaction between ICT and IDI suggests that simultaneous overinvestment may weaken competitive advantages, while macroeconomic volatility further moderates these effects. The study contributes to the literature by revealing the nonlinear and interactive mechanisms through which digital transformation and diversification jointly shape bank competitiveness in a developing economy, offering practical implications for balancing innovation and diversification strategies.

Keywords: Bank competitiveness, ICT, income diversification, nonlinear

JEL classification: C23, E44, G21, L25, O33

## 1. Introduction

In the era of digital transformation and global financial integration, information and communication technology (ICT) has emerged as a core driver of competitiveness across economic sectors, especially in banking. In Vietnam, the ICT Index serves as a benchmark for assessing financial institutions' readiness and capacity to adopt digital technologies. This composite index encompasses four dimensions: technical infrastructure, human infrastructure, internal applications and online services (Ministry of Science and Technology [MST], 2024). Beyond measuring adoption, it reflects banks' strategic alignment with digital objectives, regulatory compliance and positioning in an increasingly technology-driven financial ecosystem. Yet, despite substantial ICT

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investments, disparities persist among banks, raising questions about the true effectiveness of technological integration in sustaining competitiveness.

The rapid evolution of digital banking and fintech innovation underscores the urgency of understanding ICT's role in resilience, efficiency and profitability. The COVID-19 pandemic further amplified this need, as financial institutions globally, including those in Vietnam, faced severe operational disruptions (Elnahass et al., 2021; Xiazhi & Shabir, 2022). Banks effectively leveraging ICT demonstrated greater adaptability, customer retention and financial stability (Al-Busaidi & Al-Muharrami, 2021). However, in developing economies, structural and financial constraints continue to impede optimal ICT deployment. Given banking's central role in economic growth and capital attraction (Pham et al., 2021; Yin, 2021), identifying the determinants of digital competitiveness is crucial.

A complementary strategy increasingly adopted is income diversification, which broadens revenue sources beyond traditional lending, mitigating risk and enhancing profitability (Nguyen, 2018; Phan et al., 2022; Dao et al., 2024). Prior studies indicate ICT adoption improves efficiency (Hoque et al., 2024; Pham, 2025), while diversification strengthens stability. Nonetheless, their interaction remains underexplored, especially in emerging markets like Vietnam. Does ICT enhance the effectiveness of diversification, or does diversification facilitate better ICT utilisation? Moreover, might their relationship be nonlinear, with benefits diminishing beyond certain thresholds? Existing research often treats these dimensions separately, overlooking their combined influence on competitiveness.

To fill this gap, this study examines the nonlinear dynamics among ICT adoption, income diversification and bank competitiveness in Vietnam. Building on the resource-based view and strategic management theories, it posits that both ICT and diversification enhance competitiveness up to an optimal level, beyond which excessive expansion leads to diminishing returns. By applying advanced econometric modelling to dynamic panel data, the study provides novel insights into how digital transformation and diversification jointly shape competitive advantage in an emerging economy.

The remainder of this paper is structured as follows: Section 2 presents the theoretical framework and literature review; Section 3 details the research methodology and data sources; Section 4 discusses the analytical results; and finally, Section 5 offers conclusions and policy recommendations.

## 2. Theoretical Framework and Literature Review

Competition has long been a cornerstone of economic theory, grounded in the seminal works of Schumpeter (1942) and Smith (1904). Porter (1990) conceptualised competitiveness as the sustained ability of firms to maintain market position, generate superior value and achieve growth in dynamic environments. Competitiveness extends beyond efficiency toward innovation, adaptability and strategic differentiation, dimensions that are increasingly critical in the digital transformation era.

In emerging economies such as Vietnam, where banks serve as key intermediaries for growth and stability, assessing competitiveness is essential. Among various measures, the Lerner index (Lerner, 1934) remains a robust tool to gauge market power by quantifying price markups over marginal costs. Its methodological simplicity and

empirical validity make it well-suited to evaluate bank performance under intensified competition and digital integration (Claessens & Laeven, 2004; Demsetz, 1973; Mohapatra et al., 2023). Studies such as Pham et al. (2021) and Phuong et al. (2024) validated its relevance for Vietnamese banking, emphasising three advantages: (i) direct measurement of market power; (ii) ease of computation relative to indicators such as Boone (2008); and (iii) adaptability for integration with big data analytics for real-time insights (Zhu et al., 2021; Dilla et al., 2024).

The digital transformation era, particularly following the COVID-19 crisis, redefines ICT from a supportive tool into a strategic enabler of competitiveness. ICT enhances efficiency, service quality and transparency (Pham, 2025), shaping how banks respond to market volatility. Empirical evidence confirms ICT's transformative impact: Wu et al. (2023) found that fintech-driven ICT improvements significantly enhance efficiency and profitability in China, while Hoque et al. (2024) reported similar outcomes in Vietnam through improved risk management and reduced information asymmetry. Alzghoul and Al-kasasbeh (2024) and Weerawarna et al. (2023) further demonstrated that AI and blockchain adoption optimise transactions, mitigate risks and reduce dependence on external service providers.

Parallel to technological advancement, income diversification (IDI) emerges as a complementary strategy that strengthens resilience and competitiveness. Rooted in the resource-based view (Barney, 1991) and strategic management theory (Grant, 1996; Porter, 1985), diversification enables banks to leverage internal resources, capabilities and market knowledge to generate multiple revenue streams and reduce exposure to sector-specific shocks. Empirical studies support this perspective: Dhanora et al. (2018) link innovation and diversification to improved competitiveness, while Phan et al. (2022) confirmed their positive influence on Vietnamese bank performance. Boufounou et al. (2022) also noted that the pandemic accelerates digitalisation, creating new opportunities for diversification and customer engagement.

However, diversification introduces complexity and potential risk. Calmès and Théoret (2015) and Mehmood and De Luca (2023) showed that non-interest income can elevate credit risk, although it mitigates lending contractions during shocks (Abedifar et al., 2018; Dang & Dang, 2021). Ho et al. (2023) demonstrated that diversified institutions exhibit greater resilience during the pandemic – an insight particularly relevant to Vietnam's banking system.

Despite clear benefits, both ICT and diversification face challenges such as cybersecurity risks, cost escalation and integration inefficiencies (Pham, 2025; Weerawarna et al., 2023; Wu et al., 2023). Existing research rarely examines their joint and nonlinear effects on competitiveness. Drawing on the marginal cost-benefit framework (Pindyck & Rubinfeld, 2018; Varian, 1992) and technology adoption lifecycle theory (Moore, 2006; Rogers, 2003), this study posits that both ICT and diversification enhance competitiveness up to an optimal level, beyond which excessive expansion leads to diminishing returns due to complexity and resource misallocation.

Accordingly, this study proposes three hypotheses:

*Hypothesis H1:* Grounded in the marginal cost-benefit theory (Pindyck & Rubinfeld, 2018; Varian, 1992) and the technology adoption lifecycle theory (Moore, 2006; Rogers, 2003), ICT investment is expected to exhibit an inverted U-shaped relation-

ship with bank competitiveness. Moderate ICT adoption enhances efficiency and market expansion, whereas excessive investment reduces returns due to rising maintenance costs, cybersecurity risks and organisational complexity.

*Hypothesis H2:* Anchored in the resource-based view (Barney, 1991) and strategic management theory (Grant, 1996; Porter, 1985), income diversification is hypothesised to demonstrate an inverted U-shaped relationship with bank competitiveness. Moderate diversification enhances stability and resilience by leveraging internal capabilities, while excessive diversification increases managerial complexity and risk exposure, thereby weakening overall performance.

*Hypothesis H3:* ICT is hypothesised to moderate the relationship between income diversification and bank competitiveness. Advanced digital capabilities and data-driven analytics strengthen the profitability and risk control of non-interest income activities, whereas weak technological integration limits these synergistic effects (Brynjolfsson & Hitt, 2000; Porter, 1985).

By modelling these nonlinear and interactive dynamics, this study advances the literature beyond linear efficiency-based frameworks, providing a holistic understanding of how digital transformation and diversification jointly influence competitiveness in emerging banking markets such as Vietnam.

### 3. Data and Research Methodology

#### 3.1 Data

This study utilises an unbalanced panel dataset comprising 29 Vietnamese commercial banks over the period 2010–2022. The data are obtained from the audited annual reports of individual banks, the Vietnam Banking Almanac, and the General Statistics Office of Vietnam (GSO), complemented by the ICT database published by the Vietnam Association of Information and Communication Technology (MST, 2024). All variables were winsorized at the 1st and 99th percentiles to mitigate the influence of outliers. Figure 1 provides a summary of the dataset used in this study.

#### 3.2 Description of Variables

##### 3.2.1 Dependent Variable

Bank competitiveness is proxied by the Lerner index, calculated as the difference between output price and marginal cost divided by output price (Lerner, 1934). This measure reflects market power and is widely used in empirical studies on banking competitiveness (Claessens & Laeven, 2004; Pham et al., 2021; Phuong et al., 2024). The LERNER index is determined as the ratio of the difference between output price and marginal cost relative to the output price, as expressed in the following formula:

$$\text{LERNER}_{it} = (P_{it} - MC_{it})/P_{it} \quad (1)$$

where  $P_{it}$  is the output price, calculated as the ratio of a bank's total income to its total assets.  $MC_{it}$ , the marginal cost, is derived using a two-step procedure (Kasman & Carvallo, 2014).

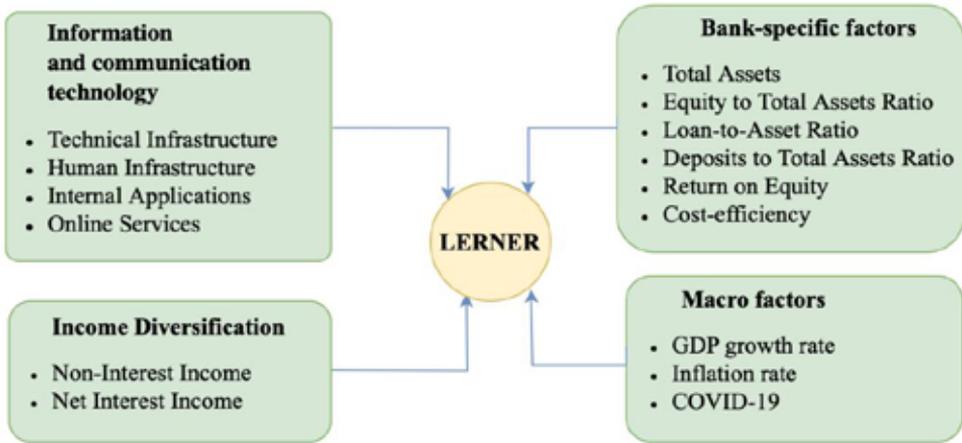


Figure 1. Overview of the research dataset

*Step 1: Natural logarithm of the total cost function*

The natural logarithm of the total cost function is specified as follows:

$$\begin{aligned} \text{Ln}(TC_{it}) = & \alpha_0 + \alpha_1 \text{Ln}Q_{it} + (1/2) \alpha_2 (\text{Ln}Q_{it})^2 + \alpha_3 \text{Ln}W_{1it} + \alpha_4 \text{Ln}W_{2it} + \alpha_5 \text{Ln}W_{3it} + \\ & \alpha_6 \text{Ln}Q_{it} \text{Ln}W_{1it} + \alpha_7 \text{Ln}Q_{it} \text{Ln}W_{2it} + \alpha_8 \text{Ln}Q_{it} \text{Ln}W_{3it} + \alpha_9 \text{Ln}W_{1it} \text{Ln}W_{2it} + \\ & \alpha_{10} \text{Ln}W_{1it} \text{Ln}W_{3it} + \alpha_{11} \text{Ln}W_{2it} \text{Ln}W_{3it} + (1/2) \alpha_{12} ([\text{Ln}W_{1it}])^2 + \\ & (1/2) \alpha_{13} [\text{Ln}W_{2it}]^2 + (1/2) \alpha_{14} [\text{Ln}W_{3it}]^2 + \alpha_{15} T + (1/2) \alpha_{16} T^2 + \\ & (1/2) \alpha_{17} T \text{Ln}Q_{it} + \alpha_{18} T \text{Ln}W_{1it} + \alpha_{19} T \text{Ln}W_{2it} + \alpha_{20} T \text{Ln}W_{3it} + \varepsilon \end{aligned} \tag{2}$$

where TC represents total cost, encompassing interest and non-interest expenses. Q denotes total assets.  $W_1$ ,  $W_2$ , and  $W_3$  are the prices of three input factors. In which,  $W_1$ : Cost of deposits, calculated as interest expenses divided by total loans;  $W_2$ : Labour cost, determined as salary expenses divided by total assets;  $W_3$ : Cost of physical capital, calculated as other operating expenses divided by fixed assets. T captures the time trend to account for the impact of technological advancements on the production function over time.  $T = 1$  for 2010,  $T = 2$  for 2011, ..., and  $T = 13$  for 2022.  $\varepsilon$  is the random error term.  $\alpha_1, \alpha_2, \dots, \alpha_{20}$  are the estimated parameters.

*Step 2: First-order derivative of equation (2)*

The first-order derivative of the total cost function, derived from Equation (2), is expressed in a simplified form as follows:

$$MC = \frac{dTC}{dQ} = \left( \frac{\alpha_1 + \alpha_2 \text{Ln}Q_{it} + \alpha_6 \text{Ln}W_{it1} + \alpha_7 \text{Ln}W_{it2} + \alpha_8 \text{Ln}W_{it3} + \alpha_{17} T}{Q_{it}} \right) * TC \tag{3}$$

3.2.2 Key Independent Variables

The income diversification index (IDI) measures the degree of income balance between interest and non-interest activities. Following Stiroh (2004), Stiroh and Rumble (2006), and recent extensions by Abuzayed et al. (2018) and Khattak et al. (2023), IDI

is computed as a normalised measure of income mix between traditional and non-traditional banking activities.

$$IDI = 1 - \left[ \left( \frac{NET}{NII} \right)^2 + \left( \frac{NON}{NII} \right)^2 \right] \quad (4)$$

where *NON* represents non-interest income; *NET* represents net interest income, and *NII* is the total income, defined as  $NII = NON + NET$ . A higher IDI indicates greater diversification between traditional and non-traditional income sources.

The *ICT Index* measures the readiness of a bank to invest in the application of information and communication technology. ICT index is measured using a composite ICT index constructed from four normalised sub-dimensions: (i) technical infrastructure, (ii) human infrastructure, (iii) internal applications, and (iv) digital services. Each sub-index is standardised using z-scores and aggregated with equal weighting following MST (2024). This composite index reflects a bank's readiness and capacity for digital transformation.

### 3.2.3 Control Variables

Control variables capture both bank-specific and macroeconomic factors that may influence competitiveness. Including these variables ensures that the estimated effects of ICT adoption and income diversification are not confounded by structural or contextual differences across banks and over time.

*Bank-specific factors (BANK)* reflect heterogeneity in capital structure, operational efficiency, and financial performance.

*Bank size (SIZE)*, measured as the natural logarithm of total assets, reflects economies of scale and market influence. Larger banks can leverage cost advantages and brand recognition to enhance competitiveness, although excessive size may reduce flexibility and innovation (Berger & Hannan, 1998).

*Equity-to-total assets ratio (ETA)* represents capital adequacy and risk absorption capacity. Higher equity strengthens solvency and stability but may constrain risk-taking, potentially reducing market power (Berger et al., 1995).

*Loan-to-total assets ratio (LTA)* indicates lending intensity. A higher LTA suggests a stronger focus on core intermediation activities, which can improve profitability and reinforce competitive positioning (Boyd & De Nicoló, 2005).

*Deposit-to-total assets ratio (DTA)* measures funding stability. Banks with a higher DTA can access low-cost deposits, enhancing pricing flexibility and competitiveness in credit markets (Claessens & Laeven, 2004).

*Return on equity (ROE)* captures profitability and managerial effectiveness. Higher ROE reflects efficient resource utilisation and signals superior competitive performance.

*Growth of total assets (GTA)* measures expansion capacity. Moderate asset growth supports market penetration, while excessive expansion may increase operational risk and dilute strategic focus.

*Cost-to-income ratio (CTI)* proxies cost efficiency, a critical determinant of competitiveness. Lower CTI values indicate superior cost control and operational productivity, strengthening market power (Lepetit et al., 2008).

*Macroeconomic factors (MACRO)* account for external conditions that shape the banking environment.

*GDP growth rate (GDP)* serves as a key indicator of economic activity, influencing credit demand, profitability and competition. Higher GDP growth enhances market opportunities but may also intensify competition among banks.

*Inflation rate (INF)* affects pricing behaviour and interest rate spreads. Moderate inflation can improve margins through flexible rate adjustments, while excessive inflation erodes real profitability and stability.

*COVID-19 dummy variable (COVID)* equals 1 for 2020–2022 and 0 otherwise, capturing the structural disruptions caused by the pandemic. COVID-19 accelerates digital transformation and modifies customer behaviour, forcing banks to adapt strategically. Its inclusion controls for exogenous shocks that influence competitiveness during crisis periods.

Collectively, these control variables provide a comprehensive representation of both internal and external determinants of bank competitiveness. Their inclusion enhances model precision, mitigates omitted-variable bias, and allows for a more accurate estimation of the nonlinear and interactive effects of ICT and income diversification.

### 3.3 Model Specification

Building on prior research on the determinants of bank competitiveness (Berger et al., 2009; Das & Pati, 2024; Dilla et al., 2024; Kasman & Carvalho, 2014; Yin, 2021), this study integrates both macroeconomic and bank-specific factors to comprehensively assess their effects on banking competitiveness. The model adopts a structured and theoretically grounded framework to analyse the interplay between technological readiness, income diversification, institutional characteristics and macroeconomic dynamics. This approach provides empirical evidence on the mechanisms shaping competitive performance in the banking sector.

The general functional form of the regression model is expressed as:

$$\text{LERNER}_{it} = \alpha_0 + \alpha_1 \text{ICT}_{it} + \alpha_2 \text{IDI}_{it} + \alpha_3 \text{BANK}_{it} + \alpha_4 \text{MACRO}_t + \alpha_5 \text{COVID}_t + e_{it} \quad (5)$$

where LERNER measures bank competitiveness (ranging from 0 to 1), ICT denotes technological readiness, IDI represents income diversification, BANK includes bank-specific characteristics (size, efficiency, equity and performance), MACRO captures GDP growth and inflation, and COVID is a dummy for pandemic years (1 during 2020–2022, 0 otherwise).

This study aims to provide a comprehensive assessment of the role of ICT and IDI in shaping the competitiveness of commercial banks. By incorporating a nonlinear analytical framework, this study explores these relationships under different economic conditions, particularly in the pre- and post-COVID-19 context. The proposed regression models are developed based on the initial research objectives.

#### *Model 1: Nonlinear relationship between ICT and banking competitiveness*

Recognising the potential threshold effects, this model explores the nonlinear impact of ICT on banking competitiveness. A quadratic formulation is employed to capture diminishing or amplifying returns of ICT development:

$$\text{LERNER}_{it} = \alpha_0 + \alpha_1 \text{ICT}_{it} + \alpha_2 (\text{ICT}_{it})^2 + \alpha_3 \text{IDI}_{it} + \alpha_4 \text{BANK}_{it} + \alpha_5 \text{MACRO}_t + \alpha_6 \text{COVID}_t + e_{it} \quad (6)$$

*Model 2: Nonlinear relationship between income diversification and banking competitiveness*

This model extends the nonlinear analysis by examining how income diversification affects banking competitiveness. A squared term for IDI is introduced to detect any potential diminishing or increasing returns:

$$\text{LERNER}_{it} = \alpha_0 + \alpha_1 \text{ICT}_{it} + \alpha_2 \text{IDI}_{it} + \alpha_3 (\text{IDI}_{it})^2 + \alpha_4 \text{BANK}_{it} + \alpha_5 \text{MACRO}_t + \alpha_6 \text{COVID}_t + e_{it} \quad (7)$$

*Model 3: Interactive effects of ICT and income diversification on banking competitiveness*

To capture the synergistic or antagonistic effects between ICT and income diversification, this model incorporates an interaction term. This allows for an investigation into whether the combined effects of ICT and IDI produce amplified or mitigated impacts on banking competitiveness:

$$\text{LERNER}_{it} = \alpha_0 + \alpha_1 \text{ICT}_{it} + \alpha_2 \text{IDI}_{it} + \alpha_3 (\text{ICT}_{it} * \text{IDI}_{it}) + \alpha_4 \text{BANK}_{it} + \alpha_5 \text{MACRO}_t + \alpha_6 \text{COVID}_t + e_{it} \quad (8)$$

### 3.4 Estimation Method

To ensure robust and unbiased estimation of the nonlinear and interaction effects between ICT, IDI and LERNER, this study employs a dynamic panel approach using the system generalized method of moments (S-GMM), as proposed by Arellano and Bover (1995). This estimator is particularly suited for short T and large N panels, effectively addressing endogeneity, simultaneity bias, measurement errors and unobserved heterogeneity by using internal instruments derived from lagged explanatory variables.

The endogeneity concern arises because variables such as ICT, IDI and ROE may be jointly determined with LERNER index. Accordingly, these variables are treated as endogenous, while SIZE, LTA, DTA, CTI and macroeconomic factors are considered pre-determined or exogenous. The model employs lagged levels of endogenous regressors as instruments for their first-differenced equations, and lagged differences as instruments for the level equations, following the framework of Blundell and Bond (1998).

The instrument matrix is collapsed to mitigate instrument proliferation and avoid overfitting, ensuring that the total number of instruments (18) remains below the number of cross-sectional units (29), consistent with Roodman (2009). To minimise potential correlation between instruments and error terms, lags of two periods or more (t-2 and earlier) are selected as valid instruments. This specification ensures the orthogonality of instruments and improves model efficiency.

The nonlinear relationships are captured through quadratic and interaction terms, allowing the estimation of inverted U-shaped dynamics between ICT, IDI and competitiveness, as well as the moderating role of ICT in the diversification-competitiveness nexus.

Several diagnostic tests are conducted to validate model reliability. The Hansen test confirms the validity of instruments ( $p > 0.10$ ), and the Arellano-Bond AR(2) test rejects the presence of second-order autocorrelation, satisfying key assumptions of the dynamic panel model. The Durbin-Wu-Hausman test identifies ETA and INF as endogenous, validating the need for the S-GMM specification, while the variance inflation factor (VIF) indicates no multicollinearity (mean VIF < 10).

By integrating these rigorous econometric procedures, this study provides a statistically sound and methodologically robust framework for examining the nonlinear and interactive effects of digital transformation and income diversification on bank competitiveness in Vietnam’s emerging financial market.

#### 4. Research Findings and Discussions

##### 4.1 Preliminary Data Analysis

The descriptive statistical analysis conducted on a dataset comprising 282 observations from 29 Vietnamese commercial banks (2010–2022) yielded the results in Table 1.

According to the results from the descriptive statistics in Table 1, the mean LERNER index (0.167) suggests a moderate level of market power among the sampled banks, though variations exist (std. dev. = 0.086). The average ICT adoption level (0.528) indicates significant digital integration, but its wide range (0.253–0.828) highlights disparities in technological investment. Similarly, IDI exhibits a mean of 0.423, suggesting a relatively high degree of income diversification, though caution is warranted due to its upper bound of 0.500. The capital adequacy ratio (ETA) remains moderate at 0.086, aligning with regulatory capital requirements. Meanwhile, cost-to-income ratio (CTI) is notably high (0.864), signaling potential inefficiencies in cost management. Macroeconomic indicators show stable conditions, with GDP growth averaging 0.060 and inflation at 0.063, reinforcing a generally stable economic environment. The high mean of the COVID-19 variable (0.372) captures the substantial presence of the pandemic’s impact across the observation period.

**Table 1.** Descriptive statistics

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
LERNER	282	0.167	0.086	-0.080	0.466
IDI	282	0.423	0.075	0.095	0.500
ICT	282	0.528	0.115	0.253	0.828
SIZE	282	18.936	1.232	15.923	21.475
ETA	282	0.086	0.037	0.026	0.255
LTA	282	0.590	0.106	0.339	0.788
DTA	282	0.662	0.120	0.292	0.912
CTI	282	0.864	0.090	0.538	0.998
GTA	282	0.194	0.205	-0.373	1.470
ROE	282	0.115	0.075	0.001	0.303
GDP	282	0.060	0.017	0.022	0.080
INF	282	0.063	0.102	-0.017	0.423
COVID	282	0.372	0.484	0.000	1.000

*Note:* This table presents the descriptive statistics for all variables included in the analysis. Detailed definitions and measurements of the variables are provided in Section 3.2.

**Table 2.** Correlation matrix

	LERNER	IDI	ICT	SIZE	ETA	LTA	DTA	CTI	GTA	ROE	GDP	INF	COVID
LERNER	1.000												
IDI	0.355	1.000											
ICT	0.270	0.136	1.000										
SIZE	0.239	0.174	0.202	1.000									
ETA	0.353	0.205	0.009	-0.548	1.000								
LTA	0.082	0.236	0.003	0.490	-0.201	1.000							
DTA	-0.167	-0.057	-0.156	0.372	-0.395	0.580	1.000						
CTI	-0.816	-0.527	-0.260	-0.251	-0.311	-0.013	0.335	1.000					
GTA	0.072	-0.000	0.164	-0.194	0.163	-0.313	-0.392	-0.153	1.000				
ROE	0.643	0.497	0.244	0.462	-0.017	0.176	-0.191	-0.809	0.111	1.000			
GDP	-0.055	0.034	-0.046	-0.079	-0.002	0.009	0.013	0.084	-0.025	-0.084	1.000		
INF	0.189	-0.065	0.259	-0.268	0.250	-0.233	-0.402	-0.087	0.495	0.087	0.085	1.000	
COVID	0.203	0.082	0.067	0.300	-0.087	0.238	0.043	-0.361	-0.144	0.340	-0.411	-0.285	1.000

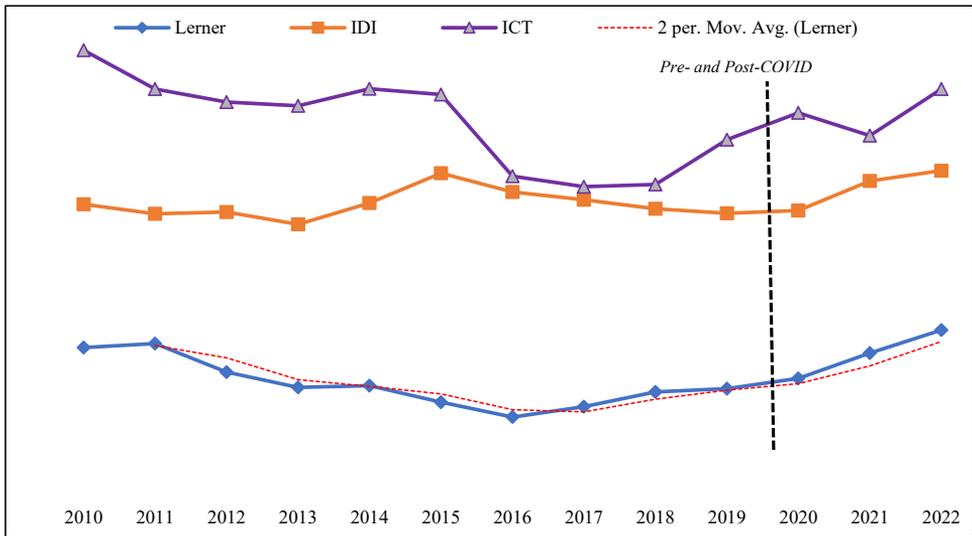
*Note:* This table presents the correlation coefficients among all variables. Values below 0.7 indicate low multicollinearity. Variable definitions are provided in Section 3.2.

The correlation matrix in Table 2 illustrates the relationships among key variables in the empirical model. A strong negative correlation ( $r > -0.8$ ) between the cost-to-income ratio (CTI) and the Lerner index indicates an inverse relationship, implying that greater cost efficiency is associated with lower market power. This pattern highlights a potential trade-off between operational efficiency and competitive behavior within the banking sector. In contrast, the remaining correlation coefficients range between 0 and 0.7, reflecting weak to moderate associations that capture the complex interdependencies shaping bank performance and market structure. Overall, since most correlation values fall below the conventional threshold of 0.7, multicollinearity is minimal and unlikely to bias the regression estimates in subsequent models.

Figure 2 depicts the data trends of key variables, IDI, ICT and LERNER, throughout the study period. The figure reveals a decline in the competitiveness of Vietnamese commercial banks from 2011 to 2016, followed by a steady rise between 2016 and 2022. Notably, competitiveness improved markedly during the post-COVID-19 period (2020–2022) compared to earlier years. The analysis also shows that banks intensified ICT investments and income diversification between 2010 and 2015, but both indicators declined from 2015 to 2018 before rebounding with the onset of COVID-19. These strategic adjustments significantly enhanced sectoral competitiveness, underscoring the dynamic evolution of Vietnam's banking industry and the pivotal role of digital transformation and income diversification in sustaining long-term advantage.

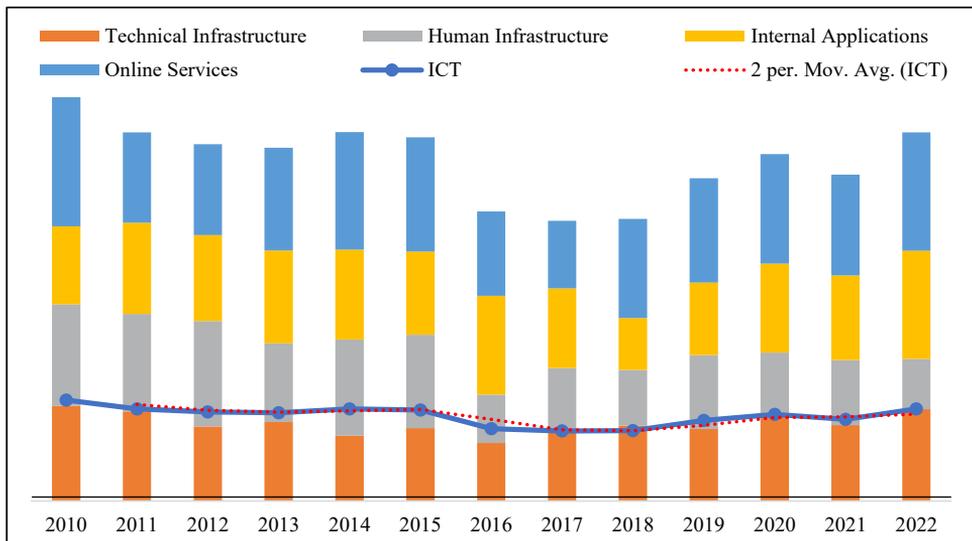
From 2010 to 2022, substantial shifts were observed across four ICT components, technical infrastructure, human resource infrastructure, internal applications and online services, reflecting the transformative integration of technology into Vietnamese banking operations. The detailed trends of these components are illustrated in Figure 3, which summarises their respective development trajectories over the study period.

Specifically, the analysis presented in Figure 3 reveals that investment in online services has increasingly taken precedence, indicating a substantial rise in the deployment



**Figure 2.** IDI, ICT and LERNER trends

*Note:* This figure shows the evolution of bank competitiveness indicators and ICT adoption in Vietnamese banks from 2010 to 2022, highlighting shifts in market power, efficiency and technological progress.



**Figure 3.** ICT investment trends and its components

*Note:* This figure illustrates the evolution of ICT and its components – technical, human, internal and online infrastructure – in Vietnamese banks from 2010 to 2022, with a two-period moving average indicating the overall trend.

of digital banking platforms, online payment systems and financial technology applications. This trend underscores the rapid adaptation of banks to the digital transformation era, aimed at optimising customer experiences and enhancing operational efficiency. Conversely, the level of investment in human resource infrastructure has shown a declining trend during the same period, reflecting a strategic shift from workforce development toward automation and process optimisation through technology.

While reduced investment in human resources might raise concerns regarding the potential shortage of high-quality personnel, it simultaneously highlights the strategic leveraging of digital tools to replace traditional processes. These shifts affirm that Vietnamese commercial banks are prioritising ICT applications as a strategic enabler in the face of intensifying global competition. The focus on online service investment not only improves operational efficiency but also strengthens the banks' capability to meet the evolving demands of customers in the digital era.

#### 4.2 Model Diagnostic Tests

To ensure the validity and reliability of the estimated regression model, a series of rigorous diagnostic tests were conducted, evaluating key econometric assumptions. The analysis assesses multicollinearity, model fit, autocorrelation, heteroskedasticity and endogeneity, critical factors that influence the robustness of the findings. The results confirm the absence of multicollinearity and heteroskedasticity, while the model fit is statistically significant. However, the presence of first-order autocorrelation and endogeneity in specific variables necessitates the adoption of an advanced estimation technique. The detailed results of the diagnostic tests are presented in Table 3.

**Table 3.** Diagnostic test results

Test	Testing method	Result	Discussion
<i>Multi-collinearity</i>	mean vif	<i>Mean vif = 2.36</i>	Since the mean VIF is 2.36, which is below the threshold of 10, there is no indication of multicollinearity in the research model.
<i>Model fit</i>	F-test	<i>Prob &gt; F = 0.000</i>	The model is statistically significant, suggesting that the specified regression model is a good fit for the data
<i>Auto-correlation</i>	Wooldridge test	<i>Prob &gt; F = 0.152</i>	The Wooldridge test reveals a p-value of 0.152, suggesting the presence of first-order autocorrelation in the model.
<i>Heteroskedasticity</i>	Breusch and Pagan test	<i>Prob &gt; chibar2 = 0.000</i>	The Breusch and Pagan test reports a p-value of 0.000, which indicates that heteroskedasticity is not present in the model.
<i>Endogeneity</i>	Durbin–Wu–Hausman test	<i>ETA (p = 0.0400) INF (p = 0.0004)</i>	The variables ETA and INF are identified as endogenous.

*Note:* This table reports the diagnostic tests assessing model validity. The results indicate no evidence of multicollinearity and confirm overall model significance. Although the Wooldridge test suggests mild autocorrelation, the model remains robust. Heteroskedasticity is not detected, while the Durbin–Wu–Hausman test identifies ETA and INF as endogenous variables.

The results indicate the presence of endogeneity in the research model, specifically with the variables ETA and INF, as identified through the Durbin–Wu–Hausman test. To address this issue and ensure robustness and reliability of the regression method, the study employs the S.GMM approach, as proposed by Arellano and Bover (1995).

4.3 Results and Discussion

To examine the effects of ICT adoption and income diversification on bank competitiveness, the study employs advanced regression techniques using the LERNER index as the primary measure of market power. The estimation results, reported in Table 4, provide comprehensive evidence on how digital transformation and diversification strategies jointly influence the competitive performance of Vietnamese commercial banks.

To ensure the robustness and validity of the estimation results, a series of diagnostic tests were rigorously conducted. The Arellano-Bond AR(2) test confirms the absence of second-order autocorrelation across all three models, as the test statistics exceed the 10% threshold, thereby affirming the appropriateness of the dynamic system GMM (S.GMM) specification. Additionally, the Sargan and Hansen tests yield p-values consistently above 10%, substantiating the validity of the instrumental

Table 4. System GMM estimation results

Variables	Model 1	Model 2	Model 3
LERNER_lag	0.465**	0.665***	0.325***
ICT	0.309*	0.018	0.606*
IDI	-0.110***	0.653*	0.756**
ICT <sup>2</sup>	-0.266*		
IDI <sup>2</sup>		-1.046**	
ICT x IDI			-1.460**
SIZE	-0.020*	-0.019**	-0.022*
ETA	-1.312**	-1.125**	-0.045
LTA	0.113*	0.154***	0.030
DTA	0.023	0.041	0.165**
ROE	-0.218*	-0.268***	0.072
GTA	-0.121**	0.045	-0.056***
CTI	-1.081***	-0.974***	-0.732**
GDP	-0.444***	-0.208**	-0.073
INF	0.257**	-0.237	0.284*
COVID	-0.060***	-0.030***	0.003
AR(2)	0.917	0.816	0.312
Sargan test	0.952	0.389	0.889
Hansen test	0.854	0.136	0.844

Note: This table presents the S-GMM estimation results. Robust standard errors are in parentheses. The description for all variables is provided in Section 3.2. \*, \*\*, \*\*\* denote statistical significance at the 10%, 5%, and 1% levels, respectively.

variables and confirming that overidentification restrictions remain unviolated. These diagnostic outcomes collectively reinforce the methodological soundness of the econometric framework, ensuring that the estimation results are both statistically reliable and robust. Furthermore, the number of instrumental variables (18) remains well below the number of observation groups (29), aligning with best practices for S.GMM estimation.

The regression results in Table 4 derived from the three S.GMM models (Model 1, Model 2, Model 3) provide critical insights into the nonlinear interactions between ICT, IDI and LERNER. These findings bear significant strategic implications for banks seeking to optimise market power through digitalisation and diversification.

*Nonlinear effects of ICT investment on bank competitiveness.* The regression results strongly support Hypothesis H1, confirming an inverted U-shaped relationship between ICT investment and competitiveness. The positive coefficient of ICT (0.3093,  $p < 0.1$ ), followed by the negative squared term  $ICT^2 = -0.2662$  ( $p < 0.1$ ), demonstrates that ICT enhances competitiveness up to an optimal threshold, beyond which returns diminish. This finding accords with the marginal cost–benefit theory (Varian, 1992; Pindyck & Rubinfeld, 2018), which posits that while early ICT investments improve efficiency and facilitate market expansion, excessive expenditure leads to higher maintenance costs, cybersecurity vulnerabilities and organisational rigidity. Hence, the nonlinear model highlights that *strategic ICT deployment*, rather than investment magnitude, is critical for sustaining competitiveness in an increasingly digitalised banking environment.

*Nonlinear effects of income diversification on bank competitiveness.* The results validate Hypothesis H2, confirming an inverted U-shaped relationship between income diversification (IDI) and bank competitiveness. The positive coefficient of IDI, followed by the negative and significant coefficient of its squared term ( $IDI^2 = -1.046$ ), indicates that moderate diversification enhances competitiveness, whereas excessive diversification diminishes it. This finding aligns with the resource-based view (Barney, 1991; Grant, 1996) and the economies of scope theory (Panzar & Willig, 1981), which posit that banks can leverage diversified income streams to exploit existing capabilities and spread operational costs. However, beyond the optimal level, diversification introduces managerial complexity, weakens strategic focus, and increases exposure to operational and regulatory risks. The nonlinear specification thus demonstrates that controlled diversification strengthens efficiency and resilience, while excessive expansion leads to strategic dilution and reduced competitive advantage.

*Interaction between ICT and IDI: A moderating effect on competitiveness.* Contrary to Hypothesis H3, the results show that the interaction between ICT and IDI exerts a negative and significant impact on competitiveness ( $ICT \times IDI = -1.4603$ ,  $p < 0.05$ ). This finding implies that excessive ICT investment can dampen the positive effects of income diversification. According to the technology adoption lifecycle theory (Moore, 2006; Rogers, 2003), technological benefits follow an S-curve, where initial gains plateau and overinvestment yields diminishing returns. Although digital platforms and AI-based analytics can enhance non-interest income activities (Brynjolfsson & Hitt, 2000; Porter, 1985), the associated costs, integration challenges and operational complexities may offset these gains. Hence, ICT does not uniformly amplify diversification benefits; instead, banks must strategically align technology adoption with diversification objec-

tives. This reinforces the notion that digital transformation should be integrated with financial strategy design, ensuring that innovation complements rather than substitutes diversified business models.

The estimated quadratic terms for both ICT and IDI confirm significant nonlinear effects on bank competitiveness. Based on the coefficients from Models 2 and 3, the turning points are computed as 0.58 for ICT and 0.31 for IDI, indicating the optimal levels at which competitiveness peaks before diminishing returns occur. These findings suggest that moderate ICT adoption enhances competitiveness through efficiency and innovation, whereas excessive investment may generate technological inefficiencies and inflated operational costs. Similarly, income diversification improves stability up to a balanced threshold ( $IDI \approx 0.31$ ), beyond which complexity and risk offset its benefits. From a policy perspective, these thresholds imply that banks should pursue measured digital transformation and balanced income diversification aligned with their absorptive capacity and regulatory frameworks. Overexpansion in either domain may reduce competitiveness, emphasising the need for strategically paced innovation and diversification within Vietnam's evolving banking landscape.

*The relationship between bank-specific characteristics and competitive power.* Bank size (SIZE) exhibits a negative effect, suggesting that larger banks may face intensified competitive pressures and diminishing pricing power, in line with the efficiency-structure hypothesis (Berger & Hannan, 1998). Similarly, *capital adequacy (ETA)* exerts a significant negative influence, reinforcing the notion that higher equity levels reduce risk-taking incentives and may constrain profit-maximising behaviour (Berger et al. 1995). Conversely, *loan intensity (LTA)* positively affects market power, indicating that a higher loan-to-asset ratio enables banks to sustain better interest margins and strengthen their competitive stance, consistent with the risk-return tradeoff (Boyd & De Nicoló 2005). The role of *deposit intensity (DTA)* appears inconclusive across models, except in Model 4, where its positive effect suggests that a stable funding base can enhance market positioning under certain conditions. Meanwhile, *profitability (ROE)* and *cost efficiency (CTI)* both exhibit strong negative impacts, highlighting that excessive cost burdens and diminishing returns can erode competitive advantages (Lepetit et al. 2008). Finally, *asset growth (GTA)* demonstrates mixed effects, reflecting the intricate balance between expansion strategies and market dominance. These findings reinforce the critical interplay between capital structure, lending strategies and operational efficiency in shaping bank competitiveness, aligning with existing literature on financial market dynamics. They underscore the imperative for banks to adopt strategic capital allocation and cost management frameworks to sustain long-term market power in an increasingly competitive landscape.

*Macroeconomic factors and the impact of COVID-19 on bank market power.* The empirical results highlight the significant influence of macroeconomic conditions on bank competitiveness. The negative relationship between GDP growth and the Lerner index (Model 2,  $-0.4440$ ,  $p < 0.01$ ) suggests that economic expansion intensifies competition, thereby constraining banks' market power. Conversely, the positive and significant coefficient of inflation ( $0.2568$ ,  $p < 0.05$ ) indicates that inflationary pressures may allow banks to adjust lending rates and pricing strategies, enhancing profit margins under rising cost environments. To further elucidate the role of the COVID-19 dummy

variable, the estimated coefficients are interpreted as evidence of structural changes between the pre- and post-pandemic periods.

Synthesising these findings, it is evident that the impact of ICT and IDI on bank competitiveness is highly nonlinear and context dependent. While income diversification enhances competitiveness under controlled conditions, excessive reliance on ICT without strategic alignment can offset potential gains. Vietnamese banks must adopt an integrated approach that balances digital transformation with diversification, ensuring that technological investments are harmonised with operational strategies. Future research should further investigate the macroeconomic and regulatory determinants shaping these dynamics, providing deeper insights into the evolving competitive landscape of the banking sector.

## 5. Conclusion

This study empirically investigates the impact of information and communication technology (ICT) and income diversification strategies (IDI) on bank competitiveness, as measured by the LERNER index. The findings underscore the pivotal role of ICT and IDI in shaping market power dynamics, with notable nonlinear and interactive effects.

The regression results indicate a positive and significant influence of ICT on the LERNER index, suggesting that technological advancements contribute to enhanced market power and efficiency. However, the negative coefficient of ICT squared ( $ICT^2$ ) highlights a diminishing marginal return, implying that excessive reliance on ICT without complementary strategies may erode competitive advantages. Similarly, IDI demonstrates a significant yet complex impact, wherein moderate diversification enhances bank competitiveness, but excessive diversification ( $IDI^2$ ) leads to inefficiencies and risk dilution. Notably, the interaction term between ICT and IDI is negative and statistically significant, indicating that while both factors independently bolster competitiveness, their simultaneous implementation may introduce operational frictions or diminishing synergies.

The empirical findings of this study provide several important policy insights for regulators and banking practitioners seeking to strengthen competitiveness in Vietnam's evolving financial landscape. First, the results suggest that digital transformation remains a critical driver of bank competitiveness; however, its benefits follow a nonlinear trajectory. Moderate levels of ICT investment enhance operational efficiency and innovation, but excessive digital expansion can lead to diminishing returns due to cost escalation, technological redundancy and rising cyber risks. Therefore, policymakers should encourage targeted and capacity-aligned ICT investments, prioritising infrastructure quality and cybersecurity resilience rather than indiscriminate technological spending.

Second, the study underscores the pivotal role of income diversification as a strategic complement to digitalisation. The post-pandemic period revealed that banks leveraging diversified income streams were better positioned to withstand market disruptions and revenue volatility. Accordingly, regulators should promote frameworks that support balanced diversification, such as prudential guidelines encouraging non-interest income generation through digital platforms, while maintaining effective risk oversight to avoid excessive exposure to non-traditional activities.

Third, the interplay between ICT and income diversification highlights the necessity of an integrated strategic approach. Banks should not pursue digitalisation and diversification in isolation but rather coordinate both within a unified competitiveness framework. For instance, leveraging ICT to enhance data analytics, product personalisation and customer segmentation can amplify the profitability of diversified income portfolios. Policymakers, in turn, should facilitate this integration by fostering digital ecosystems that connect banks, fintechs, and regulatory bodies through standardised digital infrastructures and open banking frameworks.

Finally, as macroeconomic conditions and market structures evolve, regulators must continue refining oversight mechanisms to maintain financial stability amid rapid technological advancement. Adaptive policies should balance innovation and prudence, ensuring that digital transformation enhances – not undermines, systemic resilience. Collectively, these policy directions emphasise the need for strategically paced digitalisation, risk-aware diversification, and coordinated regulation, forming the foundation for a more competitive and sustainable banking system in Vietnam.

This study is subject to several limitations that warrant consideration. Its geographic focus on Vietnam may constrain the generalisability of results across heterogeneous financial systems. Macroeconomic uncertainties and structural shocks, such as global crises, pandemics and climate risks, are only partially captured, limiting long-term predictive precision. The exclusive reliance on quantitative methods also omits qualitative dimensions, including managerial behaviour and institutional culture. Moreover, the disruptive potential of emerging technologies (e.g., AI, blockchain, decentralised finance) remains underexplored. Future research should integrate multi-market data, combine quantitative and qualitative approaches, and develop adaptive policy frameworks to strengthen banking resilience and competitiveness in an increasingly digital global economy.

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