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DIGITALISATION AND BANK EFFICIENCY: EVIDENCE FROM AN EMERGING MARKET

Tu Le[1,2,3]*, Thanh Ngo[4,5], Dat T Nguyen[1,2], Tin H Ho[1,2] and Thuong TM Do[1,2]

[1]*Faculty of Banking and Finance, University of Economics and Law, Ho Chi Minh City, 700000, Vietnam*
[2]*Vietnam National University, Ho Chi Minh City, 700000, Vietnam*
[3]*International Centre for Economic Analysis (ICEA), Ontario, N2L 3G1, Canada*
[4]*School of Aviation, Massey University, Palmerston, 4442, New Zealand*
[5]*University of Economics and Business, Vietnam National University, Hanoi, 100000, Vietnam*

*Corresponding author: tuldq@uel.edu.vn

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ABSTRACT

This study empirically assesses the impact of digitalisation on bank efficiency in Vietnam using the two-stage framework for an unabalanced sample of 27 banks from 2010 to 2019. In the first stage, we use the conventional data envelopment analysis (DEA) to estimate bank efficiency scores. Then, these efficiency scores are regressed on environmental variables to determine factors affecting bank efficiency. The findings show a negative relationship between digitalisation and bank efficiency. However, the results indicate a U-shaped relationship between digitalisation and bank efficiency, being first impeded and then facilitated. Foreign-owned and state-owned banks are more efficient than their domestic and privately owned peers. Our results, however, show that the impact of digitalisation on bank efficiency does not vary among bank ownership and listing status. Furthermore, bank efficiency is negatively affected by bank size. The results further demonstrate that large banks with higher levels of digitalisation may not be beneficial, at least in the short run. Nonetheless, our study provides additional evidence to the extant literature on the association between digitalisation and bank efficiency. Our empirical evidence also offers motivations for banks to pursue ongoing digitalisation strategies when the banking system environment is more intensively competitive.

Keywords: Digitalisation, Bank efficiency, Data envelopment analysis (DEA), Two-stage framework, Vietnam

INTRODUCTION

The banking sector, a critical component of the financial industry, plays a crucial role in any economy, especially in developing countries (Allen & Carletti, 2009; Levine, 2005). Therefore, the efficiency of the banking system has attracted much attention from academics and policymakers. A growing number of studies examine different aspects of banking efficiency (Bhatia et al., 2018; Boubaker et al., 2022), especially its determinants (Aiello & Bonanno, 2018; Ho et al., 2021; Sharma et al., 2013). Given the development of digital finance (Allen et al., 2021; Cornelli et al., 2023), this put more pressure on conventional banking systems to speed up their digital transformation further (Bernini et al., 2022; Ekinci, 2021; Nguyen, Ho, & Nguyen, 2023).

Regarding the effect of digital transformation, earlier studies examining the relationship between ICT investments (e.g., pure infrastructures and telecommunication) and IT-based services (e.g., electronic banking applications and automated teller machines (ATM) and bank performance show confounding results (Arora & Arora, 2013; Beccalli, 2007; Berger & DeYoung, 2006; Chedrawi et al., 2019; Ciciretti et al., 2009; Shaikh & Anwar, 2023). Given the emergence of fintech services, others focusing on the effect of fintech adoption as one of the strategies for the digitalisation process also indicate mixed findings. One argued that digitalisation/fintech adoption enhances bank profitability (Bian et al., 2024; Nguyen, Ho, & Nguyen, 2023; Theiri & Hadoussa, 2024) and reduces bank risk-taking (He et al., 2023). In contrast, others pointed out opposite findings (Guo et al., 2022). Furthermore, several studies suggest that the effect of digitalisation on bank performance exists up to a certain threshold of digitalisation endowment (Ben Ali, 2022; Xiang & Jiang, 2023). Such disagreement on this link inspires us to answer the following questions:

Question 1: What is the impact of digitalisation on bank efficiency?

Question 2: What is a nonlinear relationship for digitalisation-bank efficiency nexus?

Vietnam was positioned as the 17th fastest-growing economy in the world, with an average economic growth of 6.58% throughout 2010–2019 (World Bank, 2021). This nation thus is considered the emerging dragon in the

Asia Pacific. Since the financial system is still developing, the Vietnamese banking sector plays a crucial role in the economy since it contributes approximately 16%–18% towards annual economic growth (Stewart et al., 2016). Thus, the Vietnamese authorities focus more on bank efficiency since the positive relationship between bank efficiency and economic growth is documented by Belke et al. (2016) and Diallo (2018). Since it entered the World Trade Organization (WTO) in 2007, the structure of the Vietnamese banking system has become diverse (Le, 2021). The market is primarily dominated by state-owned commercial banks (SOCBs) and privately owned commercial banks (POCBs). Due to deregulation and liberalisation, those banks are market-oriented, although SOCBs are still the leading lenders of state-owned enterprises. Their equity ownership is mainly distributed among state, private and foreign investors. Additionally, the Vietnamese financial market has witnessed the increasing penetration of fintech firms since 2006 due to their virtual operations and several recent promotion incentives implemented by the Vietnamese authorities (Le, Ngo, et al., 2024). In response, one of the strategies that commercial banks have developed is digitalisation. This strategy is in line with the Vietnamese government's initiatives, especially under Decision No. 291/2006/QD-TTg and Decision No. 2545/QD-TTg on a cashless payment plan (The Vietnamese Government, 2006; 2016). Accordingly, the State Bank of Vietnam (SBV) encouraged Vietnamese banks to break through, develop infrastructure, and apply advanced information technology to design and supply banking products and services, with the main focus on internet and mobile banking. Indeed, the total number of cashless transactions in 2020 increased by 53.87% compared to the year 2018. In which the transaction channel that accounted for the highest growth in 2020 was mobile banking (314.74%), followed by QR code (66.92%), ATM (47.70%), internet banking (46.11%), and point of sale (42.22%) as compared to the year 2018 (Le & Bui, 2024). Two primary factors can explain this. First, Vietnamese consumers are more willing to adopt digital banking services than those in other countries in the Asia-Pacific region (e.g., New Zealand, Australia, Malaysia or Singapore) (Fair Isaac Corporation [FICO], 2021). Second, SBV also reported that most Vietnamese banks have mapped out developing digitalisation transformation strategies, and 39% of them have integrated the second phase of digital transformation into their business activities (Ministry of Information and Communications [MIC], 2021). However, the degree of digitalisation may vary among bank ownership and bank sizes (Nguyen,

Ho, & Nguyen, 2023). As such, Vietnam offers a unique case in which to examine the effect of digitalisation on bank efficiency. Therefore, this study can offer insights for the authorities and bank managers in promoting the digitalisation process in Vietnam and similar banking structures in other emerging markets.

The present study contributes to the literature in several ways. First, a number of studies that have examined the relationship between digitalisation and bank performance (e.g., bank profitability and bank risk-taking) in different regions show confounding results. Whether or not the findings on these markets reflect the actual effect of digitalisation and bank performance in emerging markets like Vietnam remains questionable because of substantial differences in the regulatory schemes and the level and quality of banking products and services existing in institutional quality. Because bank performance refers to the efficiency with which a bank operates (Tan, 2014), in this study, these terms are interchangeably used. Nonetheless, this study will provide additional evidence on whether digitalisation may improve or hamper bank efficiency in emerging markets in the Asia-Pacific. Second, a limited number of studies have examined the nonlinear relationship between digitalisation and bank profitability (Xiang & Jiang, 2023) or bank stability (Ben Ali, 2022), where a dependent variable is measured by financial ratios such as returns on assets or bank Z-scores. However, these accounting ratios suffer limitations since these single measures cannot capture the comprehensive reality of banking operations in which multiple inputs and outputs interact and have trade-offs (Nguyen et al., 2014). We extend to the existing literature in this matter by adding evidence on whether there is a nonlinear association between digitalisation and bank efficiency using the conventional two-stage framework of data envelopment analysis (DEA). DEA overcomes the disadvantages of accounting ratios by providing information on the relative efficiency of banks compared to best-practice (fully efficient) ones (Zhu, 2003). Third, few studies in Vietnam looked at the effect of digitalisation on bank performance (Nguyen, Ho, & Nguyen, 2023) or bank efficiency (Le, Ngo, et al., 2022; Ngo & Le, 2022) but failed to capture the existence of a nonlinear relationship for the digitalisation-bank efficiency nexus. This study also attempts to fill this gap. We also test whether the relationship between digitalisation and bank efficiency may depend on bank ownership (SOCB vs. POCB, listed vs. unlisted, foreign-owned vs. domestic). This article can provide a better understanding of

the digitalisation process, which will be necessary for bank managers and policymakers in terms of strengthening the resilience of the Vietnamese banking system.

Using an unbalanced dataset of 27 Vietnamese commercial banks from 2010 to 2019, this study shows a U-shaped relationship between digitalisation and bank efficiency. More specifically, digitalisation first reduces bank efficiency in the short run. However, digitalisation promotes bank efficiency in the long run. This finding supports the suggestion of Xiang and Jiang (2023), who found a nonlinear association between digitalisation and bank profitability in China. Also, bank efficiency in Vietnam is affected by bank ownership types (e.g., foreign and state ownership) and bank size.

LITERATURE REVIEW

Digitalisation and Bank Performance

Digitalisation is considered a crucial force reshaping the banking sector by utilising advanced technologies and information in banks' operations and increasing consumers' engagement based on digital data (Rodrigues et al., 2022; Scholz, 2017). More specifically, banks have shifted towards online and digitalised services by investing more in software, mobile and internet banking solutions, and fintech adoption. Therefore, embracing advanced digitalisation requires banks to rehabilitate distribution models, operating procedures (e.g., sales and services), human resource management policies, and training programmes (Forcadell et al., 2020). The literature on bank digitalisation can be divided into two main strands, including outside- and inside-bank digital transformation (Khattak et al., 2023). The first strand considers the effect of outside-bank digital transformation because non-banking institutions and the emergence of fintech and bigtech firms provide similar services, but digital. Most studies focus on examining whether bank performance is affected by fintech firm growth (Katsiampa et al., 2022; Lee et al., 2021; Li et al., 2017; Phan et al., 2020; Yudaruddin, 2023) and digital finance such as fintech and bigtech credit (De Roure et al., 2021; Le & Nguyen, 2021; Nguyen, Tran, & Ho, 2021; Wu et al., 2020; Zhang et al., 2019) and economy digitalisation such as information communication technology (ICT) access and usage (Ben Ali, 2022; Ekinci, 2021). This study comprehensively concentrates on the

second strand, where inside-bank digitalisation involves banks' adoption of advanced innovation. In this sense, digitalisation is a systematic and radical reformulation of all factors within banking organisations, including operational processes, organisational activities and staff competencies. In other words, digitalisation may encompass different perspectives. From a consumer standpoint, digitalisation may account for the enhancement of electronic banking services and products. From a bank standpoint, digitalisation may consider the improvement of ICT, fintech adoption, and the use of advanced technology to facilitate these digital services. Hence, any research using these terms is relevant to our study.

Le and Ngo (2020) and Ngo and Le (2022) demonstrated two research directions in this strand. Most studies on the relationship between digitalisation and bank efficiency have attempted to test two hypotheses, including information technology (IT) productivity paradox and IT strategic opportunity. As per the productivity paradox hypothesis (so-called Solow productivity paradox), digitalisation does not necessarily improve firm efficiency/performance (Capello et al., 2022; Haynes, 1990; Strassmann, 1990). This hypothesis has been tested in many research in different fields, especially the banking system (Ayadi et al., 2025; Beccalli, 2007; Markus & Soh, 1993; Nguyen, Ho, & Nguyen, 2023). More importantly, it is highlighted that such paradoxical issue is linked to an uneven and concentrated distribution of productivity gains (e.g., due to rent-seeking behaviours of firms [Brynjolfsson et al., 2019]), the presence of implementation lags (e.g., due to the decreasing marginal returns effect [Capello et al., 2022]), mismeasurement (Cardarelli & Lusinyan, 2015), and the compensation/allocation mechanism (Camagni et al., 2022). In contrast, the IT strategic opportunity hypothesis argues that digitalisation is seen as an opportunity for banks to achieve their strategic goals, such as cost savings or quality and earnings improvement (De Bandt & Davis, 2000).

Several studies investigating the effect of technology investments (e.g., pure infrastructure and technological development capacity) on bank performance show mixed results. Technological progress is found to mitigate bank costs or agency costs (Berger & DeYoung, 2006), enhance profit productivity (Berger, 2003), and reduce bad management practices (Simper et al., 2019). However, others indicate opposite findings. Although internet-based banks have low operating costs, they face low profits and core deposits (DeYoung,

2001). Similarly, others show a weak association between IT investment and enhanced bank efficiency or profitability (Beccalli, 2007) or no relationship between them (Martín-Oliver & Salas-Fumás, 2008).

The findings are also mixed regarding the evidence outside the US and Europe. Most studies support the favourable effect of IT investments, such as Dinçer and Yüksel (2020) in Asia, Salim et al. (2010) in Australia, and Appiahene et al. (2019) in Ghana. In contrast, Arora and Arora (2013), using Indian data, suggested that IT investment increases operating profits and profits per employee but not return on assets. Similarly, Le, Ngo, et al. (2022) argued that bank efficiency in Vietnam is positively associated with IT infrastructure and human-related IT investment indices, while negatively related to the IT application index.

The second direction examines the impact of ICT-based services and applications on bank performance. Consistent evidence highlighted that bank performance is positively affected by electronic banking services (Ciciretti et al., 2009; Hernando & Nieto, 2007; Weigelt & Sarkar, 2012), ATM (Holden & El-Bannany, 2004), or a combination of them (Valverde & Humphrey, 2009). Such findings are documented in single markets such as Lebanon (Chedrawi et al., 2019), Bangladesh (Siddik et al., 2016), and cross-country (Akhisar et al., 2015; Le & Ngo, 2020). Confounding findings, however, are sometimes indicated in several studies, such as DeYoung (2001) in the US and Sathye and Sathye (2017) in India. Given the rapid development of fintech innovation in the financial sector, recent research explored the relationship between adopting fintech innovation and bank performance and risk management (Dwivedi et al., 2021). One may argue that fintech development/capabilities reduce bank profitability and asset quality but improve management efficiency (Zhao et al., 2022). Others also suggest that fintech adoption or digitalisation is beneficial for banks by helping them assess borrowers' creditworthiness efficiently (Hu et al., 2022), thus increasing their profitability (Nguyen, Ho, & Nguyen, 2023; Singh et al., 2021). However, the positive effect of fintech adoption on bank performance and risk management may vary with the degree of the bank's use of technological innovation (Wang et al., 2021). Hence, the first hypothesis is constructed as follows:

H1: There is no significant impact of digitalisation on bank efficiency.

A Nonlinear Relationship Between Digitalisation and Bank Performance

Prior studies argue a complex and nonlinear relationship between digitalisation and firm performance. At the business process level, digitalisation allows firms to optimise and automate processes, thus enhancing efficiency and responsiveness to market dynamics. Firms, however, have faced several challenges. Digitalisation requires substantial investment in resources (e.g., capital, technology and experts) to operate and maintain the systems. Ultimately, this may cause resource allocation imbalances, thus hampering firm performance. From a product and service perspective, leveraging technological advancements such as artificial intelligence and big data analytics helps firms gain better insights into consumers' needs, thus increasing individualised offers and competitive capability. Once digitalisation competition becomes intensive, this requires ongoing investment in research and development and marketing, thus escalating costs and potentially outweighing market returns. Disrupting the balance between inputs and returns may reduce firm performance (Chen et al., 2024). Few studies in banking show a U-shaped association between digitalisation and bank stability (Ben Ali, 2022) or bank performance (Xiang & Jiang, 2023). However, studies in other fields suggest an inverted U-shaped relationship between digitalisation and firm performance (Chen et al., 2024). All in all, our second hypothesis is formed as follows:

H2: There is a nonlinear relationship between digitalisation and bank efficiency.

The disagreement on the effect of digitalisation on bank performance and efficiency is still ongoing. Adding new evidence to the literature, especially from emerging markets in Asia such as Vietnam, where the banking sector witnessed the substantial digitalisation process, is crucial. The possible reason for such inconclusive findings may be the use of different measures of bank digitalisation and bank performance. We, therefore, use the actual expenses of banks' investing in technology and software facilitating their digitalisation process instead of using the ICT index for Vietnamese banks as used in Le, Ngo, et al. (2022) and Ngo and Le (2022) and bank efficiency derived from DEA as a dependent variable instead using the conventional measures bank profitability in emerging markets (e.g., return on assets, return on equity)

(Nguyen, Ho, & Nguyen, 2023; Theiri & Hadoussa, 2024; Xiang & Jiang, 2023). This allows us to test whether a nonlinear relationship exists between digitalisation and bank efficiency.

METHODOLOGY AND DATA

The First Stage: Estimating Bank Efficiency Using Data Envelopment Analysis

The literature suggests no consensus on the best approach for estimating banks' efficiency scores (Berger et al., 1993; Drake & Hall, 2003). Of the two most common approaches (DEA vs. stochastic frontier analysis [SFA]), DEA is the preferred technique in our study because of several reasons. First, input prices of data are required in the specification of a cost function in SFA, especially the input prices. However, the information on the number of employees was often missing, affecting the estimate of labour price as inputs. This, thus, reduces the accuracy of the SFA measurement (Hammami et al., 2022). Second, DEA is more suitable for small sample sizes, while SFA generally requires a large dataset to produce a better analysis (Evanoff & Israilevich, 1991). This is more relevant to our case. Third, SFA may suffer from the issue of functional form dependence, especially due to the great diversity of business mix among Vietnamese commercial banks. Mester (1997) argues that the failure to account for bank heterogeneity can compute bank efficiency incorrectly. In contrast, the assumption that banks included in the sample have similar unknown production technology is not required in DEA (Drake & Hall, 2003; Paradi & Zhu, 2013). Given input and output specifications, DEA only requires the correspondence between inputs and outputs to estimate relative efficiency scores. Last, SFA may suffer the problem of random error. The use of any distributional assumptions without basis is considered entirely arbitrary (Bauer et al., 1998), leading to significant errors in calculating individual firms' efficiencies in the particular sample. DEA, however, assumes no random error, meaning that all deviations from the determined efficient frontier are considered technical inefficiencies (Avkiran, 1999; Resti, 1997). Nonetheless, the literature demonstrates that DEA has become a popular method to measure firm efficiency in various fields (Emrouznejad & Yang, 2018; Liu et al., 2013).

The efficiency of a bank [so-called Decision-Making Unit (DMU)] is calculated by its ability to utilise inputs to produce outputs. A DMU is considered the most efficient if it either uses the least inputs to generate a given set of outputs (input-oriented), or generates the most outputs from a given set of inputs (output-oriented). As Ngo and Le (2019) and Le et al. (2021) emphasise that it would be easier for a bank to control its inputs rather than outputs in an increasingly competitive condition, an input-oriented DEA model is employed in our study.

Based on the constant-returns-to-scale model proposed by Charnes et al. (1978) for a set of DMUs ($j = 1, \cdots, n$) each using s inputs $x_i (i = 1, \cdots, s)$ to produce m outputs $y_r (r = 1, \cdots, m)$, Banker et al. (1984) introduced the variable-returns-to-scale (VRS) DEA model to compute the efficiency score of the DMU as:

$$EF_{j_0} = \max_{u,v,u_0} \sum_{r=1}^{m} u_r y_{rj_0} - u_0$$

Subject to

$$\begin{aligned} &\textstyle\sum_i^s v_i x_{ij_0} = 1, \forall_{i,j} \\ &\textstyle\sum_r^m u_r y_{rj_0} - u_0 - \sum_i^s v_i x_{ij_0} \leq 0, \forall_{i,r,j} \\ &u_r, v_i \geq \varepsilon, \forall_i, r \\ &u_0 \text{ is unconstrained in sign} \end{aligned} \tag{1}$$

Where u and v are the weights or shadow prices of the outputs and inputs, respectively.

The literature on bank efficiency suggests that the bank can be treated as an intermediary, a production, or a profit-making unit (Avkiran, 2011; Sealey & Lindley, 1977). Following the suggestion of Allen and Gale (2004) and Levine (2005), and among others, we treat banks as intermediaries between depositors and borrowers because it is the primary function of commercial banks. This is consistent with the role of banks as written into law – as indicated in Chapter 2, Article 1 of Decree No. 49/2000/ND-CP (SBV, 2000). Accordingly, banks utilise two inputs (the volume of interest and non-interest expenses) to produce two outputs (the volume of interest and non-interest incomes). Such input and output selection is typical in the literature on banking efficiency (Avkiran, 1999; Hammami et al., 2022;

Sathye, 2003). The inputs and outputs are measured in billion Vietnamese Dong (VND), as presented in Table 1. Given the sample size of 27 banks, a 2 × 2 set of inputs and outputs utilised in our study is comparable with DEA literature. Avkiran (1999) demonstrates that the product of inputs and outputs used for analysis should be smaller than the sample size to discriminate between DMUs.

TABLE 1
Descriptive statistics of the data used in the first stage-DEA

Year	Number of banks	Inputs		Outputs	
		X1[1]	X2[1]	Y1[1]	Y2[1]
2010	23	6,922.9	2,153.5	10,267.6	1,062.7
2011	24	11,106.3	2,994.2	16,071.7	1,257.1
2012	24	9,846.3	2,925.7	14,440.0	1,247.1
2013	26	8,444.4	3,095.3	12,721.7	1,483.8
2014	27	7,888.8	3,319.7	12,380.0	1,775.8
2015	26	8,166.0	3,983.4	13,874.6	1,940.9
2016	27	9,678.1	3,794.9	16,088.2	2,312.4
2017	27	11,769.4	4,454.6	19,612.5	3,274.2
2018	27	13,331.3	6,251.3	22,453.8	4,092.3
2019	27	15,319.1	7,278.4	26,398.5	4,883.6
2010–2019	258[2]	10,247.3[3]	4,025.1[3]	16,430.9[3]	2,333.0[3]

Notes: [1]in billion Vietnamese Dong; [2]the total number of banks over the examined period; [3]the average value of the input and output; X1 and X2 represent the volume of interest and non-interest expenses as inputs, respectively; Y1 and Y2 represent the volume of interest and non-interest incomes as outputs, respectively.

The Second Stage: Investigating the Determinants of Bank Efficiency

Once the efficiency scores are estimated, their determinants are examined in the second stage. In this step, we focus on the effect of digitalisation on bank efficiency. Such second-stage framework is widely used in a bulk of prior studies using either the Ordinary Least Square/system generalised method of moments, Tobit, and truncated regressions (Adesina, 2019; Garza-García, 2012; Mai et al., 2023; Nguyen, Le, & Ngo, 2025; Shi et al., 2017; Simar & Wilson, 2007). However, several authors argue the Tobit and truncated regressions are more often used than others since they consider censored/

truncated properties of the DEA efficiency scores that are bounded between the (0, 1) intervals (Dao et al., 2021; Delis & Papanikolaou, 2009; Du et al., 2018; Eyceyurt Batir et al., 2017; Fernandes et al., 2018; Ngo & Tsui, 2020). Our study, thus, uses truncated regression approaches to enhance the robustness of the analysis. Following Ngo and Le (2022), we apply a bootstrap technique of Algorithm #1 proposed by Simar and Wilson (2007) to increase the reliability of the findings since this procedure can reduce biases incurred due to the association between exogenous regressors and other inputs and outputs of the banks. The results of using Tobit regression are also reported for robustness checks.

Our regression mode is formed as follows:

$$EF_i = \alpha_0 + \alpha_1 DIGI_i + \alpha_2 SQDIGI_i + \alpha_3 Z_i + \varepsilon \quad (2)$$

Where EF_i is the efficiency of bank derived from Equation (1); Z_i is a set of banks's characteristics; and ε is random errors.

Bank digitalisation is measured by either constructing an index using wording (Nguyen, Nguyen, et al., 2023), a technological gap derived from the stochastic meta-frontier (Forcadell et al., 2020), and ICT index/ investments (Le, Ngo et al., 2022; Ngo & Le, 2022). In contrast, we follow Nguyen, Ho and Nguyen (2023) to use the amount of money invested in the digitalisation phase. *DIGI* is the amount of money that a bank *i* invests in technology and software (including conventional ICT and fintech adoption) for digitalisation progress. To capture the possible nonlinear relationship between digitalisation and bank efficiency, we follow Xiang and Jiang (2023) to include *SQDIGI* as a quadratic term of digitalisation expenses in the model.

It is crucial to note that several control variables are included to consider the determinants of bank efficiency. Following prior studies, we consider foreign ownership (*FOR*), state ownership (*SOCB*), listing status (*LIST*), bank size (*SIZE*) and credit risk (*LLP*). *FOR* is an actual percentage of foreign ownership over the capital of a domestic bank (Le, 2021). As a strategic partner, local banks may receive advanced technology, high managerial skills and a broader range of financial services and products from foreign counterparts, thus enhancing their performance (Tacneng, 2015; Weill, 2003). However, Naaborg and Lensink (2008) found the opposite findings. Foreign-owned banks may face more severe information asymmetry issues due to the cultural differences between foreign and domestic shareholders.

Chan et al. (2015) documented no significant relationship between foreign ownership and bank efficiency. Additionally, *SOCB* is a dummy variable that equals 1 for a state-owned commercial bank, and 0 otherwise (Doan et al., 2018). Several studies found a positive effect of state ownership on bank efficiency (Gardener et al., 2011; See & He, 2015). In contrast, opposite findings are documented by Berger et al. (2009) and Lin and Zhang (2009) in China, and Yang and Liu (2012) in Taiwan. *LISTED* is a dummy variable that equals 1 for a listed bank, and 0 otherwise (Le, Ho, et al., 2024). Listing in the stock market may have influenced bank performance (Köhler, 2015; Umar & Sun, 2018). Jiang and Yao (2017) emphasise that listed banks tend to outperform non-listed peers due to their higher asset quality (Luo, 2003). Other studies, however, exhibit insufficient evidence that listed banks have better performance than non-listed ones (García-Herrero et al., 2009). *SIZE* is the natural logarithm of total assets (Ho et al., 2021; Yuen et al., 2022). The structure conduct performance paradigm posits that bank size can improve bank efficiency due to economies of scale. Several studies found that smaller banks are less efficient than larger ones (Stewart et al., 2016; Sufian, 2009). Sun and Chang (2011), however, showed that bank efficiency is negatively affected by size. Too large banks could be a disadvantage because of bureaucracy and other management drawbacks, such as diminishing personal relationships with customers (Berger & Humphrey, 1991; Nguyen & Nghiem, 2015). Others even claim inclusive evidence of a relationship between them (Arora, 2014; Sathye & Sathye, 2017). *LLP* is the ratio of loan loss provisions to total loans (Berger & DeYoung, 1997; Le, 2018). The bad management hypothesis postulates that inadequate loan monitoring can lower bank efficiency. Additionally, an increased credit risk under the bad luck hypothesis incurs additional managerial effort and expenses for banks to address these problem loans, thus increasing bank inefficiency. A number of studies document a negative relationship between credit risk and bank efficiency (Bonin et al., 2005; Kwan & Eisenbeis, 1997; Sathye & Sathye, 2017). Others, however, show confounding evidence (Altunbas et al., 2007; Stewart et al., 2016).

Data

This data was primarily extracted from two sources. Information on digitalisation expenditures was comprehensively collected from the State Bank of Vietnam. Additionally, information on input and output variables and other environmental factors were gathered from the Vietnamese banking

database constructed by Le, Ho, et al. (2022), which includes 44 banks (e.g., domestic and foreign banks) from 2002 to 2021. It is worth noting that foreign bank branches, joint-venture and wholly foreign banks were excluded from our analysis since their financial information was substantially missing and their operating activities in the Vietnamese market are relatively limited (Le, 2017). This exclusion is crucial to ensure the homogeneity of the sample when calculating relative bank efficiency using the conventional DEA. After matching two databases, this arrived at an unbalanced sample of 27 domestic banks at maximum. Our sample includes four SOCBs with above 50% of charter capital sponsored by the SBV and 23 POCB. In 2019, the Vietnamese banking system consisted of 4 SOCBs, namely 1 social policy bank, 1 development bank, 31 POCBs, 2 joint venture banks, 9 wholly foreign-owned banks, 51 foreign bank branches and 1 cooperative bank. Given the critical roles of commercial banks in the Vietnamese economy as our primary focus, the sample represents about 84.38% of commercial banks in the system. Four SOCBs own the most significant assets among commercial banks, accounting for more than 42% of the total assets of the whole banking system (SBV, 2019). The list of banks used in our analysis is presented in the Appendix.

The period 2010–2019 for our analysis was selected for two primary reasons. First, the exclusion of the COVID-19 pandemic allows us to examine the pure effect of digitalisation on bank efficiency in general. The unprecedented COVID-19 turmoil has substantially affected the banking systems' operation directly and their performance indirectly by reducing their borrowers' income and impacting their intermediation role in the economy (Boubaker et al., 2022; Ho et al., 2023; Nguyen & Le, 2024; Nguyen, Le & Ngo, 2025). Consequently, this increased banks' credit risk and reduced their performance by incurring unexpected digitalisation costs to address the temporary conditions caused by the health crisis. Second, this allows us to assess the effectiveness of imposing two projects on "Restructuring the system of credit institutions in Vietnam" that were approved under Decision No. 254/2012/QD-TTg from 2011 to 2015 and Decision No. 1058/2016/QD-TTg from 2016 to 2020. These schemes emphasise that Vietnamese banks should prioritise investment in ICT in providing digital products and services.

Table 2 presents the descriptive statistics of the variables used in our second-stage analysis. The average ratio of digitalisation expenses to total assets was 6.5%, with a slight standard deviation, implying that there was generally a little difference in digitalisation investment among banks in our sample. The average ratio of loan loss provisions to total loans was 1.34%. Additionally, 15.5% and 37.21% of sampled banks were state-owned and listed banks, respectively. The average share of foreign ownership over the capital of a local bank was 8.22%. Note that the maximum shareholding percentage of foreign investors in a credit institution can be at most 30%, according to Decree No. 01/2014/ND-CP.

TABLE 2
Descriptive statistics of the data used in the second stage – regression

Variable	Mean	SD	Min	Max
DIGI	0.065	0.0528	0.0037	0.2892
FOR	0.0822	0.1013	0	0.3
SOCB	0.155	0.3626	0	1
LIST	0.3721	0.4843	0	1
SIZE[1]	229,000	289,000	14,500	1,490,000
LLP	0.0134	0.0049	0.0054	0.0366

Notes: [1]in billion Vietnamese Dong; *DIGI*, the ratio of digitalisation costs over total assets; *FOR*, an actual percentage of foreign ownership over the capital of a domestic bank; *SOCB*, a dummy variable that equals 1 for a state-owned commercial bank; *LIST*, a dummy variable that equals 1 for a listed bank; *SIZE*, the volume of total assets; *LLP*, the ratio of loan loss provisions to total loans.

RESULTS

We first report the efficiency of Vietnamese banks between 2010 and 2019. Figure 1 shows that the efficiency of Vietnamese banks gradually reduced over the period 2011–2017 and started increasing in the latter years. This reflects banks' gradual shrinkage of business activities during the restructuring of credit institutions over the period 2011–2015, under Decision No. 254/QD-TT as announced by the Vietnamese Government (2012) in response to the impact of the global financial crisis (2007–2009). The lowest efficiency of the banking system in the year 2017 perhaps demonstrates the ongoing consequence of the restructuring programme, as many banks still faced difficulty in increasing the minimum charter capital

requirements as per the determined schedule to improve their ability to absorb losses and maintain their businesses without regulatory restrictions (e.g., credit ceiling) and strict supervision.

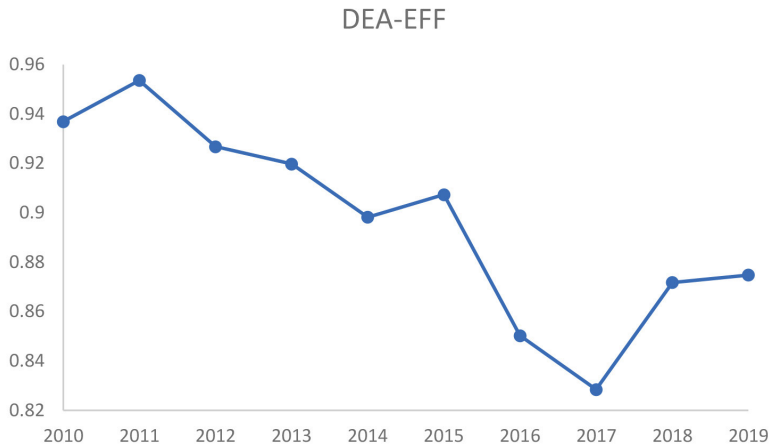

FIGURE 1: Average efficiency of Vietnamese banks, 2010–2019

Furthermore, Figure 2 shows the average efficiency of each bank in the sample. The best performance over the examined period is three state-owned commercial banks (e.g., AGR, BID and VCB) and one joint-stock commercial bank (e.g., SGB), as they obtain averaged efficiency scores of 1.

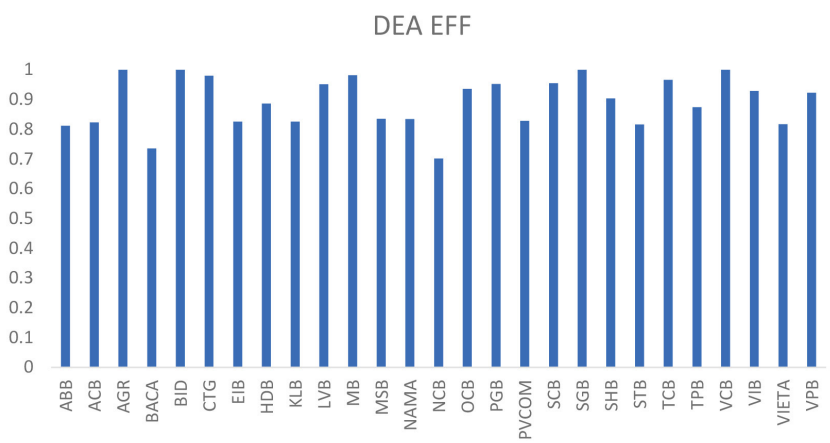

FIGURE 2: Average efficiency of individual banks, 2010–2019

The results of the second-stage regression to test our hypotheses are presented in Table 3. It is worth noting that 2,000 bootstrap replications are used in our regression models.

TABLE 3
Second-stage regression results

Variable	Tobit regression	Truncated regression
DIGI	–0.267** (0.108)	–0.231*** (0.078)
SQDIGI	0.091* (0.056)	0.08** (0.036)
FOR	–0.093 (0.124)	0.233*** (0.115)
SOCB	0.325*** (0.077)	0.435*** (0.147)
LIST	–0.044 (0.029)	0.039 (0.029)
SIZE	–0.01 (0.018)	–0.039* (0.021)
LLP	–3.75** (1.877)	–0.201 (1.672)
Constant	1.191*** (0.333)	1.535*** (0.387)
No. Obs.	258	258
No. Bootstrap replications	2,000	2,000
Log-likelihood	–15.84	147.24
$X\frac{2}{7}$	42.08	23.01
p-value	0.000	0.002

Notes: *DIGI* = the ratio of digitalisation costs over total assets; *SQDIGI* = the quadratic term of digitalisation expenditure; *FOR* = an actual percentage of foreign ownership over the capital of a domestic bank; *SOCB* = a dummy variable that equals 1 for a state-owned commercial bank; *LIST* = a dummy variable that equals 1 for a listed bank; *SIZE* = the natural logarithm of total assets; *LLP* = the ratio of loan loss provisions to total loans. ***, ** and * are significance at 1%, 5% and 10 % levels, respectively. Bootstrap standard errors are in parentheses.

The coefficient of *DIGI* is negative and significant, supporting the view of the productivity paradox hypothesis that the digitalisation process could reduce bank efficiency. Thus, the hypothesis H1 is rejected. The pressure of increasing competition from foreign banks and fintech required Vietnamese banks to make substantial investments in digitalisation. Indeed, digitalisation requires a substantial number of employees to support and run the new system, thus increasing banks' operating costs (Nguyen, Ho, & Nguyen, 2023). Because many banks were transformed from rural banks to commercial banks, their managerial capability needed to be improved when implementing the digitalisation process. Also, it may be the case of Vietnamese banks in our examined period, where they were primarily required to restructure their operating activities to manage bad debts under

Decision No. 254/2012/QD-TTg and Decision No. 1058/2016/QD-TTg for restructuring the Vietnamese banking system for the period 2011–2020. Therefore, these requirements incurred additional managerial efforts and costs for banks to deal with substandard amounts of bad debts after escalating credit growth without rigorous lending standards (Dinh, 2011). Therefore, the investment in digitalisation may outweigh the benefits. According to the survey of Apptio partnering with Forrester (Forrester Report, 2017), the financial services sector witnessed the fastest overall growth in new investments in banking services. More specifically, investing in new technologies, applications and platforms, and upgrading legacy systems equally accounted for 32%. Other costs may include mergers and acquisitions, partnerships and divestment, and restructuring. Nonetheless, this finding somewhat supports the earlier suggestions of Sathye and Sathye (2017), Arora and Arora (2013) in India, and Ho and Mallick (2010) in the U.S. Khattak et al. (2023) also found that investment in technology induces banks to be riskier and more fragile, along with increased diversification.

However, the positive coefficient of *SQDIGI* suggests a U-shaped relationship between digitalisation investment and bank efficiency in Vietnam. Therefore, the hypothesis H2 is rejected. This finding may imply that the benefits of the digitalisation process can be realised in the long run. This finding is comparable with Xiang and Jiang's (2023) finding a nonlinear relationship between digitalisation and bank profitability in China. Similarly, Ben Ali (2022) found a nonlinear association between ICT investment and bank stability in high and low-income countries. Alternatively, there exists a certain threshold that digitalisation can improve the efficiency of Vietnamese banks. When Vietnamese banks invest more in advanced and modern innovations such as artificial intelligence, blockchain, big data and cloud computing technology, they may start to reap the benefits of digitalisation. For instance, these advancements empower banks to generate a user-friendly experience and help to build better relationships, thus expanding the customer base by making banking transactions quicker and more accessible. This ultimately increases consumers' demands for banking products and services, thus improving banks' interest and non-interest income. Also, digital transformation enables Vietnamese banks to automate manual processes, streamline their internal operations, reduce paperwork, and make data-driven decisions, thus increasing cost-savings and enhancing efficiency in banking processes. Hence, digitalisation could increase bank competitiveness (Dwivedi et al., 2021) and reputation (Bernini et al., 2022) in the long run.

For control variables, *FOR* is positively and significantly associated with *EFF*, demonstrating that foreign-owned banks are more efficient than domestic peers. This result is in line with the literature on bank efficiency in transition economies (Berger et al., 2000; Havrylchyk, 2006; Tacneng, 2015) and in Vietnam (Le, 2021). Again, this emphasises that foreign strategic partners can provide their local banks with better managerial skills and knowledge. Furthermore, SOCBs are found to be more efficient than privately owned commercial banks. One of the primary reasons is that government ownership allows SOCBs to pay lower interest rates to their depositors, thus reducing their funding costs. This finding is consistent with previous studies in Vietnam (Le, Ho, et al., 2024; Le, Ngo, Nguyen, & Ho, 2023; Ngo & Le, 2022; Ngo & Tripe, 2017; Nguyen, Nghiem, Roca, & Sharma, 2016; Vu & Turnell, 2010), in China (See & He, 2015), and in South-East Asia (Gardener et al., 2011). A negative coefficient on *SIZE* highlights that size affects bank efficiency negatively. Large banks may face bureaucracy and other management disadvantages, such as the deterioration or disappearance of personal relationships with customers (Berger & Humphrey, 1991; Kwan & Eisenbeis, 1997; Nguyen & Nghiem, 2015; Sun & Chang, 2011).

We further examine whether bank ownership and size may affect the association between digitalisation and bank efficiency, as shown in Table 4. As can be seen, *DIGI* and *SQDIGI* are losing their significant signs, reflecting the impact of the interactions between diversification and other variables. This can be widely observed in the literature (Ben Ali, 2022; Ho et al., 2023). Nonetheless, Table 4 shows the negative coefficient on *SIZE * DIGI*, meaning that larger banks with greater digitalisation may face a reduction in their efficiency. It is reasonable that larger banks with greater branch networks may face substantial costs to speed up the digitalisation process in the short run, including training expenses for employees to adapt to the new system, upgrading and maintaining the consistency of the whole system. Nonetheless, this finding reinforces the evidence that smaller banks may take advantage of digitalisation to improve their profitability in Vietnam (Nguyen, Ho, & Nguyen, 2023) and reduce bank risk-taking in China (Chen et al., 2023). Furthermore, our findings suggest that bank ownership hardly impacts the relationship between digitalisation and bank efficiency.

TABLE 4
Results of interaction terms

Variable	Tobit regression	Truncated regression
DIGI	5.952 (2.871)	4.311 (2.634)
SQDIGI	0.021 (0.077)	0.022 (0.084)
LIST*DIGI	0.13 (0.148)	0.067 (0.154)
FOR*DIGI	2.18 (1.871)	2.51 (1.749)
SOCB*DIGI	–2.493 (39.756)	–4.082 (43.892)
SIZE*DIGI	–0.356** (0.164)	–0.251* (0.148)
Constant	0.671 (0.417)	1.118** (0.448)
Control variables	Yes	Yes
No. Obs	258	258
No. Bootstrap replications	2,000	2,000
Log-likelihood	–11.18	149.62
$X\frac{2}{9}$	20.21	19.29
p-value	0.042	0.056

Notes: DIGI = the ratio of digitalisation costs over total assets; *SQDIGI* = the quadratic term of digitalisation expenditure; *LIST * DIGI*, *FOR * DIGI* and *SOCB * DIGI* are the interaction terms between bank property (listing status, foreign and state ownership) and digitalisation, respectively; *SIZE * DIGI* = the interaction term between bank size and digitalisation. The same set of control variables in Equation (2) is used. ***, ** and * are significance at 1%, 5% and 10 % levels, respectively. Bootstrap standard errors are in parentheses.

CONCLUSIONS

This study empirically assessed the impact of digitalisation on bank efficiency in Vietnam using a two-stage analysis for a sample of 27 banks from 2010 to 2019. Our second-stage regression demonstrates a negative impact of digitalisation adoption and bank efficiency, implying that digitalisation could not increase bank efficiency in the short run. However, a U-shaped association between them is found. This implies that banks would benefit from digitalisation in the long run. These findings reemphasise the crucial role of digitalisation in improving bank efficiency. Bank managers should be aware of the burden costs involved in this process, so they must develop appropriate strategies for successful digital transformation for their banking organisation. Banks should first consider digitalising front-end channel developments (e.g., mobile and internet banking, e-know your customer, virtual assistants, 24/7 call centres). Then, the digitalisation of internal

processes should be implemented, including online real-time trading systems, the use of artificial intelligence (AI), robotic process automation and third-party data in risk management (Ha & Nguyen, 2022). Nonetheless, our results further support the policies of the Vietnamese government on restructuring the banking system toward digitalisation. Furthermore, we could not find any evidence of whether the relationship between digitalisation and bank efficiency differs among bank properties, such as listing status and foreign and state ownership, in the short run.

We observed that credit risk reduces bank efficiency (e.g., bad luck hypothesis), implying that banks would improve their forecasting capability in risk management to deal with external events such as financial shocks. This finding may reinforce the critical role of digitalisation for Vietnamese banks. They should consider AI, especially generative AI, in their future strategy. From modeling analytics to automating manual tasks to synthesising unstructured content, generative AI can help banks control risks effectively and maintain compliance with regulations (Agarwal et al., 2024).

Also, a negative relationship between bank size and efficiency suggests that Vietnamese commercial banks should consider restructuring and downsizing their branch networks to address the issue of diseconomies of scale. When observing the interaction between bank size and digitalisation, our analysis suggests that large banks may not benefit from digital transformation in the short term. Again, these banks should pursue digitalisation strategies cautiously to overcome the disadvantages of bureaucracy and other management while improving customers' financial journey.

Last but not least, the Vietnamese authorities should continuously speed up the digitalisation in banking to reduce the gap with other emerging and developed markets. They should impose a consistent and explicit framework for digital banking (e.g., data privacy, open banking, cybersecurity) and improve digital infrastructure and connectivity, especially cloud adoption.

However, this study has some limitations. Our methodology measures digitalisation through investments in technology and software. While this is a direct and quantifiable metric, it may only partially capture the broader effects of digitalisation. Thus, future research should incorporate more nuanced digitalisation measures when examining its effect on bank performance. Moreover, future studies may use different methods to calculate bank efficiency, such as using the Euclidean common set of weights (Hammami et al., 2022; Ngo & Le, 2022) or the inverse DEA efficiency

approach (Boubaker et al., 2022) and double frontier DEA (Boubaker et al., 2023). Although the findings suggest a U-shaped relationship between digitalisation and bank efficiency using the bootstrap technique embedded in Tobit and truncated regression, our study does not provide a turning point level that digitalisation can improve bank efficiency. Future research, thus, uses a threshold analysis along with other regression approaches (e.g., a generalised method of moments with frontier analysis [Tran & Tsionas, 2013]) to determine a certain threshold for digitalisation investment. Also, our study does not consider whether bank efficiency may vary according to different stages of digital transformation. Future studies should account for this matter. Furthermore, future research may use bootstrap-censored quantile regression to examine the changes in distribution shape and spread of DEA scores (Angrist et al., 2006; Le, Ngo, et al., 2022). Lastly, it would be interesting to extend the sample to cover a longer period of time and/or other sectors and (emerging) countries to provide a broader insight into the relationship between digitalisation and performance.

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APPENDIX

The list of banks used in this study

Bank name	Abbreviation
An Binh Commercial Joint Stock Bank	ABB
Asia Commercial Joint Stock Bank	ACB
Vietnam Bank for Agriculture and Rural Development	AGB
Bac A Joint Stock Commercial Bank	BACA
Joint Stock Commercial Bank for Investment and Development of Vietnam	BID
Vietnam Joint Stock Commercial Bank of Industry and Trade	CTG
Vietnam Export Import Commercial Joint Stock Bank	EIB
Ho Chi Minh City Development Joint Stock Commercial Bank	HDB
Vietnam Public Joint Stock Commercial Bank	VPB
Saigon Commercial Bank	SCB
Saigon Bank for Industry & Trade	SGB
Saigon – Hanoi Commercial Joint Stock Bank	SHB
Viet Nam Technological and Commercial Joint Stock Bank	TCB
TienPhong Commercial Joint Stock Bank	TPB
Kienlong Commercial Joint Stock Bank	KLB
Lien Viet Post Joint Stock Commercial Bank	LVB
Military Commercial Joint Stock Bank	MB
Vietnam Maritime Commercial Joint Stock Bank	MSB
Nam A Commercial Joint Stock Bank	NAMA

Bank name	Abbreviation
National Citizen Bank	NCB
Orient Commercial Joint Stock Bank	OCB
Petrolimex Group Commercial Joint Stock Bank	PGB
Vietnam Commercial Joint Stock Bank for Private Enterprise	PVCOM
Joint Stock Commercial Bank for Foreign Trade of Vietnam	VCB
Saigon Thuong Tin Commercial Joint Stock Bank	STB
Vietnam International Commercial Joint Stock Bank	VIB
Viet A Joint Stock Commercial Bank	VIETA