DOI: https://doi.org/10.17323/j.jcfr.2073-0438.19.4.2025.50-66
JEL classification: C23, G21

Digital Transformation and Risk-taking in Vietnamese Banks: A Principal-agent Perspective

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Abstract

This study applies the principal-agent framework to examine the impact of digital transformation on banks' risk-taking behavior in Vietnam in 2012–2022. It further expands the analysis by investigating the moderating roles of bank-specific characteristics and external shocks in this relationship. The results reveal a nonlinear, U-shaped relationship: in the early stages of digital transformation, heightened information asymmetry intensifies principal-agent conflicts, thereby reducing risk-taking. As digital maturity increases, moral hazard becomes more prominent, encouraging greater risk-taking as agents respond to performance-based incentives. Furthermore, larger banks tend to exhibit more conservative behavior due to their complex organizational structures and divergent risk perceptions, while the COVID-19 pandemic coupled with rapid technological change has amplified risk aversion across the sector. These findings offer important implications for corporate financial decision-making and regulatory policy, emphasizing the need to manage agency conflicts and align digital strategies with optimal risk-taking behavior in the evolving digital finance landscape.

Keywords: agency theory, digital transformation, emerging economies, principal-agent conflict, risk-taking, Vietnam

For citation: Dieu T.T.T., Dung N.T., Truc N. H. (2025) Digital transformation and risk-taking in Vietnamese banks: a principal-agent perspective. *Journal of Corporate Finance Research.* 19(4): 50-66. https://doi.org/10.17323/j. jcfr.2073-0438.19.4.2025.50-66

Introduction

The accelerating pace of digital transformation has fundamentally reshaped how banks operate, make decisions, and manage risk [1]. In both developed and emerging economies, technologies such as Artificial Intelligence (AI), Machine Learning (ML), Blockchain, Cloud Computing, Big Data, Biometrics, and the Internet of Things (IoT) are transforming financial services, particularly in payment systems and credit evaluation segments [2; 3]. These developments compel banks to revise their business strategies and risk-taking behavior in order to adapt and stay competitive [4].

Amid this transformation, principal–agent conflicts in the banking sector have not only resurfaced but are also gaining renewed attention, since they may serve as a key explanatory mechanism for the impact of digital transformation on banks' risk-taking behavior [5; 6]. Agency theory offers a framework to understand conflicts between principals (shareholders) and agents (managers), especially under conditions of uncertainty and information asymmetry [7; 8]. While principals bear financial risks for economic returns, agents often act in their self-interest to maximize personal gains [8; 9]. Typically, principals are risk-neutral and profit-driven, whereas agents are risk-averse [7]. Although widely applied in corporate governance, the theory's relevance in today's digital banking sector deserves further study. Technological innovation alters risk dynamics and monitoring costs, reshaping agent behavior and influencing risk-taking tendencies [2; 3; 5–7].

Prior studies have yielded mixed evidence regarding the relationship between digital transformation and bank risk-taking. While some scholars argue that digitalization increases risk exposure due to evolving business models and heightened cybersecurity threats [10–12], others suggest that it enhances transparency and mitigates risk [4; 13]. Furthermore, Guo and Shen reveal a nonlinear U-shaped relationship between Internet finance and bank risk-taking in China, showing that the initial development of Internet finance reduces risk, whereas further progress may amplify it [14]. More recently, a growing body of research has proposed an inverted U-shaped relationship, in which risk-taking first rises but later declines as banks become more adept at utilizing digital technologies [15]. Despite these insights, most studies have yet to explicitly adopt agency theory as a theoretical lens to explain the underlying mechanisms driving this relationship.

Although extensive research has investigated risk-taking behaviors in the banking systems of Western countries, the United States, and China, relatively little is known about how digitalization influences such behavior in emerging markets like Vietnam, where digital transformation is occurring rapidly and often bypassing traditional banking infrastructure [16]. Vietnamese banks operate in a transitional economy characterized by strong state influence, rapid tech adoption, and evolving regulatory frameworks. In 2020, Vietnam was still in the early stages of digital transformation, with the banking sector facing challenges such as infrastructure limitations, regulatory uncertainties, and a skills gap in the workforce [17]. These factors created a dynamic environment where the initial adoption of digital technologies might help banks reduce operational risks, streamline processes, and enhance efficiency. However, as of 2023, more than 87% of adults in Vietnam had a bank account, and over 95% of bank transactions were processed digitally[1]. Mobile and QR code payments grew at an annual rate exceeding 100% from 2017 to 2023, while digital infrastructure continues to expand. As digitalization progresses, banks may face increasing competition and rising capital costs, potentially leading to higher risk taking. These developments may intensify agency problems, as agents navigate trade-offs between innovation, performance incentives, and risk oversight. In this context, agency theory provides a compelling explanation for why Vietnam is expected to follow a U-shaped pattern in the relationship between digital transformation and bank risk-taking. During the early stages of digitalization, information asymmetry widens as agents gain greater control over data and technological tools than principals, while monitoring and governance mechanisms remain underdeveloped. Consequently, managers tend to adopt conservative, risk-averse strategies to avoid regulatory and reputational risks. As digital maturity advances, however, improved information systems, incentive alignment, and performance pressure increase managerial discretion and moral hazard, prompting higher risktaking. Thus, agency theory captures how digital transformation initially constrains but later amplifies managerial risk appetite in Vietnam's evolving institutional and technological environment. Therefore, a clarification of the impact of digital transformation on bank risk-taking in Vietnam may serve as a reference for other emerging economies striving to modernize their financial systems while addressing the unique challenges posed by rapid digitalization.

Given these dynamics, and drawing on agency theory as an interpretive lens, this study seeks to answer the following research questions: 1) To what extent does digital transformation affect bank risk-taking behavior? 2) Do bank-specific characteristics, such as bank size, moderate this relationship? 3) Do uncontrollable external events, such as the COVID-19 pandemic, influence this relationship?

To address these questions, we apply a two-step system GMM model using panel data from 27 Vietnamese commercial banks (2012–2022). The results support agency theory: 1) a U-shaped nonlinear relationship exists – early digitalization increases information asymmetry, reducing risk-taking; later digital maturity fosters moral hazard and higher risk appetite; 2) larger banks exhibit greater risk aversion due to information asymmetry and divergent risk perceptions, making bank size a moderator; 3) the COVID-19 pandemic amplified principal-agent conflicts amid technological change, reinforcing risk-

[1] See more at: URL: https://baochinhphu.vn/ngan-hang-va-bai-toan-chuyen-doi-so

averse behavior and moderating the effect of digital transformation on risk-taking.

This study contributes to the literature in several ways. First, from a theoretical perspective, it applies agency theory to explain the "black box" of banks' risk-taking behavior during digital transformation, emphasizing principal-agent conflict and moral hazard as the core mechanisms underlying the nonlinear relationship, behavioral differences in large banks, and responses to external shocks. This extends the relevance of agency theory to the digital era, which prior studies have largely overlooked. Second, while Guo and Shen (2016b) found a U-shaped link between Internet finance and risk-taking using a text-mining-based measure [14], this study adopts a more comprehensive and multidimensional ICT index to assess digital transformation, thereby pioneering the analysis of its nonlinear impact on bank risk-taking. Third, digital transformation and risk-taking are shaped by both internal factors (e.g., bank size) and external shocks (e.g., the COVID-19 pandemic), yet prior research has not examined their modera8ting effects [18]. This study addresses that gap by demonstrating that both bank size and the COVID-19 pandemic moderate the effect of digital transformation on bank risk-taking behavior. Finally, the findings provide practical implications for regulators and bank managers in developing incentive-compatible governance and digital monitoring systems aligned with long-term risk objectives.

The remainder of this paper is organized as follows. Second section presents the theoretical framework and research hypotheses. Third section outlines the methodology. Fourth section reports the empirical findings. Fives section concludes with implications, limitations, and directions for future research.

Theoretical framework and hypotheses development

Theoretical framework

Bank risk-taking and Digitalization

Bank risk-taking refers to the intentional acceptance of risks by banks to pursue higher profits [4]. Common risks include credit, liquidity, and insolvency risks [19]. Risk-taking is influenced by both internal factors, such as corporate and risk governance, and external factors, such as economic policy uncertainty [20]. Corporate governance plays a key role in determining risk appetite [21], while effective risk governance can reduce excessive risk-taking [13].

Digitalization refers to the conversion of information into digital formats, enabling value creation through technology and prompting major organizational changes [22]. In banking, it leverages tools like AI, big data, and internet networks to transform service delivery in areas such as payments, lending, and asset management [3; 23]. This shift boosts speed and access, especially for underserved groups like non-standard borrowers and micro-enterprises, but also disrupts traditional banking. Capital increasingly flows to online platforms, reducing banks' lending profits [24], while fintech firms take over payment processing, lowering banks' service revenue [25]. In response, banks may engage in higher-risk activities. Conversely, digitalization may reduce risk-taking by enhancing transparency, cutting costs, and improving credit risk control [11; 19]. With fintech also reducing operational costs and encouraging innovation [4], further study is needed to assess its impact on bank risk across varying contexts.

Principal-Agent Theory

Agency theory examines the risk-sharing dilemma between principals and agents, which stems from differing risk preferences and objectives [26]. While principals (e.g., shareholders) are generally risk-neutral due to diversified investments, agents (e.g., managers) tend to be risk-averse, prioritizing job security and personal utility [27]. This divergence underpins principal-agent conflicts, particularly in resource allocation decisions [7].

Two important mechanisms through which agency conflicts influence risk-taking are information asymmetry and moral hazard [7]. Information asymmetry arises when agents possess more or better information than principals, making it difficult for principals to monitor managerial behavior. This leads to increased caution among agents, who may avoid high-risk decisions to protect their positions, thereby reducing overall risk-taking [8; 9]. In contrast, moral hazard occurs when agents are incentivized to act in their own interest, particularly when their compensation is tied to short-term performance metrics. Although performance-based pay can incentivize better outcomes, it may also result in inefficient risk-sharing, thereby jeopardizing long-term benefits [2]. In such contexts, agents may pursue aggressive, high-risk strategies to maximize personal gains, even at the expense of long-term value creation [2], whereas the board of directors plays a crucial role in monitoring agents and protecting shareholder interests [28]. By providing comprehensive information about agents' actions, boards can decouple compensation from short-term performance, encouraging agents to undertake thoughtful, high-risk initiatives aligned with shareholder interests [7; 8]. Thus, moral hazard can amplify risk-taking behavior.

These conflicts are especially pronounced in large corporations where ownership and control are separated [7]. Effective boards help mitigate these issues by enhancing transparency and aligning incentives through long-term evaluation and contract mechanisms [8; 28]. In contrast, smaller or younger banks often suffer from severe information asymmetry, enabling agents to manipulate outcomes to the detriment of external investors [29].

From an agency perspective, organizations also face uncertain futures that may lead to prosperity, bankruptcy, or intermediate outcomes [7]. Agency theory deepens organizational analysis by linking outcome uncertainty with risk creation. This risk arises because outcomes depend not only on behaviors but also on uncontrollable factors, such as government policies, economic conditions, competitor actions, and technological changes. Such outcome uncer-

tainty creates challenges in planning and introduces risks that must be managed.

Hypotheses development

Principal-agent conflicts are particularly salient during the early stages of digital transformation, as banks shift from traditional operations to internet-based technologies [2]. This transition heightens information asymmetry, with agents often having greater access to digital tools and data than principals, thereby intensifying agency conflicts—especially in contexts with weak regulatory and technological infrastructure [11]. As a result, agents may adopt more conservative lending strategies, reducing overall risk-taking [2]. However, digitalization enhances communication, lowers transaction costs, and improves resource allocation, which in turn reduces management expenses and boosts profitability, diminishing incentives to transfer risk to depositors [20]. It also mitigates information asymmetry with customers, facilitating better credit assessments and prudent lending [11; 19], while encouraging innovation, online service expansion, and market entry—thereby improving efficiency and reducing dependence on high-risk strategies [4].

The second phase, accelerated by the internet and interconnected technologies such as cloud computing, big data, AI, and IoT [30], has elevated the relevance of agency issues and corporate governance, especially with fintech disrupting traditional banking revenues [2; 25]. Banks may respond with riskier investments to offset income losses, elevating digital technologies to a strategic priority at the board level [6]. Evidence shows that digital adopters often outperform the market as internet-based models mature, aided by improved systems and stakeholder engagement that enhance profitability and market share [31]. Digital transformation also reduces agency conflicts via improved transparency, faster decision-making, and stronger accountability. Yet, performance-linked incentives may induce moral hazard, as managers prioritize short-term gains over long-term value. In highly digitized environments, weakened monitoring may further encourage excessive risk-taking [2].

Some scholars suggest that digitalization reshapes business models and raises debt-financing costs, amplifying risk [12]. Studies conducted by Guo and Shen, Chen et al. identify nonlinear (U- or inverted U-shaped) relationships between digitalization and risk-taking [14; 15]. In early phases, internet finance improves efficiency and reduces risk; yet as digital ecosystems mature – e.g., through third-party platforms displacing core banking functions and increasing capital costs – banks face greater uncertainty and strategic complexity [22]. Thus, while early-stage monitoring curbs risk, moral hazard may intensify later, prompting high-risk decisions driven by performance incentives.

In Vietnam, although the government launched Decision No. 1755/QĐ-TTg[2] in 2010 to promote national digital development, comprehensive legal frameworks specific to banking digitalization were only formalized beginning in 2019, through directives such as Resolution No. 52-NQ/TW[3], Decision No. 749/QD-TTg[4], and Decision No. 810/QD-NHNN[5]. This indicates that Vietnam's banking sector remained in the early stage of digital transformation during the research period, where information asymmetry was prevalent, resulting in more cautious risk-taking behavior. As digital maturity advances, however, the likelihood of moral hazard is expected to increase, potentially encouraging more aggressive risk-taking. Thus, we propose the following hypothesis:

H1: Digital transformation has a U-shaped nonlinear impact on bank risk-taking in Vietnam over time

Large and small-to-medium-sized banks differ in ownership structure, customer base, and policy constraints, leading to heterogeneous risk-taking responses to digitalization [14]. Large banks benefit from economies of scale, enabling greater investment in advanced technologies and enhanced risk management capabilities [32]. In contrast, smaller banks often lack sufficient infrastructure, increasing their exposure to digital risks and reducing risk-management efficiency [4; 15]. To stay competitive, they may engage in high-risk digital initiatives without fully grasping the potential consequences. Moreover, while large banks can scale digital platforms for effective risk monitoring, smaller banks face technological limitations. Accordingly, we propose the following hypothesis:

H2: Bank size moderates the impact of digital transformation on risk-taking in Vietnam

The COVID-19 pandemic compelled banks to enhance digital strategies and strengthen risk management to ensure operational continuity [33]. While digitalization improved information flow, lending accuracy, and borrower engagement [4], it also introduced new cyber risks and systemic vulnerabilities [34]. Thus, although essential during the crisis, digital transformation created new risk dimensions. The pandemic ultimately accelerated the adoption of more robust, risk-sensitive digital strategies, moderating its impact on bank risk-taking. Based on these arguments, we propose the following hypothesis:

H3: The COVID-19 pandemic moderates the impact of digital transformation on risk-taking in Vietnam.

[2] See more at: Decision No. 1755-QD-TTg.

[3] See more at: Resolution No. 52-NQ-TW.

[4] See more at: Decision No. 749-QD-TTg.

[5] See more at: Decision No. 810/QD-NHNN.

Methodology

Model specification

Dependent variable

To ensure bank stability, agents must make investment decisions that balance potential risks and expected cash flows [27; 35]. This behavior is described by the ZSCORE, a common proxy for bank risk-taking, where higher values indicate lower risk and default probability [36; 37]. The ZSCORE is calculated as follows:

$$ZSCORE_{i,t} = \left[ROA_{i,t} + \left(Equity_{i,t} \div Total\ Assets_{i,t} \right) \right] \div \partial ROA_{i,t},$$

where i denotes the bank, t denotes the time, ROA is the return on assets, and ∂ROA is the standard deviation of ROA over an eleven-year rolling window. For easier interpretation of the results, we used the natural logarithm of the inverse ZSCORE (denoted as Z) [35; 37; 38]. A higher value of Z indicates greater bank risk-taking and vice versa.

Independent variable

Following Hoque et al. (2024), this study employed an index measured by a government agency as a proxy for digital transformation: the ICT index, which is publicly reported annually by the Vietnamese Ministry of Information and Communications[6] [19]. The Viet Nam ICT Index uses Z-Score standardization and expert evaluations to align with the United Nations E-Government Report. It comprehensively measures digital transformation across four dimensions: technical infrastructure, human resources, internal information technology applications, and online banking services – capturing key aspects such as core banking, e-payments, cybersecurity, and internet banking to assess sector-wide digital maturity.

Moderating variables

To clarify the moderating effect of bank size, a dummy variable (sizedum) is introduced. It is assigned a value of 1 for banks with total assets exceeding 100,000 billion VND[7], and 0 otherwise. To examine the moderating impact of the COVID-19 pandemic, a dummy variable (COVID) was assigned a value of 1 for the years 2020 to 2022, and 0 for all other years. Additionally, two interaction terms – ICTsize and ICTCOVID – were constructed to capture the moderating effects of bank size and the pandemic on the relationship between digital transformation and bank risk-taking.

Control variables

Bank risk-taking is influenced by several characteristics. Bank size (SIZE), measured by the log of total assets, has an ambiguous effect: large banks may take more risks due to "too big to fail" status but can also reduce risk via diversification and stronger controls [39]. Bank efficiency, proxied by the cost-to-income ratio (CIR), is positively associated with risk-taking, as higher CIR may drive riskier behavior to boost profits, while lower CIR reflects efficiency and conservatism [37]. Income diversification (DIV), the ratio of net non-interest income to total income, can stabilize earnings but also increase risk due to volatility in non-traditional activities [40]. Capital Adequacy Ratio (CAR) affects risk-taking through regulatory buffers: higher CAR limits excessive risk, whereas lower CAR may encourage risk-taking to enhance returns [41].

Among external factors, inflation and economic growth are key determinants of bank risk-taking [42]. High inflation erodes loan repayment value, prompting aggressive lending to protect margins, while low inflation supports stability and caution. Economic growth, measured by GDP growth, generally reduces short-term risk by improving borrower creditworthiness [20; 37] (Table 1).

Table 1. Definition of variables

Variable		Definition	Measurement
Dependent variable	Z	Bank risk-taking	$Ln[\partial ROA_{i,t} / \left(ROA_{i,t} + Equity_{i,t} / Total\ Assets_{i,t} \right)]$
Independent variables	ICT	Digital transformation	
	ICT2	The quadratic term of ICT	ICT2
Moderating variables	sizedum	Bank size	1 for size > 100,000 billion VND; 0 for others
	ICTsize		ICT x sizedum
	COVID	COVID-19 pandemic	1 for the year 2020–2022; 0 for others
	ICTCOVID		ICT x COVID

[6] See more at: URL: https://www.most.gov.vn

[7] This classification aligns with Circular No. 52/2018/TT-NHNN, which designates banks with assets above this threshold as large-scale banks.

Variable		Definition	Measurement
Control Variables	SIZE	Bank size	Ln(Total assets)
	CIR	Bank efficiency	Cost to Income ratio
	DIV	Income diversification	Net non-interest income/Net income
	CAR	Capital Adequacy Ratio	(Tier 1 + Tier 2)/Risk-Weighted Assets
	INF	Inflation	Annual inflation rate
	GDP	GDP growth	Annual GDP growth rate

Source: Compiled by the authors.

Empirical model

The Generalized Method of Moments (GMM) is widely applied in finance and economics to address endogeneity caused by correlation between regressors and error terms, which biases estimates [43]. By using instrumental variables – often internal instruments from lagged variables – GMM ensures consistent parameter estimation even with endogenous regressors [44; 45]. It is well suited for dynamic panel data affected by simultaneity, omitted variables, and measurement error, and is robust to heteroscedasticity and autocorrelation [46]. The two-step System GMM is preferred for small samples due to its efficiency in handling endogeneity and model complexity [45]. Instrument validity is assessed via Sargan and Hansen tests, while Arellano – Bond tests (AR(1) and AR(2)) check for autocorrelation. The models estimated index banks by i and time by t as follows:

$$Z_{i,t} = \beta_1 Z_{i,t-1} + \beta_2 ICT_{i,t} + \beta_3 ModeratingVari_{i,t} + \\ + \beta_4 InteractionVari_{i,t} + \beta_5 ControlVari_{i,t} + \varepsilon_{it} .$$

Table 2. Summary statistics

Variables	Z	ICT	SIZE	CIR	DIV	CAR	INF	GDP
Obs.	290	223	290	290	290	256	297	297
Mean	1.58	0.51	4.94	51.85	15.64	12.24	4.28	6.39
S.D.	0.48	0.11	1.18	9.27	9.11	2.14	2.67	0.73
Min	0.64	0.31	2.58	39.67	5.86	8.34	0.63	5.50
Max	2.54	0.74	7.47	63.83	33.84	15.2	9.09	7.46
Correlations								
Z	1.000							
ICT	–0.138**	1.000						
SIZE	0.101*	0.320***	1.000					
CIR	0.015	–0.311***	–0.457***	1.000				
DIV	0.231***	0.058	0.360***	0.170***	1.000			
CAR	0.116*	–0.118	–0.482***	0.150**	–0.177***	1.000		
INF	–0.143**	–0.078	–0.266***	0.004	–0.059	0.199***	1.000	
GDP	0.111*	–0.275***	0.045	0.043	0.0008	–0.036	–0.387***	1.000

Note: ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.
Source: Compiled by the authors.

Data description

This study examines the impact of digital transformation on bank risk-taking in Vietnam using an unbalanced panel dataset comprising bank-level data from 27 commercial banks (2012–2022) and macroeconomic indicators from the World Bank. Bank-specific data were obtained from audited annual reports, collected through FiinPro's database, one of the largest and most reputable data companies in Vietnam. Banks were selected based on the availability of ICT index data for at least five years. The dataset ends in 2022 due to data disclosure timelines, and outliers were removed using quantitative regression techniques to ensure robustness. Our sample includes 27 out of the 31 commercial banks in Vietnam, representing 87% of their total number, which ensures the sample's robustness and solid representation of the banking system. This period reflects a critical phase of structural adjustments and accelerated digitalization in the sector.

Table 2 reports summary statistics and pairwise correlations. Risk-taking, proxied by Z, ranges from 0.64 to 2.54 (SD = 0.48), while the ICT index has a mean of 0.51 (SD = = 0.11). The Pearson correlation matrix indicates no significant multicollinearity among explanatory variables.

Table 3. Regression results

Regression method	2-step system GMM					
Models	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Zt-1	0.8071***	0.7058***	0.6558***	0.6625***	0.7761***	0.8080***
ICT	–0.1356***	–0.9754**	–0.1693***	–0.5182***	–0.1252**	–0.1377***
ICT2		0.8040**				
SIZE	–0.0281***	0.0072			0.0022	0.0109
CIR	0.0113***	0.0125***	0.0116***	0.0138***	0.0122***	0.0138***
DIV	0.0112***	0.0091***	0.0088***	0.0067**	0.0110***	0.0108**
CAR	0.0111***	0.0156***	0.0164***	0.0144***	0.0145***	0.0168***
INF	–0.0179***	–0.0122**	–0.0183***	–0.0146***	–0.0219***	–0.0248***
GDP	–0.0421***	–0.0297***	–0.0319***	–0.0210***	–0.0674***	–0.0939***
Sizedum			–0.0097	–0.2253*		
ICTsize				0.5188**		
COVID					–0.0876**	–0.2682***
ICTCOVID						0.2392*
No. of groups	26	26	26	26	26	26
No. of instruments	26	26	26	26	26	26
Sargan test	0.154	0.537	0.218	0.089	0.694	0.369
Hansen test	0.304	0.236	0.356	0.481	0.224	0.282
AR(1)	0.018	0.018	0.020	0.022	0.017	0.023
AR(2)	0.951	0.928	0.954	0.973	0.967	0.920

Note: This table provides regression results on the correlation between digital transformation and bank risk-taking in Vietnam by the two-step SGMM approach. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels respectively.
Source: Compiled by the authors.

Results and discussions

The findings confirm Hypothesis H1 and address Research Question 1 by revealing a U-shaped relationship between the ICT index and bank risk-taking: the linear term is negative while the squared term is positive. This result supports principal–agent theory [26] and is consistent with prior studies (Chen et al., 2022; Guo & Shen, 2016b) [14; 15]. In the early stages of digital transformation, increased information asymmetry – due to agents' privileged access to digital tools and internal data – intensifies principal–agent conflicts, prompting risk-averse behavior. This aligns with agency theory, which highlights divergent risk preferences between owners and managers. Between 2012 and 2022, most Vietnamese banks were slow in adopting digital innovations, focusing primarily on process digitalization rather than business model transformation. Only a few private banks (e.g., TPBank, Nam A Bank, VPBank, MB Bank) pioneered advanced technologies. According to the State Bank of Vietnam's 2021 Annual Report, merely 30–40% of banks had adopted comprehensive digital strategies, with most still in the "digitalization" rather than "digital innovation" stage.

As digital transformation advances, it reduces agency conflicts by enhancing transparency, monitoring, and incentive alignment. However, in the later phase, moral hazard becomes more pronounced. Agents, incentivized by performance-based systems and supported by digital infrastructure, may pursue aggressive risk-taking to meet short-term targets, particularly in competitive digital markets [7]. When compensation is tied to short-term metrics (e.g., quarterly profit, market share), agents may prioritize immediate rewards over long-term stability, leading to high-risk strategies that, while beneficial in the short run, increase systemic vulnerabilities over time (Table 3).

The results also confirm Hypothesis H2, address Research Question 2, and support the information asymmetry perspective of Eisenhardt (1989) [7] and Barnea et al. (1981) [29]. The negative impact of digital transformation on bank risk-taking is stronger in large banks, suggesting that size amplifies the effects of digitalization on risk behavior. ICT Index data reveal uneven digital development, with state-owned banks (e.g., Agribank, BIDV) lagging behind private peers in customer experience. From an agency perspective, the organizational complexity of large banks exacerbates information asymmetry, making it difficult for agents to assess and communicate digital risks, which often leads to cautious strategic choices. Regulatory scrutiny and pressure from diverse stakeholders further reinforce conservative behavior. Moreover, reputational concerns discourage agents from adopting overly ambitious technologies, fostering a risk-averse culture where digital initiatives are implemented gradually and with caution. These factors explain why large banks tend to adopt a more measured approach to digital transformation.

Regarding Hypothesis H3, the findings confirm that the COVID-19 pandemic significantly moderates the relationship between digital transformation and risk-taking, addressing Research Question 3. The pandemic accelerated digital adoption while intensifying its risk-mitigating effects. From an agency theory lens, heightened uncertainty increased principals' preference for stability, prompting agents to act more conservatively to align with expectations and avoid reputational or performance-related consequences. Greater information asymmetry during the crisis and enhanced regulatory requirements further encouraged risk-averse behavior. Consequently, banks pursued more cautious digital strategies throughout the pandemic period.

Regarding control variables, bank efficiency, income diversification, and capital adequacy positively affect risk-taking, whereas inflation and economic growth exert a negative influence.

Robustness

To reinforce the reliability of our findings and validate the underlying mechanism of the U-shaped relationship between digital transformation and bank risk-taking, several robustness and mechanism-oriented analyses were conducted.

First, we have sequentially replaced the independent and dependent variables with alternative measures. Specifically, bank risk-taking is measured using the volatility of net interest income (∂NIM), which captures variations in interest income related to lending activities [47], with a more volatile NIM indicating a riskier lending strategy [20]. Online Banking Services (ONBS) is used as an alternative measure of digital transformation, reflecting the online services provided to customers. The results (see Appendix 1 and 2) are consistent with the previous findings, confirming the reliability of the estimates.

Second, to address the dynamics of digital transformation and its effect on risk-taking over time, the model was run with subperiod checks for the years 2012–2018 and 2019–2022. The first period corresponds to the early stage of digital transformation in Vietnam's banking sector, characterized by high information asymmetry and more cautious risk-taking. The second period reflects increasing digital maturity following the formalization of banking digitalization policies in 2019, as mentioned above, which may encourage more aggressive risk-taking. The results suggest that the effect of digitalization on risk-taking becomes stronger in the digital-intensive period (see Appendix 3). While early-stage ICT adoption tends to reduce risk due to information asymmetry, the more advanced wave of digital transformation after 2019 appears to increase banks' willingness to take risks. This pattern aligns with the agency-theoretic mechanism: as digital capabilities expand, managerial discretion and short-term performance incentives may amplify moral hazard, encouraging higher risk-taking to pursuit of short-term business goals, such as profits from digital services or increased market share.

Moreover, we use the Average Marginal Effect to plot the coefficients of ICT and ICT^2 in relation to bank risk-taking (Z) (see Appendix 4). The results reveal a non-linear

relationship between digital transformation and bank risk-taking, which aligns with a U-shaped curve. This pattern is confirmed alongside the panel quantile regression approach [37] (see Appendix 5). Quantile regressions were conducted on pooled data and are intended to be an additional robustness check to illustrate the U-shaped pattern. Given the sample size (~290 observations), estimates in the upper tails are less stable and should be interpreted with caution. Nevertheless, the results provide consistent evidence supporting the non-linear ICT–risk-taking relationship, particularly in the central quantiles (35th to 50th), and further reinforce the robustness of our findings.

Third, to provide indirect empirical evidence for the agency-theoretic mechanism, we introduced interaction terms between ICT (and ICT2) and key bank structural characteristics, including bank size, state ownership, and capital adequacy ratio. The results provide strong indirect evidence that managerial discretion and monitoring strength substantially shape the intensity and form of the non-linear effect of digitalization on risk-taking, rather than exerting a limited influence (see Appendix 6, 7 and 8). Interactions with bank size and state ownership are positive for ICT and negative for ICT2, indicating that managerial discretion in larger or state-owned banks amplifies the non-linear impact of digitalization while moderating extreme risk-taking at high ICT levels. Interactions with CAR show an opposite pattern (negative for ICT and positive for ICT2), suggesting that higher capital adequacy acts as a monitoring strength that constrains risk-taking at moderate ICT levels. However, as ICT progresses to higher levels, the monitoring capacity of CAR allows for greater managerial discretion, leading to an increase in risk-taking behavior due to the growing influence of moral hazard at higher levels of digitalization. Overall, these results demonstrate that bank structural characteristics critically moderate the non-linear relationship between ICT and risk-taking, while preserving the underlying mechanism: In the early stages of digital transformation, information asymmetry and lower managerial discretion reduce risk-taking. However, as digital transformation matures, moral hazard becomes a more significant driver, leading to higher risk-taking behavior, especially when combined with strong monitoring systems and performance-based incentives. This highlights the complex role that ICT plays in influencing risk-taking behavior, which is not merely a linear progression but rather a dynamic process influenced by both internal (e.g., managerial discretion) and external (e.g., monitoring strength) factors.

Conclusion

This study employs a two-step system GMM model using panel data from 27 Vietnamese commercial banks (2012–2022) to investigate the impact of digitalization on bank risk-taking. Anchored in agency theory, the study provides strong empirical support for the principal–agent framework by: 1) identifying agency conflicts as central to the nonlinear relationship between digital transformation and risk-taking; 2) showing that information asymmetry and divergent risk perceptions make large banks more risk-averse; and 3) demonstrating that the COVID-19 pandemic heightened agency conflicts, reinforcing conservative behavior amid uncertainty.

This research advances the understanding of digitalization's effect on risk-taking in Vietnam's rapidly transforming banking sector and offers important policy implications for managers and regulators in similar developing economies. Key recommendations include: 1) establishing a digital transformation roadmap based on agency theory to manage information asymmetry and moral hazard; 2) leveraging bank size to enhance digital risk management capacity; 3) promoting collaboration with Fintech firms and facilitating access to public funding for technological infrastructure; 4) developing flexible digital strategies to respond to economic volatility; and 5) introducing supportive regulatory tools such as sandboxes and tax incentives for digital risk control.

Despite its contributions, this study has several limitations. The relatively small sample size may limit the generalizability of the findings. Moreover, while agency theory serves as the main explanatory lens, the empirical analysis does not directly capture specific agency channels such as information asymmetry and moral hazard. However, the interaction analyses with bank structural characteristics – including state ownership, bank size, and capital adequacy ratio – as well as the observed U-shaped pattern provide strong indirect evidence supporting these mechanisms. Future research could incorporate explicit governance-related proxies, such as ownership concentration, board composition, or executive compensation, to test these channels more directly. Expanding the dataset across countries and integrating qualitative insights (e.g., executive interviews) would further enrich the understanding of how internal governance and incentive mechanisms shape the evolving link between digital transformation and bank risk-taking.

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APPENDICES

Appendix 1. Regression results with alternative dependent variable (∂NIM)

Regression method	2-step system GMM					
Models	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
∂NIMt-1	0.5053***	0.4931***	0.4900***	0.4808***	0.4519***	0.7382***
ICT	–0.0778**	–1.7260**	–0.1427**	–0.5990***	–0.0855**	–0.2009*
ICT2		2.0890**				
SIZE	–0.0117	–0.0205			0.0245	–0.0422*
CIR	0.0057***	0.0086***	0.0048***	0.0102***	0.0039	0.0032
DIV	0.0081*	0.0103*	0.0096*	0.0046	0.0005	0.0186***
CAR	0.0137***	0.0208***	0.0128***	0.0098***	0.0408***	0.0128**
INF	0.0164**	0.0013	0.0181**	0.0216**	0.0112	–0.0052
GDP	–0.0580***	–0.0447***	–0.0565***	–0.0564***	–0.0961***	–0.0339
Sizedum			–0.0076	–0.4170**		
ICTsize				0.9010**		
COVID					–0.0830**	–0.4104*
ICTCOVID						0.8069*
No. of groups	26	26	26	26	26	26
No. of instruments	26	25	25	25	26	25
Sargan test	0.423	0.872	0.459	0.486	0.247	0.768
Hansen test	0.342	0.668	0.388	0.396	0.330	0.783
AR(1)	0.008	0.031	0.015	0.007	0.021	0.015
AR(2)	0.110	0.114	0.104	0.104	0.133	0.126

Note: This table provides the 2-step SGMM regression results on the impact of digital transformation on bank risk-taking for robustness purposes. Bank risk-taking is measured using the volatility of net interest income (∂NIM), which captures variations in interest income related to lending activities. ∂NIM is calculated as the standard deviation of eleven-year rolling net interest margin values for each bank. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Appendix 2. Regression results with alternative independent variable (ONBS)

Regression method	2-step system GMM					
Models	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Zt-1	0.8023***	0.6659***	0.7994***	0.8112***	0.7659***	0.8922***
ONBS	–0.0708**	–0.5124***	–0.0967***	–0.2766***	–0.1065***	–0.0879**
ONBS2		0.3228***				
SIZE	–0.0323***	–0.0167***			–0.0079	–0.0209
CIR	0.0108***	0.0119***	0.0083***	0.0092***	0.0119***	0.0133***
DIV	0.0116***	0.0161***	0.0123***	0.0175***	0.0143***	0.0207***
CAR	0.0097***	0.0166***	0.0120***	0.0124**	0.0173***	0.0135***
INF	–0.0173***	–0.0205***	–0.0184***	–0.0197***	–0.0262***	–0.0299***
GDP	–0.0365***	–0.0243***	–0.0377***	–0.0401***	–0.0647**	–0.1029***
Sizedum			–0.0869**	–0.2934***		
ONBSsize				0.2607**		
COVID					–0.0869*	–0.2707***
ONBSCOVID						0.1771***
No. of groups	26	26	26	26	26	26
No. of instruments	26	26	25	26	26	26
Sargan test	0.737	0.721	0.189	0.276	0.854	0.874
Hansen test	0.253	0.413	0.332	0.577	0.322	0.659
AR(1)	0.017	0.013	0.017	0.012	0.013	0.019
AR(2)	0.895	0.521	0.654	0.390	0.806	0.564

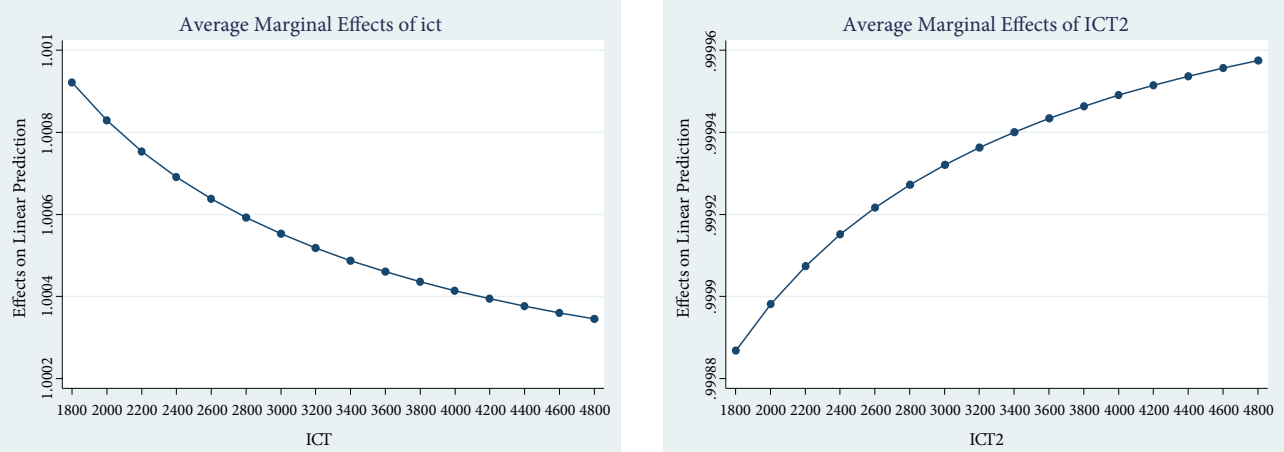
Note: This table provides the 2-step SGMM regression results on the impact of digital transformation on bank risk-taking in Vietnam for robustness purposes. Online Banking Services (ONBS) is used as an alternative measure of digital transformation. ONBS reflects the online services provided to customers and is standardised according to the Z-score method, including three components: the bank's website, internet banking services, and electronic banking services. This indicator is derived from the ICT index report published by the Vietnamese Ministry of Information and Communications. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Appendix 3. Subperiod check

Models	(1)	(2)
Zt-1	0.7946***	0.8607***
ICT	–0.1159**	–0.1163**
SIZE	–0.0118	–0.0328*
CIR	0.0081***	0.0074***
DIV	0.0120***	0.0132**
CAR	0.0081*	0.0074**
INF	–0.0160***	–0.0139***
GDP	–0.0193**	–0.0196**
timeperiod	–0.0753***	–0.2230***
ICT_timeperiod		0.3058**
No. of groups	26	26
No. of instruments	26	25
Sargan test	0.832	0.338
Hansen test	0.362	0.318
AR(1)	0.024	0.032
AR(2)	0.900	0.801

Note: This table provides the 2-step SGMM regression results on the impact of digital transformation on bank risk-taking in Vietnam for robustness purposes. The model was run with subperiod checks for the years 2012–2018 and 2019–2022 by using the dummy variable timeperiod (with values 0 for 2012–2018 and 1 for 2019–2022) and an interaction term between ICT and timeperiod (ICT_timeperiod). The dummy variable timeperiod enters with a negative coefficient, indicating that the later period is associated with a lower baseline level of risk-taking after controlling for ICT. This is consistent with tighter regulatory pressure, Basel II implementation, and enhanced supervisory standards that were introduced after 2019. However, the interaction term ICT_timeperiod is positive and statistically significant, suggests that as digital transformation increased in banks during 2019–2022, the relationship between ICT and Z strengthened, indicating that risk-taking increased as digitalization progressed. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Appendix 4. Average Marginal Effect results



Note: This figure is derived from the Average Marginal Effects estimated using STATA. We first run an Ordinary Least Squares (OLS) regression of the model, incorporating all independent and control variables. Subsequently, we generate a margins plot to visualise the marginal effects of ICT and ICT2 on Z. The figure demonstrates that an increase in ICT index is associated with a decline in Z (left panel), whereas an increase in ICT2 corresponds to a rise in Z (right panel). The figure indicates a non-linear relationship between digital transformation and bank risk-taking, consistent with a U-shaped pattern.

Appendix 5. Panel quantile regressions

Dependent variable: Z						
Quantiles						
	30th	**35th**	**40th**	**45th**	**50th**	**80th**
ICT	–17.1015	–28.3196***	–26.8051**	–25.3057**	–24.8999**	–8.0513
ICT2	14.8767	24.7095***	23.0817**	21.3011**	21.1208*	3.4548

Note: This table presents pooled quantile regression. For brevity, we present only the results concerning the relationship between ICT, ICT2, and Z. Estimated coefficients are reported for the 30th, 35th, 40th, 45th, 50th, and 80th percentiles of the conditional distribution of risk-taking. *, ** and *** denote statistical significance at 10%, 5% and 1% respectively.

Appendix 6. Interaction terms of ICT and bank size

Models	**(1)**	**(2)**	**(3)**	**(4)**
Zt_{-1}	0.6558***	0.6625***	0.8281***	0.8183***
ICT	–0.1693***	–0.5182***	–1.5532***	–3.4447***
ICT2			1.4360***	3.4565***
CIR	0.0116***	0.0138***	0.0145***	0.0195***
DIV	0.0088***	0.0067**	0.0067**	0.0058*
CAR	0.0164***	0.0144***	0.0142***	0.0191***
INF	–0.0183***	–0.0146***	–0.0146***	–0.0141***
GDP	–0.0319***	–0.0210***	–0.0398***	–0.0238**
sizedum	–0.0097	–0.2253*	–0.0056	–1.0032***
ICTsize		0.5188**		4.2209***
ICT2size				-4.0462***
No. of groups	26	26	26	26
No. of instruments	26	26	26	26
Sargan test	0.218	0.089	0.335	0.240
Hansen test	0.356	0.481	0.236	0.288
AR(1)	0.020	0.022	0.017	0.014
AR(2)	0.954	0.973	0.962	0.720

Note: This table provides the 2-step SGMM regression results on the impact of digital transformation on bank risk-taking in Vietnam for robustness purposes. The model includes interaction terms between ICT and bank size, using the dummy variable sizedum and the interaction variables ICTsize and ICT2size (ICT2 multiplied by sizedum). The results indicate that larger banks are more likely to take on higher risk as digital transformation advances. This is consistent with agency theory, which posits that larger organizations have greater managerial discretion and better risk management resources, enabling them to pursue more aggressive digital strategies. However, the negative interaction of ICT2size suggests that as digitalization matures, the moral hazard effect intensifies, leading to increased risk-taking. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Appendix 7. Interaction terms of ICT and state ownership

Models	(1)	(2)	(3)	(4)
Zt_{-1}	0.7292***	0.9380***	0.7312***	0.5522***
ICT	–0.2495***	–0.2248***	–1.1724**	–
				3.8613**
ICT2			0.9585*	3.1106**
SIZE	0.0070	–0.0458***	0.0551***	0.0706
CIR	0.0064***	0.0039**	0.0113***	0.0240***
DIV	–0.0006	0.0079**	–0.0086***	0.0006
CAR	0.0353***	0.0304***	0.0165***	0.0265***
INF	0.0003	–0.0096**	0.0015	–0.0147
GDP	–0.0269***	–0.0286***	–0.0203***	0.0037
statedum	–0.0461***	–0.2461***	–0.0642**	–3.3828**
ICTstate		0.5478***		10.9198**
ICT2state				–8.6144*
No. of groups	26	26	26	26
No. of instruments	26	26	25	26
Sargan test	0.066	0.308	0.246	0.561
Hansen test	0.293	0.345	0.194	0.347
AR(1)	0.025	0.023	0.038	0.046
AR(2)	0.617	0.592	0.669	0.751

Note: This table provides the 2-step SGMM regression results on the impact of digital transformation on bank risk-taking in Vietnam for robustness purposes. The model includes interaction terms between ICT and bank state ownership, using the dummy variable statedum (taking the value 1 if the bank has state ownership, 0 otherwise) and interaction variables ICTstate and ICT2state (ICT and ICT2 multiplied by statedum). The results suggest that state-owned banks may assume more risk, though less than private banks, as they digitize. This is likely due to monitoring constraints and lower managerial discretion in state-owned banks, which face stricter regulatory oversight and conservative risk management. However, the negative interaction with ICT2 reflects the agency conflict, where managers, incentivized by performance-based pay and supported by improved monitoring, may engage in higher-risk behavior as digital transformation advances. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Appendix 8. Interaction terms of ICT and capital adequacy ratio

Models	(1)	(2)	(3)	(4)
Zt_{-1}	0.7772***	0.6051***	0.8538***	0.7245***
ICT	–0.0732**	–0.3027***	–0.8939***	–2.0995***
ICT2			0.8075***	1.8939***
SIZE	–0.0135	0.0508***	0.0268***	0.0777***
CIR	0.0100***	0.0165***	0.0115***	0.0181***
DIV	0.0109***	–0.0024	–0.0028	–0.0087***
INF	–0.0116***	–0.0118**	–0.0068	–0.0032
GDP	–0.0319***	–0.0302***	–0.0324***	–0.0331***
CARdum	0.0813**	0.2038	0.0687**	0.9269***
ICTCARdum		–0.5806*		–3.5720***
ICT2CARdum				3.4344***
No. of groups	26	26	26	26
No. of instruments	26	26	26	26
Sargan test	0.413	0.967	0.110	0.600
Hansen test	0.343	0.286	0.173	0.180
AR(1)	0.005	0.013	0.021	0.015
AR(2)	0.843	0.536	0.837	0.454

Note: This table provides the 2-step SGMM regression results on the impact of digital transformation on bank risk-taking in Vietnam for robustness purposes. The model includes interaction terms between ICT and bank capital adequacy ratio, using the dummy variable CARdum (taking the value 1 if the bank's CAR is higher than the median CAR value of the entire sample, and 0 otherwise) and interaction variables ICTCARdum and ICT2CARdum (ICT and ICT2 multiplied by CARdum). Converting CAR into a dummy variable simplifies the analysis by categorizing banks into high CAR and low CAR groups. This approach helps capture how different capital adequacy levels influence risk-taking, especially in the context of digital transformation. It makes it easier to interpret the moderating effect of higher capital buffers on the relationship between ICT and risk-taking, while isolating the impact of CAR without the complexity of continuous values. The results suggest that banks with higher capital adequacy ratios are more conservative in their risk-taking, even as they undergo digital transformation. ICT helps reduce information asymmetry, enhancing monitoring and thereby limiting risk-taking in banks with higher CAR. However, the positive interaction with ICT2 indicates a moral hazard effect, where greater digital maturity leads to higher risk-taking, particularly in banks with high CAR and greater managerial discretion. This aligns with agency theory, which posits that performance-based incentives linked to digital outcomes, such as profitability from digital services, may encourage risk-taking in banks with strong capital buffers. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Contribution of the authors: the authors contributed equally to this article.

The authors declare no conflicts of interests.

The article w**as submitted on** 14.10.2025; **approved after reviewing on** 12.11.2025; **accepted for publication on** 05.12.2025.