

Digitalization and Bank Stability: Challenges and Opportunities for the Banking Industry Across Different Levels of Financial Development

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Abstract

Background and Objectives: Digitalization has fundamentally transformed the global banking sector by reshaping financial intermediation, operational efficiency, and risk management practices. The rapid expansion of digital technologies—such as mobile banking platforms, big data analytics, and automated credit scoring—has created new opportunities for financial inclusion and cost reduction. However, its implications for financial stability remain ambiguous and highly context dependent. While digitalization can improve information processing and enhance credit assessment, it may also introduce new vulnerabilities, including cybersecurity threats, model risk, and operational disruptions, particularly in data-constrained environments. This study aims to examine the complex relationship between digitalization and two critical dimensions of banking performance: credit risk, measured by non-performing loans (NPLs), and overall bank stability, proxied by the Z-score. In addition, the study investigates how these relationships vary across different levels of financial development and assesses the role of bank-specific and macroeconomic factors in shaping these outcomes. By adopting a broad cross-country perspective, the study seeks to provide policy-relevant insights into whether digital transformation strengthens or undermines banking sector resilience.

Methodology: The analysis is based on an unbalanced panel dataset covering 143 economies over the period 2010–2021, allowing for comprehensive cross-country comparisons across diverse institutional and financial environments. To address potential endogeneity issues—including reverse causality between digitalization and bank stability—as well as unobserved heterogeneity, the study employs the Dynamic System Generalized Method of Moments (DGMM) estimator. This approach is well-suited for dynamic panel models with persistent dependent variables and endogenous regressors. The empirical specification incorporates lagged dependent variables to capture dynamic adjustments in bank stability and credit risk, alongside a set of control variables including bank size, profitability, capital adequacy, cost efficiency, and key macroeconomic indicators. Furthermore, the analysis conducts sub-sample estimations by grouping countries according to their level of financial development, enabling a

more nuanced evaluation of heterogeneous effects. A series of robustness checks is also performed to confirm the consistency and reliability of the empirical findings.

Key Findings: The results indicate that digitalization exerts a statistically significant and heterogeneous effects on bank stability and credit risk. In the full sample, digitalization is associated with a decline in bank stability (Z-score) and an increase in non-performing loans, suggesting that the costs and risks linked to digital adoption—such as high initial investment, cybersecurity exposure, and limitations of automated credit models in data-poor settings—may outweigh its benefits in the short to medium term. However, the effects vary considerably across different levels of financial development. In financially advanced economies, digitalization contributes positively to banking sector performance by reducing credit risk and enhancing stability, reflecting stronger institutional frameworks, better data infrastructure, and more effective regulatory oversight. In contrast, in less developed financial systems, digitalization improves borrower screening and loan quality to some extent, but the associated implementation costs and structural constraints tend to weaken banks' capital buffers and overall stability. The findings also highlight the importance of control variables, with profitability consistently supporting bank stability, while bank size, cost efficiency, and capital investment exhibit varying effects depending on the financial development context. Overall, the evidence supports the view that digitalization functions as a “double-edged sword,” with its net impact determined by the maturity of the financial ecosystem.

Policy Implications: The findings underscore the need for a differentiated policy approach to digital transformation in the banking sector. In developing economies, policymakers should prioritize investments in digital infrastructure, data systems, and regulatory capacity, particularly in areas related to cybersecurity and digital risk supervision. Targeted support measures—such as subsidies, public–private partnerships, and phased implementation strategies—may be necessary to mitigate the high upfront costs associated with digital adoption and to prevent adverse effects on bank stability. In more advanced financial systems, regulatory attention should focus on managing systemic risks linked to technological concentration, including “too-big-to-fail” concerns arising from dominant digital financial institutions. Strengthening prudential oversight, promoting responsible innovation, and ensuring competition in digital financial services are essential to maintaining long-term stability. Overall, aligning digitalization strategies with institutional readiness and financial development levels is crucial to maximizing benefits while minimizing risks in the evolving banking landscape.

Keywords: Digitalization; Financial Development Levels; Bank Stability; Z-Score; Non-Performing Loans

JEL Classification Codes: G21; G28; O33; C23

1. Introduction

The banking system is a vital component of a country's financial system, and its development is closely linked to overall economic growth (Douglas, 2008; Khairullah & Rosita, 2022). Banks perform several core functions that are essential to the operation of modern economies. First, their primary role is to act as financial intermediaries (Goddard & Wilson, 2016; Khafagy, 2025; Kosmurzaevich, 2024). Specifically, banks receive deposits from individuals and businesses and channel these funds into loans, thereby facilitating capital allocation and promoting economic growth.

Second, banks provide payment services through the operation of payment systems, transaction processing, and the provision of financial instruments such as electronic funds transfers, checks, and drafts (Douglas, 2008). Through these functions, banks support both domestic and international trade. Third, banks contribute to financial stability by managing default risks and safeguarding depositors. To achieve this, they employ advanced technologies such as artificial intelligence and data analytics, along with credit risk management, borrower monitoring, and insurance mechanisms (Adesanya, 2024; Allen et al., 2025). Finally, banks play an active role in supporting entrepreneurship, government projects, and technological advancement, thereby fostering innovation and economic development (Dou & Xu, 2021; Douglas, 2008; Kosmurzaevich, 2024). However, maintaining these core functions in the modern era requires banks to adapt to the rapid and ongoing wave of global digitalization.

Digitalization has become increasingly important in today's global economy, influencing nearly all aspects of economic activity through technological advancements such as the internet, big data, artificial intelligence, and blockchain. It is also a key driver of sustainable development, economic growth, and financial inclusion. As the digital economy expands, commercial banks—central players in the financial system—are increasingly adopting financial technologies (FinTech) and undergoing internal digital transformation to remain competitive. Existing research generally suggests that digitalization enhances bank stability. Digital innovation can improve bank soundness by reducing risk-taking behavior and promoting diversification (Hu et al., 2025). Similarly, digitalization may increase profitability and risk-taking capacity, ultimately strengthening overall stability (Liang et al., 2025). By adopting advanced financial technologies, banks can expand their customer base, reduce transaction and operational costs, and diversify revenue streams.

However, the impact of digitalization is not uniformly positive. Some studies suggest that digitalization may adversely affect banks' long-term sustainability. For example, Khattak et al. (2023) find that increased investment in technology and diversification may raise risk exposure and vulnerability. Excessive spending on technology—particularly in competitive environments—can reduce profitability. Moreover, once investment surpasses a certain threshold, banks may take on disproportionate levels of risk relative to returns, particularly in relation to disruptive cyber technologies (Uddin et al., 2020).

Over the past decade, rapid technological advancements have transformed nearly every aspect of human life, enhancing education, increasing personal freedom, and improving overall well-being. This transformation was further accelerated by the COVID-19 pandemic, which significantly increased the adoption of digital technologies. Emerging technologies such as cloud computing, blockchain, smartphones, robotics, artificial intelligence (AI), and the Internet of Things (IoT) have become central to this transformation. Digitalization continues to reshape and redefine modern society. According to Gradillas and Thomas (2025), digitalization refers to processes involving data generation, collection, and analysis to create value and enable innovation. It also encompasses the development of new digital products and the integration of digital technologies into innovation processes (Cappa et al., 2021; Lanzolla et al., 2021; Pesch et al., 2021).

Digitalization has significant implications for bank stability, as it fundamentally changes how financial institutions operate and adapt to a technologically advanced environment. Its impact is multifaceted, presenting both opportunities and challenges. On the one hand, digitalization enhances bank soundness by improving efficiency, reducing risk-taking, and promoting diversification (Hu et al., 2025; Liang et al., 2025).

On the other hand, it introduces risks such as increased dependence on digital platforms, privacy concerns, and exposure to cybercrime (Antwi & Kong, 2023; Hordofa, 2024). Despite ongoing debate, existing literature is largely limited to bank-level analyses and is heavily concentrated on specific contexts, particularly China (Hou & Yang, 2024; Hu et al., 2025; Liang et al., 2025; Yang & Masron, 2024). As a result, macro-level empirical evidence remains scarce. This study addresses this gap by employing country-level indicators of both digitalization and bank stability, thereby providing a more comprehensive global perspective. The objective is to generate policy-relevant insights that help mitigate risks and enhance the sustainability of banking systems in the digital era.

Furthermore, this study contributes to the literature by examining how the effects of digitalization on bank stability vary across countries with different levels of financial development. This distinction is important, as the impact of digitalization is likely to be heterogeneous across institutional contexts (Anton & Afloarei Nucu, 2024; Antwi & Kong, 2023; Liang et al., 2025; Vuong et al., 2025). To capture these differences, the sample is divided into two groups—low and high financial development—based on the Financial Development Index. In countries with low financial development, financial systems tend to be less diversified, more bank-dependent, and characterized by weaker regulatory quality and limited market depth. In contrast, countries with more advanced financial systems typically exhibit greater diversification, deeper markets, and stronger integration with global financial systems (Cicchello et al., 2021; Dalloshi, 2022; Morales & Reding, 2021). These differences have important policy implications, particularly in areas such as risk governance, financial inclusion, and liquidity management. The findings can help policymakers design digital transformation strategies that are aligned with institutional capacity.

Finally, this study employs the Digitalization Index (DIG), developed by Afolabi (2025), as a comprehensive measure of digitalization. The index is constructed from multiple information and communications technology (ICT) indicators, including secure internet servers, mobile cellular subscriptions, internet users, fixed broadband subscriptions, and fixed telephone subscriptions. Using a composite index allows for a more robust and comprehensive assessment of digitalization compared to single-indicator measures. It captures variations in digital development across countries and reflects differences in ICT infrastructure, technological adoption, and government investment. As such, DIG provides a more nuanced understanding of how digitalization influences economic and financial systems.

The remainder of this paper is structured as follows. Section 2 presents the theoretical framework, literature review, and hypothesis development. Section 3 describes the data and methodology. Section 4 discusses the empirical results, and Section 5 concludes.

2. Literature Review

2.1. Theoretical Framework

In the context of the Competition-Stability Theory, digitalization acts as a catalyst for bank robustness by augmenting franchise value and reducing information asymmetry. Traditionally, this theory argues that a reduction in market power, or an increase in banking competition, may enhance bank stability (Amidu & Wolfe, 2013; Boyd & De Nicolo, 2005). More competition, in particular, usually leads to lower lending interest rates, which reduces borrowers' repayment burden and default risk. As a result, there is less chance of loan defaults and non-performing loans, which

contributes to the banking system's increased stability. Furthermore, the theory suggests that stability is enhanced through superior risk screening; the integration of Big Data and AI allows banks to better differentiate between high- and low-quality borrowers (Chai & Sun, 2024; Sinha & Aggarwal, 2025). Banks can lessen adverse selection and lower the number of non-performing loans by substituting accurate, real-time digital analytics for opaque "soft information". Therefore, digital competition can promote a more robust banking system where stability is derived from technological superiority, diversified fee-based income, and improved monitoring capabilities, rather than creating fragility through margin compression.

The Competition–Fragility Theory, developed by Keeley (1990), suggests that digitalization can increase banking fragility by intensifying competitive pressure and reducing banks' charter value. According to this theory, greater competition in the banking sector erodes banks' charter value and profit margins, thereby encouraging greater risk-taking behavior. Digitalization, through the adoption of financial technologies, online banking platforms, and data-driven financial services, can intensify competition by lowering entry barriers and enabling new players such as fintech firms and digital platforms to provide alternative financial services (Hao et al., 2023; Khattak et al., 2023). As competitive pressure increases, traditional banks may face declining market power and shrinking profitability. To maintain their returns and market share, banks may respond by expanding lending activities or engaging in riskier financial operations. Such behavior can weaken banks' financial resilience and increase their vulnerability to shocks (Wang et al., 2024). Therefore, consistent with the Competition–Fragility hypothesis, the expansion of digitalization may reduce bank stability by intensifying competition and encouraging higher levels of risk-taking within the banking sector.

2.2. Digitalization and Bank Stability

Digitalization may influence bank stability in positive as well as negative ways. On the one hand, digitalization can increase stability by enhancing operational efficiency, expanding financial services, boosting risk management, and lowering transaction costs. On the other hand, swift digital adoption may also provide new concerns, including cybersecurity threats, operational vulnerabilities, and heightened competitive pressure from fintech companies, which could possibly undermine bank stability. Therefore, its benefits depend on careful implementation, appropriate investment levels, and integration with broader bank strategies, underscoring the need for balanced, well-governed digital adoption in banking. In accordance with previous studies (Luu et al., 2023; Xu & Yang, 2024; Yang & Masron, 2024), we employ the z-score, non-performing loans ratio (NPL), and liquidity risk as indicators of bank stability for banks.

2.2.1. Z-Score

The z-score quantifies the divergence from bank failure by employing accounting metrics to ascertain the distance from default. A bank is more stable the greater the divergence. It is computed as the sum of return on assets and the equity-to-asset ratio, divided by the standard deviation of return on assets. The z-score is used in a number of studies to determine banks' stability (Liang et al., 2025; Quagliariello, 2008; R. Wang & Luo, 2022).

Similarly, Liang et al. (2025) discovered that digital financial development (DFD) enhances the stability of commercial banks. Using unbalanced panel data from 187 Chinese commercial banks over the period 2010–2021, the authors examine banks' profitability and risk-taking behavior and analyze how DFD influences bank stability.

The empirical results indicate that DFD strengthens overall bank stability by improving profitability and increasing banks' risk-taking capacity. DFD enhances operational efficiency, which subsequently boosts profitability and risk-taking ability, thereby reinforcing the stability of commercial banks.

Globally, Luu et al. (2023) demonstrate that the adoption of central bank digital currencies (CBDCs) enhances financial stability, particularly within the banking sector. The study analyzes a dataset covering 1,176 financial institutions across 86 countries over the period 2010–2021, together with an international database on CBDC adoption. The empirical results reveal that the adoption of CBDCs is positively associated with greater bank stability. By strengthening the resilience of the banking sector, CBDCs contribute positively to overall financial stability.

Furthermore, Uddin et al. (2020) investigate how disruptive digital transformation influences bank stability. The authors specifically examine whether banks' stability is impacted by the rule of decreasing marginal returns from excessive CyberTech spending. According to a worldwide dataset spanning 43 nations, bank stability is adversely affected when CyberTech spending exceeds a particular threshold. Beyond this point, banks take on disproportionately greater risks for each dollar spent on disruptive CyberTech, which is the primary cause of this negative effect. There are two technological regimes: one of diminishing returns and one of increasing returns. In the diminishing returns regime, more aggressive investment in technology enhances stability, whereas in the increasing returns regime, excessive CyberTech spending undermines bank stability.

According to Khattak et al. (2023), digital transformation influences bank stability in Asian economies, particularly when the role of diversification is considered. The study examines banks operating in 29 Asian economies and finds that banks tend to become more vulnerable and riskier when they invest in technology while simultaneously diversifying their activities. Furthermore, digital transformation has a positive impact on bank stability when banks maintain a lower level of diversification. However, as diversification increases, the positive effect of digital transformation gradually weakens and may even become negative at higher levels of diversification. These findings suggest that digital transformation in less diversified activities may have a more favorable and sustainable effect on bank stability.

2.2.2. Non-Performing Loans Ratio

Lending is the core activity of banking institutions, serving as the primary channel through which banks distribute their financial resources and generate income. However, banks have created a large number of non-performing loans due to information asymmetry, endangering the stability of the financial system. In that context, digitalization has emerged as a transformative force that improves credit risk management and enhances bank stability. Existing research has deeply explored how digitalization has a negative relationship with non-performing loans.

Using survey data of 432 branches of the city's commercial banks in Beijing from 2005 to 2022, Wang et al. (2023) discovered that fintech can considerably lower the probability of non-performing loans. Banks use advanced analytics, artificial intelligence, and big data to better evaluate borrower creditworthiness, identify risks early, and make better lending decisions.

Similarly, Yang and Masron (2024) used data from 116 Chinese banks between 2014 and 2021 and the Generalized Method of Moments (GMM) to investigate how digital transformation substantially and dynamically lowers bank credit risks. Digitalization promotes financial inclusion, which can lower overall credit risk and increase borrowers' capacity to repay.

In addition, Sinha and Aggarwal (2025) investigated how technology innovation reduces non-performing assets. Banks can automate credit risk assessment procedures, spot possible non-performing assets early, and make well-informed decisions to avoid defaults thanks to AI-powered algorithms. Furthermore, blockchain technology lowers the risk of fraud and improves the integrity of loan transactions by offering a transparent and safe platform for managing loan contracts and collateral documentation.

Moreover, based on listed firms from 2011 to 2022, Chai and Sun (2024) adopted a two-fixed model to explore the effects and underlying mechanisms of how commercial banks' fintech development can mitigate non-performing loan risk. Results show that fintech development can reduce non-performing loan (NPL) risk by lowering pre-lending and post-loan costs and increasing revenue.

Furthermore, Wang et al. (2024) offer conflicting evidence, indicating that digitalization may have both stabilizing and destabilizing effects. The empirical findings demonstrate that: (1) digitalization dramatically reduces balance sheet risk-taking while simultaneously increasing off-balance sheet risk exposure; (2) digitalization reduces on-balance sheet risk by mitigating competition distortions caused by government guarantees, thereby generating a competition effect related to on-balance sheet guarantees; (3) digitalization raises the upper bound of expected returns on bank financial products, thereby increasing off-balance sheet risk-taking and leading to an off-balance sheet price competition effect; and (4) bank digitalization has a more pronounced positive impact on off-balance sheet risk-taking for banks with a longer average maturity of wealth management products.

2.2.3. Liquidity Risk

Digitalization generally supports improved liquidity risk management and reduces liquidity risk when implemented effectively, but it can also introduce new vulnerabilities. The overall effect is determined by the particular financial climate, regulatory adaptation, and the quality of digital transformation.

Several studies indicate that digitalization can lower liquidity risk and improve banks' efficiency in managing liquidity. For instance, Xu and Yang (2024) employ an empirical econometric model to examine the impact of digitalization on bank liquidity creation, focusing on 198 Chinese commercial banks from 2011 to 2019. The authors indicate that a higher level of digitalization in commercial banks significantly enhances their ability to create liquidity. Moreover, heterogeneity test results show that the impact of digitization on enhancing liquidity creation differs based on the bank's size and the level of integration between the financial and industrial sectors.

Similarly, Hou and Yang (2024) examine the bidirectional relationship between bank digital transformation and liquidity mismatch, using data from 181 Chinese commercial banks prior to the COVID-19 pandemic. They reveal a two-way causal relationship between digital transformation and the liquidity mismatch index. Specifically, a higher level of digital transformation significantly reduces the liquidity mismatch index, while a decrease in the index encourages banks to further accelerate their digital transformation. This suggests that digital transformation may increase banks' vulnerability to liquidity stress, although banks facing higher levels of liquidity mismatch tend to promote digital transformation more actively.

Moreover, other branches of studies highlight the risks of digitalization under certain conditions. Hao et al. (2023) investigate the effect of the expansion of digital finance on the production of bank liquidity using 118 Chinese banks from 2011 to 2020. The authors discover that bank liquidity creation is negatively impacted by the growth of digital finance. The inhibitory effect has less of an influence on off-balance sheet

liquidity creation and is primarily present in asset-side and on-balance sheet liquidity creation. This negative impact is more pronounced in large banks, national banks, and banks in the western region of China. The bank risk-taking level mediates the relationship between digital finance development and bank liquidity creation.

However, other research suggests that by decreasing banks' ability to generate liquidity, digitalization may raise liquidity risk. For example, Wang et al. (2025) examine 162 Chinese commercial banks from 2012 to 2022 and find that digital transformation leads to a decline in liquidity creation. This outcome is mainly driven by management digitalization, which reduces banks' willingness to take risks. The improvement in managerial efficiency and the streamlining of internal processes brought about by digitalization can lead banks to hold fewer liquid assets, thereby weakening their role in providing liquidity to the economy.

In contrast, empirical evidence from the Vietnamese banking sector presents a more neutral perspective. Based on panel data from 26 Vietnamese commercial banks between 2013 and 2022, Hoque et al. (2024) find that digital transformation significantly reduces credit and insolvency risks by improving risk management capabilities and lowering costs. However, it shows no significant effect on liquidity risk, as digital channels simultaneously expand lending activities and mobilize more deposits, creating an offsetting effect. This indicates that digitalization's influence on liquidity risk may depend on how digital technologies are integrated into banks' lending and funding strategies.

3. Methods and Data

3.1. Data

To investigate the determinants of bank stability across the globe, this study applies an unbalanced panel dataset for 143 economies covering 2010-2021 due to data availability. To fully address the concern about whether the determinants of bank stability differ across economies with different financial development levels, our sample is divided into two groups: low financial development level and high financial development level. Even though we tried our best to balance the panel, it was not possible to do so for all countries and variables. Therefore, the panel remains to some extent unbalanced due to the lack of data for all the variables for every year and every economy. Furthermore, the degree to which the economy report determines the accessibility of secondary data from global sources. Our data sources are BankFocus, the International Monetary Fund (IMF), the World Development Indicator (WDI), and the World Bank (WB).

In order to examine the varied effects according to the financial development level, we use a dummy variable (FD), to divide economies into two groups: High Financial Development level and Low Financial Development level. The following is how the classifying procedure is carried out: The annual cross-sectional mean of the financial development level for every economy in the sample is first determined for each particular year. The dummy variable $FD_{i,t}$ is then given a value that represents the nation's standing when compared to that yearly average; $FD = 1$ indicates that a country's financial development level is above the mean for that specific year (corresponding to the High Financial Development level group), and $FD = 0$ indicates that the level is equal to or lower than the mean (corresponding to the Low Financial Development level group). Instead of employing a static, possibly biased benchmark, this time-varying threshold guarantees that the categorization takes into account worldwide patterns in financial growth across the sample period. Next, we sorted

groups of high and low financial development level economies by FD dummy. We divided full sample into 2 sub – samples: sample of high financial development level economies and sample of low financial development level economies.

Table 1. Variable Description

Variable name	Variable	Measurement	Sources	Expected sign
Bank stability				
Banking system Z-score	ZSCORE	The sum of return on assets and the equity-to-asset ratio, divided by the standard deviation of return on assets.	BankFocus	
Non-performing loan	NPL	Ratio of non-performing loans to total loans	WDI	
Digitalization				+/-
Digitalization index	DIG	Composite indicator constructed from digital infrastructure and usage variables.	Author's calculation (based on WDI indicators)	
Fixed telephone subscriptions	FTE	Fixed telephone subscriptions (per 100 people)	WDI	
Fixed broadband subscriptions	FBB	Fixed broadband subscriptions (per 100 people)	WDI	
Internet penetration	IPE	Individuals using the Internet (% of population)	WDI	
Secure internet servers	SIS	Secure Internet servers (per 1 million people)	WDI	
Mobile cellular subscriptions	MOS	Mobile cellular subscriptions (per 100 people)	WDI	
Control variables				
Bank assets	BAS	Total assets held by deposit money banks as a share of GDP	IMF	+
Bank cost-to-income ratio	BCI	Banks' operating costs as a percentage of total revenue.	BankFocus	-
Bank interest revenue	BIR	Net interest revenue as a percentage of average interest-earning assets.	BankFocus	+
Bank concentration	BCT	Ratio of the total assets of the three largest banks to total banking system assets.	BankFocus	-
Household final consumption expenditure	HCE	Household consumption expenditure as a percentage of GDP.	WB	+
Capital investment	CIB	Natural logarithm of gross capital formation (including inventory changes).	WB	+

Source: Authors' compilations.

Table 2. Descriptive Statistics

Panel	Statistics	ZSCORE	NPL	DIG	BAS	BCI	BIR	BCT	HCE	CIB
Global panel	Mean	16.770	6.807	0.133	66.290	55.661	4.194	67.369	62.286	2.632
	SD	9.628	7.748	0.131	45.011	13.846	2.531	19.371	16.713	2.168
	Min.	-0.330	0.090	0.000	2.980	5.030	0.170	16.140	5.040	-3.507
	Max.	66.630	61.120	1.000	283.910	202.040	15.440	100.000	129.740	8.947
Low financial development level	Mean	16.188	8.642	0.058	39.432	57.363	5.629	67.292	69.916	1.340
	SD	8.225	7.944	0.071	22.924	13.728	2.554	20.473	15.574	1.594
	Min.	0.500	0.130	0.000	4.370	21.060	0.280	16.140	5.040	-3.507
	Max.	66.630	55.080	0.342	211.870	202.040	15.440	100.000	117.390	4.861
High financial development level	Mean	17.226	5.423	0.196	91.134	54.308	3.070	67.430	55.944	3.675
	SD	10.581	7.303	0.137	46.152	13.798	1.855	18.469	14.881	2.003
	Min.	-0.330	0.090	0.000	2.980	5.030	0.170	27.990	12.770	-1.427
	Max.	62.440	61.120	1.000	283.910	118.190	12.830	100.000	129.740	8.947

Source: Authors' calculations.

Table 3. Pearson Correlation Matrix

No.	Variables	1	2	3	4	5	6	7	VIF
1	DIG	1							1.87
2	BAS	0.560	1						2.17
3	BCI	0.169	-0.160	1					1.26
4	BIR	-0.518	-0.620	0.048	1				2.33
5	BCT	0.066	0.019	-0.056	-0.074	1			1.34
6	HCE	-0.317	-0.342	0.289	0.463	-0.152	1		1.67
7	CIB	0.406	0.481	-0.066	-0.445	-0.310	-0.426	1	1.94

Source: Authors' calculations.

Table 3 presents the Pearson correlation coefficients among the independent variables used in the model. The results indicate that the highest correlation is observed between BIR and BAS (-0.620), suggesting a moderate negative relationship. Overall, the correlation coefficients remain below commonly accepted thresholds, indicating no severe multicollinearity concerns. This is further supported by the variance inflation factors (VIFs), which range between 1 and 3, confirming that multicollinearity is not a significant issue in the estimation.

3.2. Research Model and Methodology

This study develops two dynamic panel models to examine the impact of digitalization on bank stability:

$$\begin{aligned} \text{ZSCORE}_{i,t} = & \beta_0 + \beta_1 \text{ZSCORE}_{i,t-1} + \beta_2 \text{DIG}_{i,t} + \beta_3 \text{BAS}_{i,t} + \beta_4 \text{BCI}_{i,t} \\ & + \beta_5 \text{BIR}_{i,t} + \beta_6 \text{BCT}_{i,t} + \beta_7 \text{HCE}_{i,t} + \beta_8 \text{CIB}_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (1)$$

$$\begin{aligned} \text{NPL}_{i,t} = & \beta_0 + \beta_1 \text{NPL}_{i,t-1} + \beta_2 \text{DIG}_{i,t} + \beta_3 \text{BAS}_{i,t} + \beta_4 \text{BCI}_{i,t} \\ & + \beta_5 \text{BIR}_{i,t} + \beta_6 \text{BCT}_{i,t} + \beta_7 \text{HCE}_{i,t} + \beta_8 \text{CIB}_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2)$$

where i and t denote economy and year, respectively. The dependent variables are bank stability (ZSCORE) and credit risk (NPL). Consistent with prior studies (Alam & Yusuf, 2024a; DeYoung & Jang, 2016; Mahmud, 2023), bank stability is proxied by the Z-score, where higher values indicate lower insolvency risk. Credit risk is measured by the ratio of non-performing loans (NPL), with higher values reflecting greater credit risk, reduced profitability, and weaker asset quality, all of which may undermine banking stability (Park & Shin, 2021).

Following Afolabi (2025), a composite digitalization index (DIG) is constructed using Principal Component Analysis (PCA) based on five indicators: fixed telephone subscriptions, fixed broadband subscriptions, internet users, secure internet servers, and mobile cellular subscriptions. All data are obtained from the World Development Indicators (WDI) database. The resulting index ranges from 0 (low digitalization) to 1 (high digitalization). To ensure comparability across variables with different units and scales, all indicators are standardized prior to PCA by subtracting the mean and dividing by the standard deviation. This procedure prevents variables with larger magnitudes from disproportionately influencing the results. Zero values are treated as valid observations reflecting the absence of ICT infrastructure rather than missing data, thereby preserving the underlying variation in the dataset. Observations with missing values are excluded. The PCA is conducted on the full global sample rather than within subgroups, allowing for a consistent benchmark of digital development and enabling cross-country comparability along a unified technological frontier.

The set of control variables includes bank assets (BAS), bank cost-to-income ratio (BCI), bank interest revenue (BIR), bank concentration (BCT), household final consumption expenditure (HCE), and capital investment (CIB).

To address potential endogeneity and unobserved heterogeneity, this study employs the Dynamic System Generalized Method of Moments (DGMM) estimator. The inclusion of lagged dependent variables introduces dynamic panel bias, which DGMM effectively mitigates by using internal instruments. Compared with Fixed Effects (FEM) and Pooled Ordinary Least Squares (POLS), DGMM provides more efficient and consistent estimates by exploiting additional moment conditions. It also accounts for time-invariant unobserved heterogeneity, autocorrelation, and heteroskedasticity. When the number of instruments is appropriately controlled relative to the sample size, DGMM yields reliable and robust parameter estimates.

4. Results and Discussion

This section presents the empirical findings from the DGMM estimation. The analysis focuses on the impact of digitalization on bank stability (ZSCORE) and credit risk (NPL), using both the full sample and subsamples based on the level of financial development. Table 4 reports the regression results for the global sample, as well as for economies with low and high levels of financial development.

Table 4. Regression Results

	Global sample		Low financial development level		High financial development level	
	(1) ZSCORE	(2) NPL	(1) ZSCORE	(2) NPL	(1) ZSCORE	(2) NPL
L.ZSCORE	0.810*** (0.070)		0.666*** (0.103)		0.796*** (0.034)	
L.NPL		0.980*** (0.017)		0.932*** (0.018)		1.283*** (0.023)
DIG	-9.985* (5.619)	6.238* (3.190)	-40.400*** (15.450)	-8.428** (3.413)	5.574* (3.080)	-7.767*** (2.580)
BAS	0.019** (0.008)	0.047*** (0.011)	-0.002 (0.020)	-0.007 (0.005)	0.017** (0.007)	0.021*** (0.006)
BCI	0.002 (0.020)	-0.049 (0.039)	0.042 (0.062)	-0.043** (0.019)	-0.020 (0.019)	-0.041*** (0.015)
BIR	0.004 (0.076)	0.442** (0.177)	0.897*** (0.233)	-0.263*** (0.082)	0.034 (0.188)	-0.317*** (0.115)
BCT	-0.012 (0.013)	-0.008 (0.011)	0.039** (0.016)	-0.002 (0.005)	-0.070*** (0.022)	0.069*** (0.017)
HCE	-0.019 (0.018)	0.028 (0.023)	-0.031 (0.028)	0.011 (0.007)	-0.115* (0.065)	0.222*** (0.031)
CIB	0.009 (0.147)	-0.386* (0.200)	0.993*** (0.310)	-0.173** (0.082)	-0.730* (0.400)	0.545 (0.332)
Constant	5.113*** (1.919)	-3.289 (2.636)	-1.463 (4.658)	4.751*** (1.236)	14.940*** (4.536)	-18.160*** (2.513)
Observations	1,341	1,063	768	573	528	452
Number of Instruments	11	42	14	43	13	42
AR (1)	0.000	0.008	0.000	0.053	0.000	0.008
AR (2)	0.646	0.113	0.680	0.328	0.997	0.113
Hansen Test	0.379	0.278	0.168	0.377	0.549	0.278
Different-in-Hansen Test	0.379	0.597	0.168	0.363	0.549	0.597

Source: Authors' calculations.

Note: This table shows the DGMM estimation of the impact of digitalization on bank stability, proxied by ZSCORE and NPL, respectively. The numbers in parentheses are standard errors. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

4.1. Baseline Results (Global Sample)

Table 4 indicates a negative and statistically significant relationship between digitalization (DIG) and bank stability (ZSCORE) in the global sample. This suggests that digital expansion may initially weaken banks' resilience, primarily due to high technology adoption costs and increased exposure to cyber risks. In many financial systems, digitalization remains at an early stage, where substantial installation and adaptation expenses may reduce short-term profitability and overall stability. This finding is consistent with Wang et al. (2024), who report that digitalization may adversely affect bank soundness.

From a theoretical perspective, this result aligns with the competition–fragility hypothesis, which posits that intensified competition in the banking sector can undermine financial stability. Digitalization lowers entry barriers and increases competition from fintech firms and technology-driven financial service providers, thereby compressing banks' profit margins. In response, banks may undertake riskier activities to sustain profitability, ultimately weakening their stability.

In addition, digitalization (DIG) is found to have a positive and statistically significant effect on credit risk (NPL) at the 10% level. This implies that digitalization may increase credit risk, particularly in environments with limited data infrastructure. The early adoption of digital technologies and heavy reliance on automated credit assessment models may reduce the accuracy of borrower evaluation. Consequently, rapid expansion of digital lending may increase default risk. This finding is consistent with Cao et al. (2022), who document a positive association between digitalization and non-performing loans.

4.2. Heterogeneity by Financial Development Level

The impact of digitalization varies substantially across different levels of financial development. In economies with low financial development, digitalization is negatively associated with ZSCORE and NPL. This indicates that while digital tools may improve borrower screening and reduce non-performing loans, the high initial costs of digital adoption and operational adjustments may weaken overall bank stability.

In contrast, digitalization has a stabilizing effect in economies with high financial development. The results show a positive relationship with ZSCORE and a negative association with NPL. This suggests that banks in more developed financial systems are better able to leverage digital technologies due to more advanced infrastructure, greater data availability, and stronger regulatory frameworks. Digitalization enhances credit screening, monitoring, and risk management, thereby improving asset quality, strengthening capital buffers, and promoting overall banking stability.

4.3. Control Variables and Economic Interpretation

Bank assets (BAS) have a positive and statistically significant effect on ZSCORE, indicating that larger banks tend to be more stable. This reflects economies of scale, improved diversification, and better access to capital. In addition, large banks may benefit from implicit government guarantees, consistent with the “too-big-to-fail” argument. This finding is in line with Alam and Yusuf (2024b), who emphasize the superior shock-absorption capacity and risk management capabilities of larger banks.

However, BAS also exhibits a positive and significant relationship with NPL, suggesting that larger banks may face higher credit risk. As banks expand their asset base, they may engage in more aggressive lending strategies, potentially lowering credit standards and increasing exposure to riskier borrowers. This result is consistent with Dao (2020), Isa et al. (2023), and Harimurti et al. (2022).

The bank cost-to-income ratio (BCI) does not show a significant relationship with either ZSCORE or NPL in the global sample, indicating that operational efficiency does not have a consistent effect on bank stability or credit risk. However, in both low and high financial development subsamples, BCI is negatively associated with NPL, suggesting that higher operating costs—potentially reflecting more intensive monitoring and screening—may help reduce credit risk.

Bank interest revenue (BIR) is positively and significantly related to NPL in the global sample, indicating that banks relying heavily on interest income may expand lending aggressively, thereby increasing credit risk. However, this relationship differs across subsamples. In some contexts, higher interest income reflects better-performing loans and stronger repayment capacity, resulting in improved loan quality. This highlights the dual role of interest income depending on the structure and maturity of financial systems.

Bank concentration (BCT) exhibits contrasting effects across subsamples. In highly developed financial systems, BCT is negatively associated with ZSCORE and positively associated with NPL, suggesting that concentrated banking systems may encourage risk-taking due to moral hazard and “too-big-to-fail” expectations. This finding is consistent with Uhde and Heimeshoff (2009). In contrast, in less developed financial systems, BCT is positively associated with ZSCORE, indicating that concentration may enhance monitoring efficiency and improve credit screening, thereby strengthening stability (Yudaruddin, 2022).

Household final consumption expenditure (HCE) shows a negative relationship with ZSCORE and a positive relationship with NPL in highly developed economies. This suggests that consumption in these economies is often credit-driven, increasing household leverage and repayment risks, which may weaken bank stability and raise non-performing loans.

Capital investment (CIB) has a positive effect on ZSCORE, particularly in economies with low financial development, indicating that higher investment supports economic activity, improves borrower performance, and enhances bank stability. However, in highly developed financial systems, CIB is negatively associated with ZSCORE, suggesting that rapid investment growth may be accompanied by excessive lending and risk-taking, which can weaken asset quality and increase vulnerability to economic shocks (Bruno & Shin, 2015).

Moreover, CIB is negatively and significantly associated with NPL, indicating that higher levels of capital investment contribute to improved loan quality and reduced credit risk. Increased investment supports business expansion and stable cash flows, thereby enhancing borrowers’ repayment capacity and strengthening banks’ asset quality (Abbas et al., 2021).

4.4. Discussion and Theoretical Implications

Overall, the findings highlight the dual nature of digitalization as a “double-edged sword” in banking systems. While digitalization can enhance efficiency, risk management, and financial inclusion, it may also introduce new vulnerabilities, particularly in the early stages of adoption or in less developed financial systems.

The results provide strong support for the competition–fragility hypothesis, suggesting that increased competition driven by digital transformation may encourage risk-taking behavior and weaken stability. At the same time, the heterogeneous effects across financial development levels emphasize the importance of institutional quality, regulatory capacity, and digital infrastructure in shaping the outcomes of digitalization.

These findings underscore that the benefits of digitalization are not automatic but depend critically on the maturity of the financial ecosystem. Policymakers should therefore consider the stage of financial development when designing digitalization strategies, ensuring that supporting infrastructure, regulatory frameworks, and risk management systems are sufficiently developed to mitigate potential adverse effects.

5. Conclusions

This study contributes to the literature by providing a comprehensive assessment of how digitalization affects bank stability across economies with different levels of financial development. By comparing countries at varying stages of financial and technological advancement, the findings demonstrate that the impact of digitalization is not uniform but depends critically on differences in technological infrastructure, regulatory capacity, and the overall sophistication of the financial system.

This contribution is strengthened using a multidimensional Digitalization Index (DIG), following Afolabi (2025), which incorporates five ICT indicators: secure internet servers, mobile cellular subscriptions, internet users, fixed broadband subscriptions, and fixed telephone subscriptions. By capturing multiple dimensions of digital progress, the index provides a more comprehensive measure of digitalization and allows for meaningful cross-country comparisons.

Using a panel dataset of 143 economies from 2010 to 2021, the empirical results show that digitalization is generally associated with lower bank stability and higher non-performing loans at the global level. These findings suggest that, particularly in the early stages of adoption, digitalization may expose banks to higher operational costs, cyber risks, and limitations in automated credit assessment systems.

Importantly, the effects of digitalization vary significantly across levels of financial development. In economies with low financial development, digitalization reduces credit risk but weakens overall bank stability due to high implementation and operational costs. In contrast, in highly developed financial systems, digitalization enhances bank stability and improves asset quality, supported by more advanced infrastructure, greater data availability, and stronger regulatory frameworks. However, risks related to moral hazard, bank concentration, and credit-driven consumption may still pose challenges in these economies.

Overall, the findings highlight that digitalization acts as a “double-edged sword” in the banking sector. Its impact depends fundamentally on the maturity of the financial system and the supporting institutional environment.

6. Policy Implications

The empirical findings suggest that policy responses to digitalization should be tailored to the structural characteristics and institutional capacity of each group of economies.

For economies with low levels of financial development, digitalization is associated with reduced credit risk but declining bank stability. While digital tools improve borrower screening, the high costs of technology adoption and operational adjustments may weaken banks' profitability and capital buffers. Policymakers should therefore focus on reducing the financial burden of digital transformation. This can be achieved through targeted incentives for digital infrastructure investment and phased implementation strategies that allow banks to gradually adopt new technologies. Strengthening national digital infrastructure, including reliable internet connectivity and secure data systems, is also essential to improve the effectiveness of digital tools and reduce operational inefficiencies.

In contrast, in economies with high levels of financial development, digitalization enhances bank stability and reduces credit risk. In these contexts, policymakers should prioritize strengthening supervisory and regulatory frameworks to ensure that digital technologies are effectively used for credit monitoring and risk management. Maintaining a balance between innovation and financial stability is crucial, particularly in highly concentrated banking systems where moral hazard and excessive risk-taking may arise.

Overall, digitalization should not be viewed as a universally stabilizing force. Its effectiveness depends on the level of financial development and the quality of the regulatory environment. Tailored policy frameworks that reflect these structural differences are therefore essential to ensure that digital transformation contributes to a more stable and resilient banking system.

7. Ethics Statement

This study used secondary data from publicly available sources and did not involve human participants, personal identifiable information, or primary data collection. Therefore, ethics committee approval was not required.

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9. Appendices

Table 5. Digitalization Index using Principal Component Analysis (PCA)

Principal components/correlation		Number of obs = 2,515		
		Number of comp.= 5		
		Trace = 5		
Rotation: (unrotated = principal)		Rho = 1.0000		
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.974	2.062	0.594	0.594
Comp2	0.911	0.212	0.182	0.777
Comp3	0.698	0.400	0.139	0.916
Comp4	0.297	0.180	0.059	0.976
Comp5	0.117	-	0.023	1.000

Principal components (eigenvectors)

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Unexplained
FBB	0.539	0.019	-0.289	-0.134	-0.779	0
FTE	0.471	-0.241	-0.502	0.544	0.412	0
IPE	0.522	-0.053	0.104	-0.717	0.445	0
MOS	0.388	-0.260	0.801	0.359	-0.097	0
SIS	0.249	0.933	0.106	0.203	0.121	0

Source: Authors' calculations.

Table 6. Variable Definition

Variable	Definition	Source
ZSCORE	“It captures the probability of default of a country's banking system. Z-score compares the buffer of a country's banking system (capitalization and returns) with the volatility of those returns. It is estimated as $(ROA + (equity/assets))/sd(ROA)$; $sd(ROA)$ is the standard deviation of ROA, calculated for country-years with no less than 5 bank-level observations. ROA, equity, and assets are country-level aggregate figures. Calculated from underlying bank-by-bank unconsolidated data from Bankscope and Orbis. The result is not reported if a country-year has less than 3 bank-level observations.”	(World Bank, 2025d)
BAS	“Total assets held by deposit money banks as a share of GDP. Assets include claims on domestic real nonfinancial sector which includes central, state and local governments, nonfinancial public enterprises and private sector. Deposit money banks comprise commercial banks and other financial institutions that accept transferable deposits, such as demand deposits.”	(World Bank, 2025e)
BIR	“Accounting value of bank's net interest revenue as a share of its average interest-bearing (total earning) assets. Raw data are from Bankscope and Orbis. The formula applied to Bankscope is $\sum \text{Net revenue} / \sum \text{Average interest-bearing assets}$ and a comparable approach is applied to Orbis. Numerator and denominator are aggregated on the country level before division. Note that banks used in the calculation might differ between indicators. Calculated from underlying bank-by-bank	(World Bank, 2025c)

Variable	Definition	Source
BCT	unconsolidated data from Bankscope and Orbis. The result is not reported if a country-year has less than 3 bank-level observations.” “Assets of three largest commercial banks as a share of total commercial banking assets. Total assets include total earning assets, cash and due from banks, foreclosed real estate, fixed assets, goodwill, other intangibles, current tax assets, deferred tax assets, discontinued operations and other assets. Raw data are from Bankscope and Orbis. The formula applied to Bankscope is $\sum \text{Total of assets of the three largest banks} / \sum \text{Total banking assets}$ and a comparable approach is applied to Orbis. Calculated from underlying bank-by-bank unconsolidated data from Bankscope and Orbis.”	(World Bank, 2025a)
BCI	“Operating expenses of a bank as a share of sum of net-interest revenue and other operating income. Raw data are from Bankscope and Orbis. The formula applied to Bankscope is $\sum \text{Operating expense} / \sum (\text{Net interest revenue} + \text{other operating income})$ and a comparable approach is applied to Orbis. All Numerator and denominator are first aggregated on the country level before division. Note that banks used in the calculation might differ between indicators. Calculated from underlying bank-by-bank unconsolidated data from Bankscope and Orbis. The result is not reported if a country-year has less than 3 bank-level observations.”	(World Bank, 2025b)
Financial development (FDI)	The Financial Development Index (FDI) is an aggregate measure at the country level that reflects the overall advancement of the financial system, including financial institutions and markets, across the following aspects: depth, access, and efficiency; following the methodology of Svirydzenka (2016).	(International Monetary Fund, 2025)

Source: Authors' compilations.