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Digital Finance and Banking Stability: Balancing Inclusion and Risk in Asian Economies

(Kewangan Digital dan Kestabilan Perbankan: Mengimbangi Rangkuman dan Risiko dalam Ekonomi Asia)

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ABSTRACT

This study investigates the relationship between digital financial inclusion (DFI), the digital economy (DE), and bank stability across 33 Asian economies from 2010 to 2022. Using Z-score (ZS) and Non-Performing Loans (NPLs) as measures of stability, the analysis employs Generalized Method of Moments (GMM), Generalized Least Squares (GLS), and Panel-Corrected Standard Error (PCSE) models. The findings show that DFI negatively impacts ZS and increases NPLs, indicating higher risks associated with financial inclusion. Conversely, DE positively affects ZS, enhancing bank stability, although its effect on NPLs is minimal. These results highlight the double-edged nature of DFI and the stabilizing role of DE in the banking sector. Policymakers must balance efforts to promote DFI with measures to manage associated risks, such as improving credit assessment tools and strengthening digital infrastructure. This study contributes to understanding the dynamics of digital financial transformation and its implications for banking risk in developing economies.

Keywords: Asian economies; banking sector risk management; business strategies; digital economy; digital financial inclusion

ABSTRAK

Penyelidikan ini mengkaji hubungan antara rangkuman kewangan digital (DFI), ekonomi digital (DE) dan kestabilan bank merentas 33 ekonomi Asia dari 2010 hingga 2022. Menggunakan skor-Z (ZS) dan Pinjaman Tidak Berbayar (NPL) sebagai ukuran kestabilan, analisis menggunakan model Kaedah Umum Detik (GMM), Kuasa Dua Terkecil (GLS) dan Ralat Piawai Panel-Diperbetulkan. Keputusan menunjukkan bahawa DFI memberi kesan negatif kepada ZS dan meningkatkan NPL, menunjukkan risiko yang lebih tinggi yang berkaitan dengan rangkuman kewangan. Sebaliknya, DE memberi kesan positif kepada ZS, meningkatkan kestabilan bank, walaupun kesannya terhadap NPL adalah minimum. Keputusan ini menyerlahkan sifat dwi-mata DFI dan peranan penstabilan DE dalam sektor perbankan. Pembuat dasar mesti mengimbangi usaha untuk mempromosikan DFI dengan langkah mengurus risiko yang berkaitan, seperti menambah baik alat penilaian kredit dan mengukuhkan infrastruktur digital. Kajian ini menyumbang kepada pemahaman dinamik transformasi kewangan digital dan implikasinya terhadap risiko perbankan dalam ekonomi membangun.

Kata kunci: Ekonomi Asia; ekonomi digital; pengurusan risiko sektor perbankan; rangkuman kewangan digital; strategi perniagaan

INTRODUCTION

Digitalization has transformed banking sectors worldwide, significantly impacting developed and developing countries (Bakhsh et al. 2024). The global financial crisis and the COVID-19 pandemic over the past two decades have exposed the vulnerability and systemic risks in the international financial system (Hoffart et al. 2024). These events highlighted the urgent need for a more resilient and inclusive banking sector, one capable of withstanding economic shocks and supporting long-term economic viability. However, the World Bank Global Findex Report (2021) shows that 1.4 billion adults remain unbanked, with a large proportion residing in Asian economies (World Bank 2021). In these regions, although over half of the adult population owns mobile phones, 65% of adults in the poorest developing countries still lack access to a

formal bank account, and only 20% use a formal financial institution to save (Demirgüç-Kunt et al. 2022a). Banks from developing countries have started pursuing digital financial services with a more enthusiastic interest in reducing the unbanked population and incorporating them into the mainstream banking sector. This has deepened financial access and aims to improve economic stability and growth.

In the wake of these developments, DFI has emerged over the years as one of the most debated topics worldwide because it is critical and of utmost importance in bridging the gap in the financial inclusion of people across the world (Demirgüç-Kunt et al. 2022b; Pazarbasioglu et al. 2020). The growing adoption of digital financial services by banks across Asia and other developing regions presents significant potential for economic development. The financial system lies at the heart of the broader economy (Anu et al. 2023), mobilizing capital and facilitating efficient resource allocation (Yan & Haroon 2023). Banks are central to these systems and are considered the prime conduits for economic progress (Ashraf & Shen 2019). Their role in providing working capital and investment financing means that instability in the banking industry can trigger widespread negative effects on the broader economy (Rahman, Misra & Kumar 2024). Therefore, banks' importance is crucial due to the rising adoption of efforts to extend financial inclusion and economic growth.

In other words, the banking industry's stability becomes one of the critical pillars of global economic development (Ashraf, Arshad & Yan 2018). The role of financial intermediaries, particularly banks, in ensuring stability has attracted growing scholarly interest (Saha & Dutta 2023). The COVID-19 pandemic has highlighted the economic inequities among countries globally and, more importantly, the systemic flaws that necessitate improved financial access and financial literacy (Vasile, Panait & Apostu 2021). Likewise, the DE involves digital products contributing to the GDP and compels banks to adopt innovations connected with cutting-edge technology and methodologies (Banna & Alam 2021a). This is essential for maintaining long-term financial viability and economic stability (Tsindeliani et al. 2022). However, the precise connections between DFI, DE, and bank stability remain underexplored, particularly within emerging economies. This study therefore seeks to answer two key questions: 1) How and to what extent does DFI affect bank stability? and 2) How does DE impact the Z-score (ZS) of banks in Asian economies? Understanding these relationships is vital for formulating strategies that promote financial inclusion while safeguarding the stability and resilience of the banking sector.

To answer these questions, the research considers Asian countries as a sample due to their disparate DFI and DE development levels. The large and varied economies in these Asian countries provide a good context for analyzing the effects of DFI and DE on bank stability and NPL. Asia has some of the fastest-growing economies in the world, with the region collectively contributing about 34% to global GDP as of 2022, according to the World Bank (2022). There is a considerable variation in DFI levels, from significantly highly developed markets like Singapore and South Korea to developing economies such as Bangladesh, Sri Lanka, and Pakistan, all in one region, a rich dataset for this analysis (GSMA 2021). This further diversifies the investigations to affirm differences in digital integration and their impacts on banking stability and loan performance across varied economic contexts. The study has a robust methodological framework using the GMM for principal empirical analysis and methods like GLS and PCSE for robustness analysis. Such methodological diversity would increase the reliability of our findings. It thoroughly explains the complex relationship between DFI, DE, and bank risk proxied by ZS and NPL in this vital continent.

This study brings a significant advancement in our understanding of how DFI and the DE influence banking sector risk in Asian economies. Although existing literature has explored the relationship between DFI and individual banking indicators such as ZS (Banna & Alam 2021b; Chinoda & Kapingura 2023), DE and ZS (Guo et al. 2022; Wang, Hu & Ali 2022) or DFI and NPL (Ozili 2021b; Song, Jing & Akeba'erjiang 2021), few studies have jointly examined the combined effect of DFI and DE on bank stability, particularly using both ZS and NPL as comprehensive indicators of banking sector risk (Chen, Yan & Chen 2022; Sun et al. 2024). Moreover, most studies have been conducted in the context of developed economies or limited to individual proxies, leaving a notable gap in understanding the multi-dimensional effects of digitalization in the Asian context.

This study contributes to filling that gap by offering a novel integrated framework that jointly analyzes DFI and DE and their simultaneous effects on two key risk indicators, ZS (banking stability) and NPL (loan performance). It also employs a richer set of proxies to better capture the complex and multifaceted nature of DFI and DE, improving upon previous studies that relied on single or narrow measures. Furthermore, the study uniquely focuses on Asian economies, which exhibit varying levels of digital and financial development. By using a panel of diverse countries, from developed nations like Singapore to lower-income economies like Bangladesh and Pakistan, this research provides region-specific insights that are often lacking in global literature. The methodological robustness, including the use of GMM, GLS, and PCSE techniques, further strengthens the reliability of the findings. This approach not only enhances empirical rigor but also enables the detection of nuanced relationships that might be obscured in simpler models.

Ultimately, this research offers a new perspective on how financial digitalization, through DFI and DE, jointly shapes banking sector risks in emerging Asian economies,

offering valuable implications for policymakers, regulators, and financial institutions. The study's findings further called for developing more effective strategies and policies toward better financial inclusion and stability, ultimately contributing to the primary goal of sustainable economic development of Asian economies.

The rest of the paper is organized as follows: Next section presents the relevant literature review; Subsequent section provides the methods and data used in the study; The following section includes the empirical estimation and analysis of estimations; the conclusion and policy recommendation round out in the last section.

LITERATURE REVIEW

More studies coherently and consistently analyze the variables under consideration across different settings. Many scholars have extensively researched the influence of DFI and DE on bank stability in all forms (Gomber et al. 2018; Ozili 2018; Sahay et al. 2021). Hence, these studies explicate the view and debate that centers on these relationships to derive relevant testable hypotheses.

DFI AND BANK STABILITY

The effects of DFI on bank stability are mixed, often measured using the ZS approach. On the one hand, the DFI can increase access to essential financial services, promoting financial inclusion and economic development. Ediagbonya and Tioluwani (2023) emphasized that there will only be real financial inclusion for poor families if all barriers to providing digital financial services are taken down. However, these advantages come with huge risks. Agarwal and Assenova (2024) suggest that as access to digital financial services increases, so do the cybersecurity threats and operational risks that have the potential to undermine bank stability. Similarly, Ozili (2021a) warns that the growing use of digital services heightens the risk of cyberattacks and operational failures, potentially destabilizing banks. This is validated by indicating that there are even issues within DFI in developed economies, and hence, the contention that the presence of enormous risks is also high in developed markets. He and Li (2021) also emphasize that banks' rapid and increased digitalization is often marked by the inadequacy of regulatory oversight, thus, increasing the systemic risks to the disadvantage of ZS. Li (2020) supports this view, suggesting that weak regulatory frameworks make the banking sector vulnerable. Mieg (2022) and Syed et al. (2021) add that digital finance expansion in poorly regulated regions contributes to systemic risks and financial instability. Although DFI can encourage savings and formalize the economy, the associated risks may outweigh the benefits, undermining bank stability as reflected in the ZS. This highlights the dual nature of DFI: it offers both significant benefits and notable risks.

Furthermore, DFI increases access to financial services, it also elevates the risk of NPLs. Sahay et al. (2021) argue that enhanced credit availability through DFI promotes financial inclusion but simultaneously introduces vulnerabilities, particularly in regions with weak regulatory frameworks. Expanded credit access, especially among less creditworthy customers, will likely result in higher NPLs. Sahay et al. (2021) argue that increased credit availability due to DFI increases financial inclusion while simultaneously introducing vulnerabilities, especially for regions with weak regulatory frameworks. This heightened credit access, especially among less creditworthy customers, would likely result in NPLs. The same assertion is supported by Qadri et al. (2023), whose study shows that digital finance inflates systemic risks and, concurrently, financial instability and NPLs increase in South Asian countries. It is here that extreme regulatory measures become necessary. Ozili (2023) also finds that DFI raises operational costs and credit risks, further fueling NPLs. While, Chen and Nesterov (2023) believe digital finance supports risk management, Mieg (2022) counters this, pointing out systemic threats. The contrast underlines the increased access and associated risks as a nature of a complex balancing exercise. Besides, appropriate risk management practice is paramount in mitigating the possibility of DFI negatively affecting bank stability. The latter often warns of the need to lower the financial services bar, even for poor families, as increased inclusion could make it riskier (Ediagbonya & Tioluwani 2023). This perspective highlights the need for inclusive but properly managed financial policies if an escalation in NPLs is to be avoided. Similarly, Bharathi et al. (2023) further pinpoints that associated with DFI's large-scale embrace are emerging challenges and suggest that the risks it bears could raise even NPLs in advanced economies. Experiences from advanced economies attested that the risks of DFI are not confined to developing regions but, instead, they are a global concern.

The theoretical basis for the DFI-related hypotheses stems from the Financial Intermediation Theory and Diffusion of Innovations Theory (DOI). Financial Intermediation Theory explains the role of banks in efficiently channeling funds from savers to borrowers, and how digital inclusion may affect their ability to perform this role while managing risk. The DOI theory (Rogers 2003) supports the idea that the adoption of digital finance spreads across institutions and regions at different rates, creating diverse outcomes. Where adoption is rapid but poorly regulated, systemic risks and instability, measured through indicators like Z-score and NPLs, can emerge. These theories help explain the observed mixed effects of DFI on bank risk and performance.From the above discussion, we have derived the following hypothesis: H1: DFI has a significant negative impact on the Z-score. H2: DFI has a significant positive impact on non-performing loans (NPLs).

DE AND BANK STABILITY

Digitalization significantly improves financial intermediation and operational efficiency, both essential for bank stability. Studies by Beck, Demirgüç-Kunt and Levine (2007) and Tan et al. (2024) show that digital credit assessments and risk management practices reduce NPLs and enhance asset quality. This will be imperative if bank stability is sustained in a financial world that has been digitized over the years. According to academicians, among them Bickley, Macintyre and Torgler (2024), what drives sustainable growth is digital currency, big data, blockchain, and artificial intelligence. The latter also highlights that said technologies make a more resilient financial infrastructure, contributing to bank stability (Chen, You & Chang 2021; Demertzis, Merler & Wolff 2018). Support is also by Fu and Mishra (2022), Peng et al. (2022), Wen et al. (2023), and Yang, Tang and Yang (2023) who argue that DE reduce information asymmetry and improve access to capital, promoting capital formation and bank liquidity. They do that collectively, ensuring that banks receive essential financial resources that are available to be afloat. Shen, Zhang and Liu (2022) highlight that DE supports high-quality financial services that reduce credit risks and enhance stability. Equally, Hasan, Yajuan and Khan (2022) showed that DE can foster inclusive finance and bank stability by reducing NPLs, improving effective risk management, and enhancing the efficiency of providing financial services. Effective risk management practices and efficient financial service delivery are thus vital for reducing financial disruptions and sustaining stability.

Risk and capacity management in banks have been much stabilized with DE practices, and the cases associated with NPL incidents have been lesser. Gebreab and Tekle (2024) and Singh (2021) noted that better credit assessment and management are allowed with DE and digital tools like credit reporting, improved asset quality, and reduced NPLs. DE enhances bank stability in different ways, such as reducing information asymmetry and easy access to capital, and it increases diversification of funding sources. These factors collectively contribute to low NPLs (Ren et al. 2024). As remarked by Liu et al. (2024), this is a cardinal point in the efficient and quality provision of financial services that hugely support the real economy while containing the credit risk. Gong and Zhao (2024) go on further to add that DE catalyzes inclusive finance, which aids in improving the stability of banks through the reduction of NPLs due to more efficient risk management and financial service delivery. Jameaba (2024) added that digital technologies such as blockchain and AI, in their part, resulted in building a much more resilient infrastructure for the financial system; this translated to better bank stability. Raihan (2023) and Tchapchet Tchouto (2023) report that DE lowers costs and removes traditional financial barriers. Moreover, Shaikh et al. (2023) observe that digital tools improve financial inclusion and operational efficiency through mobile and online banking, reducing NPLs and increasing stability. These advances not only enable the lowering of NPLs but also increase bank productivity and efficiency in financial services, reduce credit risk, and make banks more stable. Fernandes, Borges and Caiado (2021) confirm that digital tools revolutionize risk management in banking.

Combined, these findings infer that DE significantly reduces NPLs and hence formulated the following hypothesis. The hypotheses regarding the DE are underpinned by the Technology-Organization-Environment (TOE) Framework and Resource-Based View (RBV). The TOE framework suggests that banks adopt digital transformation based on technological readiness, organizational capacity, and environmental conditions. These factors influence how digitalization impacts performance and stability. The RBV posits that technology is a strategic resource; when effectively deployed, it enhances operational efficiency and risk management. Hence, digitalization should improve bank resilience, reduce credit risk, and strengthen ZS. H3: DE economy has a positive impact on the Z-score. H4: DE has a significant negative impact on non-performing loans. The preceding scholarly works are briefly outlined in Table 1. The academic paper emphasizes the duration of the research, the methodologies used, the researchers involved, and the outcomes obtained.

THEORETICAL FRAMEWORK

The relationship between DFI, the DE, and bank stability is rooted in several complementary theoretical perspectives. One central argument is that the growing penetration of digital finance increases banks' exposure to risk. As financial access becomes more inclusive, individuals with varying creditworthiness gain easier access to financial services, potentially raising the likelihood of defaults. This dynamic can result in increased NPLs and heightened threats to overall bank stability. This perspective aligns with the Risk Compensation Hypothesis, which suggests that enhanced financial inclusion, particularly in its early phases, may initially expose banks to greater risks. These risks arise from the evolving nature of digital financial services and the lag in regulatory development (Mieg 2022; Syed et al. 2021). In the absence of robust oversight and effective risk assessment tools, the expansion of digital finance may compromise financial stability.

However, over time, the digital finance ecosystem tends to mature. With improved regulatory frameworks, enhanced credit assessment tools, and higher financial literacy, banks can better manage associated risks. As a result, the banking sector becomes more resilient. Ozili (2021) argues that with institutional learning and regulatory adaptation, financial systems can stabilize and manage the inherent risks of digital inclusion more effectively.

The Efficiency Hypothesis further supports this trajectory. It posits that technological innovation leads to reduced transaction costs, enhanced service delivery, and improved risk management. In the context of the digital economy, technologies such as broadband internet, secure servers, artificial intelligence, and blockchain play pivotal roles in streamlining operations and enhancing decision-making processes (Gong & Zhao 2024). According to the efficiency hypothesis, technological changes result in reduced NPLs and increased stability of banks. First, technological innovations enhance operational efficiency and improve risk management and the banking sector's stability over time (Fernandes, Borges & Caiado 2021).

Figure 1 illustrates the conceptual structure of this study. Arrows in the framework represent direct relationships tested in the empirical model. Specifically: Arrows from DFI to ZS and NPL represent the hypotheses testing how digital inclusion affects bank stability and loan performance; Arrows from DE to ZS and NPL capture the influence of technological infrastructure on financial resilience; Arrows from control variables (e.g., Economic Growth, Institutional Governance, Efficiency Ratio) to ZS and NPL reflect their role in shaping financial stability, as established in the literature; and The dual-path structure, via ZS and NPL, allows for a comprehensive assessment of both performance-based and risk-based dimensions of bank stability.

TABLE 1. Digital financial inclusion, digital economy and bank stability literature summary

Authors	Period	Approach to analyze	Findings
Khan et al. (2023)	2010-2022	GMM estimator	(-) Bank stability
He and Li (2021)	2011 to 2018	Analysis by regression	(-) Platform
Banna et al. (2022)	2011-2020	PCSE; 2SLS-IV	(+) Bank stability
Syed et al. (2021)	2004-2018	ARDL bound	(-) Bank efficiency & stabilit
Li et al. (2023)	2010-2019	Analysis by regression	(+) Export completeness
Banna et al. (2021)	2011-2019	2SLS-IV; GMM	(+) Bank risk-taking
Qadri et al. (2023)	2016-2021	Wilcoxon signed-rank test	(-) Bank Z-score
Chen & Nesterov (2023)	2014-2017	qualitative empirical study	(+) Digital economy
Tan et al. (2024)	2011-2020	Two-step system GMM	(-) NPL
Syed et al. (2021)	2004 to 2018	CUP-FM; CUP-BC	(-) Financial inclusion

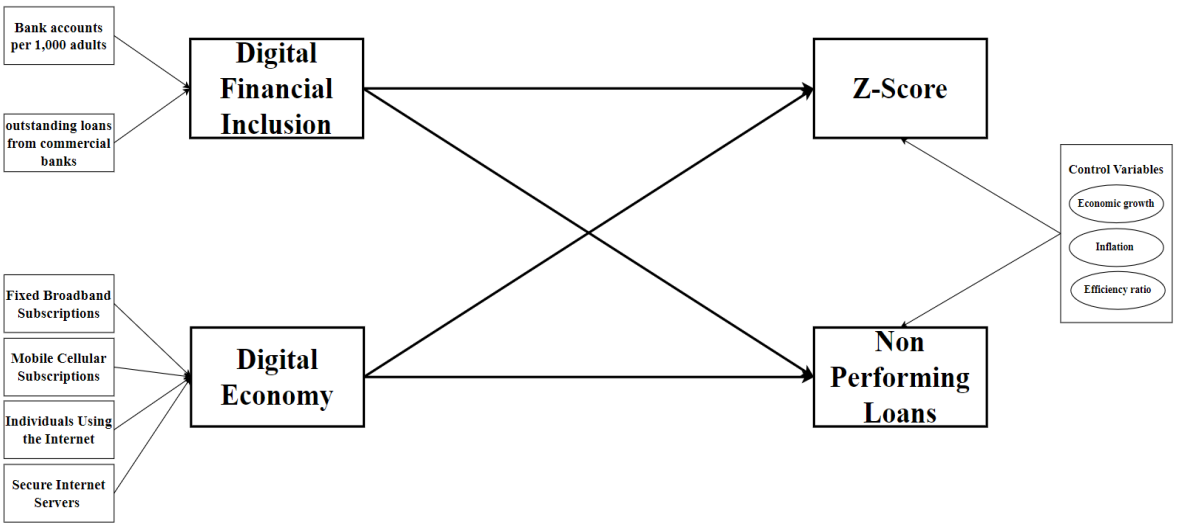

FIGURE 1. Conceptual framework

This framework forms the basis for testing hypotheses as discussed in the literature review, linking theoretical constructs to empirical testing and guiding the econometric analysis of the study. This framework draws connections between empirical observations and established theories to clarify the mechanisms through which digital finance and technological infrastructure influence financial system resilience in Asian economies.

METHODS

DATA

Figure 2 presents data from 33 Asian countries, collected from secondary sources including the World Development Indicators (WDI), BankFocus (Bureau van Dijk), and the International Monetary Fund's Global Findex. The dataset spans the years 2010 to 2022, and all variables have been transformed into natural logarithms to ensure consistency in scaling. In this study, ZS and NPL are used as the dependent variables to measure bank stability. The key independent variables are the DE and DFI. The DE is constructed using Principal Component Analysis (PCA) from the following indicators: Fixed broadband subscriptions (per 100 people); Mobile cellular subscriptions (per 100 people); Individuals using the Internet (% of the population); Secure internet servers (per 1 million people). Similarly, the DFI index is derived using PCA, representing the percentage of the adult population with bank accounts and outstanding loans from commercial banks relative to GDP. Sub-indices under the dimensions of 'access' and 'usage' were developed based on this PCA. To control for macroeconomic conditions that may also influence bank stability, the study includes the following control variables: Economic Growth (EG): Measured by GDP per capita growth (annual %); Inflation (ING): Measured by the GDP deflator (annual %); Efficiency Ratio (ER): Represents a bank's operating expenses as a percentage of its income. The selection of countries and the study period were partly guided by the availability of consistent data across all variables. This approach ensures the robustness of the findings and enhances the policy relevance of the results. Furthermore, by incorporating various levels of contextual control, the analysis gains broader applicability both within and beyond the specific economies under investigation.

MODEL SPECIFICATIONS

The present study used two regression models to measure the bank stability and formed the following equations:

$$ZS_{it} = \alpha_i + \beta_1 DFI_{it} + \beta_2 DE_{it} + \varepsilon_{it} \quad (1)$$

$$NPL_{it} = \alpha_i + \beta_1 DFI_{it} + \beta_2 DE_{it} + \varepsilon_{it} \quad (2)$$

where t is 2010-2022 and i represent Asian economies. The influence of independent variables on dependent variables can be seen in the above equations. Next, the control variables are added to form Equations (3) and (4), which will determine the overall impact of variables of the study as follows:

$$ZS_{it} = \alpha_i + \beta_1 DFI_{it} + \beta_2 DE_{it} + \beta_3 EG_{it} + \beta_3 EG_{it} + \beta_4 ING_{it} + \beta_5 ER_{it} + \varepsilon_{it} \quad (3)$$

$$NPL_{it} = \alpha_i + \beta_1 DFI_{it} + \beta_2 DE_{it} + \beta_3 EG_{it} + \beta_4 ING_{it} + \beta_5 ER_{it} + \varepsilon_{it} \quad (4)$$

where α_i is the intercept term specific to country *i*. It captures the effects unique to each bank that are not explained by the independent variables. *ZS* is Z-score, *NPL* is non-performing loans, collectively representing bank stability; $\beta_1 DFI_{it}$ is the effect of DFI on ZS and NPL; $\beta_2 DE_{it}$ is the effect of DE on ZS and NPL; and *EG*, *ING*, and *ER* represent economic growth, inflation, and efficiency ratio, respectively. ε is the model's error term.

METHODS OF ECONOMETRICS

The first analysis is the preliminary examination of the data through descriptive statistics and a correlation matrix. Following these two analyses, the test by Pesaran and Yamagata (2008) done here is the Slope Heterogeneity/ Homogeneity (SLH) test for checking the heterogeneity among variables for the selected countries. The next move is to check the stationarity of variables through more than one unit root test Levin, Lin and Chu (LLC); Im, Pesaran & Shin (IPS); Augmented Dickey-Fuller (ADF); and Phillips-Perron (PP). Panel unit root testing is essential because different segments or entities might render different results for stationarity. To this end, one turns to the Westerlund test as a substitute for cointegration tests by Kao and Pedroni since the Westerlund method applies bootstrapping, which is more universal. The Westerlund error correction-based study uses two groups of mean data and two-panel statistics data types, such as G_t, G_a *and* P_t, P_a.

In addition, this study employed two dynamic versions of the System Generalized Method of Moments (Two Step-GMM) to analyze the relationship between variables, addressing potential endogeneity and cross-sectional dependence. GMM effectively handles lagged endogenous variables and individual effects, providing a robust framework by instrumenting dependent variables with their lagged values and avoiding multicollinearity issues. The validity of GMM instruments was assessed using Hansen J-statistics. Two-step system estimators ensured the efficiency and consistency in the parameters' estimates, relieving the weakness of lagged regressors in GMM difference equations. Further robustness checks were conducted using GLS regression and PCSE models.

The choice of GMM was based on its strength in addressing unobserved heterogeneity, endogeneity, and dynamic relationships in macro-panel data. Unlike Fixed Effects models, GMM can efficiently handle lagged

dependent variables and avoid biased estimates. It also performs better than Difference-GMM when instruments in first differences are weak or when the sample is relatively small. To ensure robustness, this study also applied Generalized Least Squares (GLS) and Panel Corrected Standard Errors (PCSE). These methods help control for heteroskedasticity, autocorrelation, and cross-sectional dependence in panel data. GLS is suitable for correcting known patterns of variance across panels, while PCSE improves the reliability of standard errors when such assumptions are uncertain. GMM, GLS, and PCSE were preferred due to their ability to handle the key econometric issues present in multi-country panel data, including endogeneity, heteroskedasticity, and correlation across time and countries.

EMPIRICAL RESULTS AND DISCUSSIONS

Descriptive statistics offer comprehensive insights into the variables studied, and the results are reported in Table 2. ZS shows a notable disparity between its mean of 2.681 and its standard deviation (SD) of 0.698. Azerbaijan has the minimum ZS value at 0.39, indicating its banks are among the least stable in the dataset. The other countries with the lowest ZS values are Cyprus, Kazakhstan, the Syrian Arab Republic, and Indonesia, reflecting higher banking sector risk for them. The maximum ZS value (4.13) was attributed to Jordan in 2013 and other economies, including Sri Lanka, Mongolia, Iraq, Singapore, and Nepal. Furthermore, the NPL mean value and SD are 1.263 and 0.797, respectively, showing significant variability in NPL across countries. Notably, Uzbekistan, Singapore, China, and Japan have

FIGURE 2. Graphical mapping

TABLE 2. Descriptive statistics

Variables	Mean	Maximum	Minimum	SD
ZS	2.681	4.13	0.39	0.698
NPL	1.263	3.87	-0.34	0.797
DFI	-1.191	2.435	-4.54	1.294
DE	-5.365	3.011	-6.068	1.711
EG	8.732	11.49	6.29	1.306
ING	1.493	5.02	-8.35	1.408
ER	3.816	5.31	2.04	0.297

lower NPL values, with Uzbekistan having the lowest at -0.34 in 2011, indicating better loan performance in these regions.

The DFI mean is -1.191 with an SD of 1.294 values. Notable countries like Tajikistan, Kyrgyzstan, Iraq, Cambodia, Pakistan, and Azerbaijan consistently exhibit negative DFI values. Tajikistan reported a minimum value of -4.54 in 2011, indicating varied levels of DFI. On the other hand, Singapore, Cyprus, Qatar, Japan, UAE, and China consistently exhibit higher DFI values, often surpassing 2. Nevertheless, Singapore recorded a peak value of 2.44 in 2021, an appreciable accomplishment showing substantial adoption of digital financial services. DE contains a mean of -5.365 and an SD of 1.711. The maximum value reported by Singapore is 3.010, which shows substantial dependence on DE sources. Iraq had a minimum value of -6.068 in 2000 but moved in an upward positive trend in the following years. This was the lowest value, and this was because prolonged political instability made the infrastructure stand without any further developments. However, a new wave of improvements in digital infrastructure and the promotion of digital literacy is the reason behind an upward trend.

The sample period average of EG is 8.732, with an SD of 1.306. It is predominantly positive in Qatar, Singapore, and UAE with only a few exceptions, while high EG values are always in Qatar, with the maximum one-time being at 11.49 in 2013; the minimum one is for the Syrian Arab Republic, at 6.29 in 2020. The average value for ING is 1.493, while its standard deviation equals 1.408. In the data sample, Japan, China, Iraq, and Malaysia reported minimum values, Japan reported a minimum of -8.35, and Lebanon, Turkey, and the Syrian Arab Republic reported maximum values. The average ER equals 3.816; SD equals 0.297. The maximum value, which reaches the efficiency ratio, is also very high for the Syrian Arab Republic, amounting to 5.31. The Syrian Arab Republic scored at least 2.04 in 2020, showing an upward, increasing positive trend.

The statistical parameters of the critical explanatory and control variables are visually represented using box plots (Figure 3). These graphs uniformly present the 25th, 50th, and 75th percentiles across all plots. In this graphical depiction, the median is denoted by a circle, while squares denote the mean values. The upper and lower values signify the maximum and minimum data points. The findings mentioned in Figure 3 are almost aligned with Table 2 output; both methods show consistent statistical parameters, confirming the reliability of the findings. In addition, the correlation matrix results are presented in Table 3, which shows that no coefficient value is more than 0.70, implying that the model does not have a multicollinearity problem.

It also remains critical to select which estimation to prefer: whether the slope coefficients are heterogeneous or homogeneous. The SLH test tested for that (Table 4), and as the significance of the p-values at a one-percent level shows, the Asian nations are heterogeneous. Moreover, the panel unit root outcomes of LLC, IPS, ADF, and PP tests, as shown in Table 5, consistently indicate significant evidence of stationarity. Specifically, both the LLC and IPS tests exhibit statistical significance at the 1% level for all variables, confirming strong indications of stationarity. Likewise, the ADF and PP tests further affirm these findings, demonstrating significant stationarity for most variables at the level or first difference form. The consistency in statistical significance across different testing methods suggests that these variables maintain stable characteristics across distinct segments or entities within the dataset.

Further, as depicted in Table 6, using the Westerlund method, the cointegration test is crucial in assessing the long-run relationships among the variables tested. *Gt* and *Pt* statistics are significantly valued in this estimation, meaning the variables were cointegrated. The *Gt* statistic is computed to have a value of -9.407, portraying a high significance level as confirmed by an associated p-value of 0.000. On the other hand, the *Pt* statistic is -14.395, indicating very strong significance. All in all, these findings indicate the importance of cointegration analysis in understanding the interconnectedness and stability of variables over a long period.

The GMM empirical results provided in Table 7 make it easy to discern that the present study draws very important insights into the impact of DFI and DE on the bank stability measures proxied by ZS and NPL in Asian economies. The aforementioned table depicts column-wise results in column 1, System-GMM (ZS), and column 2, System-GMM (NPL). The results prove that the DFI and DE are separate but highly important factors concerning ZS and NPL, pointing to an essential but complicated relationship between digital improvements and financial soundness in this region. The coefficient of DFI (-0.017) shows a significant negative association with ZS at a 1% level of significance, indicating that more DFI is related to less bank stability. The coefficient of DE (0.013) reflects the significant positive relationship with ZS at a 1% level of significance, suggesting that a robust DE enhances bank stability. The positive coefficient of DFI (0.031) with NPL indicates that increased DFI is linked to higher levels of NPL. The coefficient of DE (-0.007) depicts a significant negative association with NPL at a 5% significance level, suggesting that a more robust DE reduces the incidence of NPL. The finding aligns with the research by (Banna & Alam 2021b; Banna et al. 2022b; Ozili 2023), saying that DFI accelerates the NPL, which not only decreases the default risk of the banks but also upturns the financial mobility. Syed et al. (2021) showed that DFI negatively influences the banking sector's efficiency and stability.

The results further show that increased levels of DFI drastically decrease bank stability (low stability is indicated by reduced levels of ZS and increased NPL levels in a country). In contrast, increased levels of DE drastically increase bank stability (high stability is marked by increased levels of ZS and decreased NPL levels in a country). DFI has enabled many people in Asia to become

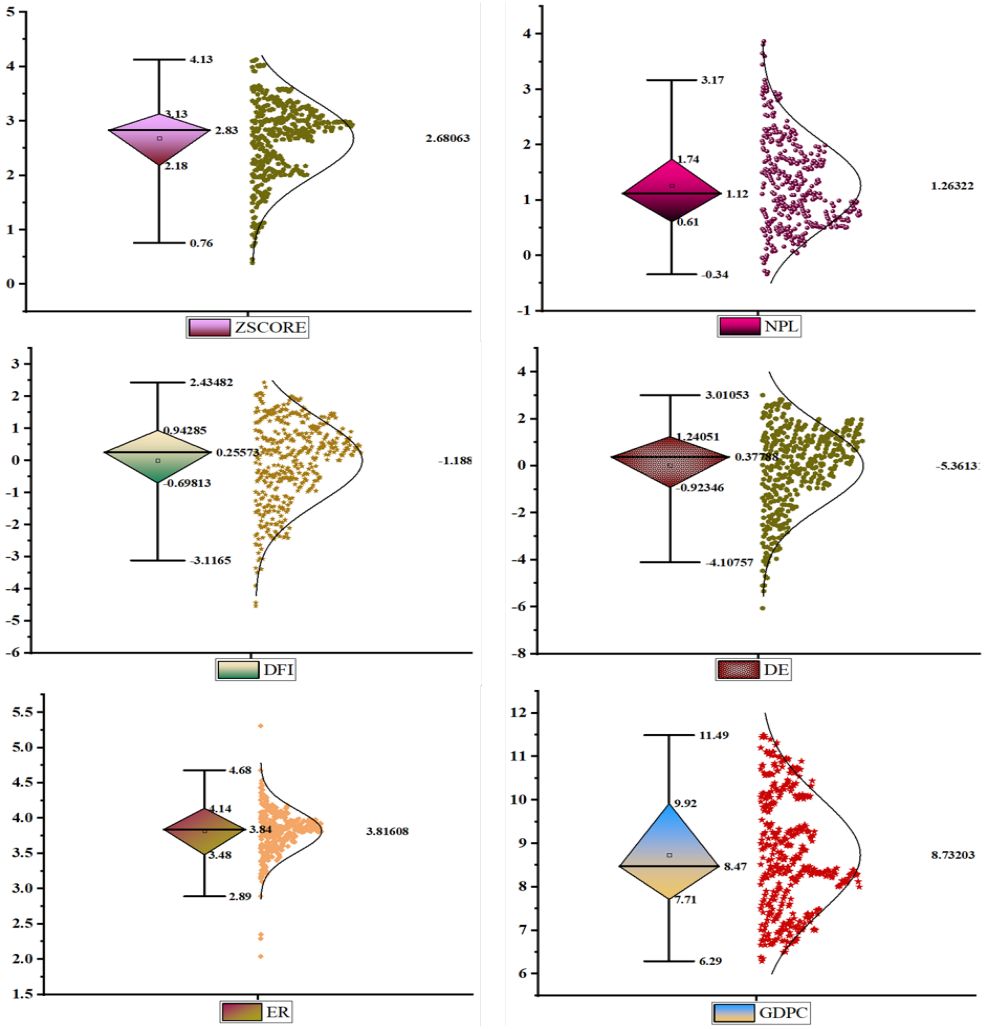

FIGURE 3. Box plots of statistical parameters

TABLE 3. Matrix of correlations

Variables	ZS	NPL	DFI	DE	EG	ING	ER
ZS	1.000						
NPL	-0.296	1.000					
DFI	0.212	-0.265	1.000				
DE	-0.028	-0.160	0.700	1.000			
EG	0.050	-0.224	0.682	0.700	1.000		
ING	-0.156	0.138	-0.294	-0.220	-0.231	1.000	
ER	-0.141	0.189	-0.168	-0.098	-0.244	-0.114	1.000

TABLE 4. Slope coefficients are homogenous

$\tilde{\Delta}$	$\tilde{\Delta}^{Adjusted}$
3.636***	5.863***

The coefficient is significant at 1%***, 5%** and 10%*

part of the banking sector and, therefore, has made the industry stable by developing new credit facilities and other commercial activities. These initiatives have made it possible to start a wide range of financial products and services as financial organizations are trying to ensure a steady increase in income. Moreover, DE can also increase the profitability of the banks, which brings economic growth and stability. Additionally, DE reduces NPL, suggesting improved lending practices and enhanced risk mitigation. The novelty of this study lies in its empirical investigation of the dual and often divergent effects of DFI and DE on banking sector stability, a dimension that has been largely overlooked in the existing literature. Unlike prior studies that treat DFI and DE in isolation, this study contributes a unique perspective by evaluating their simultaneous influence on two crucial indicators of financial stability: Z-score and NPL. The findings highlight that DFI and DE do not function as homogenous or complementary forces; instead, they exert asymmetric effects on financial stability. While DFI expands financial access, it also increases the risk exposure of banks by integrating less experienced and lower-income borrowers. DE, on the other hand, supports infrastructure improvements and strengthens internal risk assessment tools, thereby enhancing the system's overall resilience.

TABLE 5. Panel unit root outcome

Variables	LLC	IPS	ADFF	PPF
ZS	-7.887***	-4.388***	-5.126***	-5.265***
NPL	-10.544***	-2.887***	-5.016***	-4.895***
DFI	-7.779***	-1.875**	-5.351***	-5.373***
DE	-10.999***	-4.709***	-5.231***	6.697***
EG	-2.344***	-4.745***	-4.496***	-4.594***
ING	-4.961***	-4.476***	-11.812***	-11.867***
ER	-8.994***	-4.868***	-5108***	-10.231***

The coefficient is significant at 1%***, 5%** and 10%*

TABLE 6. Cointegrations results (Westerlund)

Statistic	Gt	Ga	Pt	Pa
Values	-10.274***	-0.876	-10.770***	-5.047***

The coefficient is significant at 1%***, 5%** and 10%*

TABLE 7. GMM test

Variable	2 System-GMM (ZS)	2 System-GMM (NPL)
L.ZS	1.071***	-
L.NPL	-	1.052***
DFI	-0.017***	0.031***
DE	0.013***	-0.007**
EG	-0.022***	-0.020***
ING	-0.005*	0.002*
ER	-0.122***	-0.058***
C	0.473	0.319
AR^2	0.368	0.438
Hansen	0.525	0.401
Obs.	396	396
Prob>chi^2	0.000	0.000

The coefficient is significant at 1%***, 5%** and 10%*

This combined effect analysis presents a nuanced and policy-relevant insight: financial inclusion policies (DFI) should not be implemented in isolation from digital infrastructure strategies (DE). Only when DFI is supported by a strong digital economy can the negative externalities, such as high default rates, be effectively managed. This integrated approach offers a fresh empirical contribution to the discourse on digital finance and banking stability in emerging Asian economies. At the same time, DFI and DE also go a long way in changing the banking playing field, affecting bank risk and loan performance. An effective balance between harnessing the benefits of digital advancement and responding to its inherent risks will lead to more stable and resilient banking in Asia.

These findings suggest that while the influence of DFI may be weak at the lower levels, it becomes more pronounced as the level progresses toward the upper extremes within the distribution. As a result, if DFI can boost economic development by mainstreaming the marginalized people into formal finance, the loan recovery behavior can also see a positive change based on increased bank stability for these groups. In that regard, the intricate relationship among DFI, ZS, and NPL forms only the beginning of change. Though uncertainty was associated with DFI's impact on ZS and NPL at the outset, mainstreaming riskier borrowers through improved DFI might see the future as different with a stable banking sector. This would occur as institutions evolve and the economy realizes gains from greater financial inclusion. This coefficient pattern is also observed in DE, meaning a constant negative relationship, justifying a stable/long-run relationship between DE and ZS. Furthermore, Khan et al. (2023) and Khattak et al. (2023) affirmed that the determinants of the DE have a significantly negative relation with bank stability, which agrees with our findings from the estimations. However, Luu et al. (2023) reported contrasting results, indicating that adopting DE improves bank stability. This paradox can be explained by the fact that higher levels of digital inclusion introduce new entrants who benefit from digital access but also increase default risk. As a result, the rapid rise in financial inclusion poses a challenge to financial service providers. Suppose banks cannot adjust their operations to manage the increased level of digital transactions and adequately assess the risk of new customers. In that case, this may lead to a temporary increase in NPL. However, institutions can achieve stability in the long run by improving their risk assessment methods and strategies for this customer segment.

The analysis of control variables provides additional insights. EG shows a negative impact on ZS -0.022 and NPL -0.020 at a 1% significance level, suggesting that higher EG enhances bank stability and reduces loan defaults. This finding is consistent with prior studies indicating that economic growth supports better financial health (Yu et al. 2023). ING has a mixed impact, negatively affecting ZS -0.005 and positively impacting NPL 0.002 at a 10% significance level, reflecting its dual role in banking sectors. The ER significantly negatively impacts both ZS -0.122 and NPL -0.058 at a 1% significance level, respectively, highlighting the importance of operational efficiency in financial institutions, a finding supported by Doumpos et al. (2023).

Besides these, Table 8 showed robustness analysis under GLS and PCSE models. The coefficients of DFI showed a negative association with ZS and a positive relation with NPL. Moreover, the DE coefficients are positively associated with ZS and negatively associated with NPL at 1% and 10%, respectively. The two variables, DFI and DE, point out that they are genuinely transformative forces in the banking sector. However, their impact on bank stability and loan performance may be relatively nuanced within Asian countries. Most importantly, the two models passed the robustness tests, complementing the benchmark analysis and indicating that the estimations are stout and reliable.

CONCLUSION AND IMPLICATIONS

This study investigates the nuanced relationship between bank stability, DFI, DE, and various control variables across 33 Asian economies from 2010 to 2022. Using advanced econometric methods, including GMM, GLS, and PCSE models, the analysis explores how DFI and DE influence two critical dimensions of bank stability: the ZS

TABLE 8. Robustness analysis

Variables	GLS		PCSE	
	ZS	NPL	ZS	NPL
DFI	-0.230***	0.135***	-0.230***	0.135***
DE	0.127***	-0.038*	0.127***	-0.038*
EG	-0.045*	-0.046*	-0.045*	-0.046*
ING	-0.067***	-0.052**	-0.067**	-0.052**
ER	-0.318**	0.409**	-0.318**	0.409**
C	4.392***	2.024**	4.392**	2.024**

The coefficient is significant at 1%***, 5%** and 10%*

and NPLs. The results indicate a differentiated impact of DFI and the DE on banking stability across Asia, calling for context-specific interpretation and policy direction. The negative association of DFI with ZS and its positive link with NPLs reflect risk pressures arising from rapid digital onboarding, particularly in lower-income economies with weak financial literacy and underdeveloped regulatory oversight. For instance, in countries like Pakistan, Cambodia, or Nepal, where digital outreach has expanded without proportional investment in borrower education or risk screening, banks are more likely to face credit quality issues. In contrast, countries with relatively mature digital ecosystems, such as Malaysia or China, experience a more managed integration of digital services, showing that the institutional environment significantly shapes the outcomes of DFI on financial stability. The positive relationship between DE and ZS points to the broader structural benefits of DE infrastructure in reinforcing banking resilience. However, the absence of a significant effect on NPLs implies that macro-level improvements alone are insufficient to curb borrower-level risk, especially in countries where debt enforcement, credit reporting, and consumer protection frameworks remain weak. This gap underlines the importance of aligning digital investments with micro-level borrower safeguards, as reflected in Figure 4.

The study significantly contributes to the discourse on financial transformation and risk management within the Asian context. Policy recommendations should therefore avoid a one-size-fits-all approach. For lower-tier economies, there is an immediate need to embed financial risk awareness into digital financial services, possibly by mandating literacy modules during digital onboarding. Regulators in these countries should prioritize low-cost credit assessment tools and encourage their integration into banking operations. Where data infrastructure is still developing, alternative indicators such as utility payment histories or mobile usage patterns can be institutionalized to inform credit decisions. These countries may also benefit from phased or conditional digital financial expansion, tied to verified improvements in user comprehension and institutional readiness. For middle- and upper-income countries, the focus should shift towards refining existing frameworks. Banks operating in relatively advanced digital environments need to invest in behavioural credit scoring models that capture risk profiles beyond traditional metrics. Regulatory bodies should ensure data privacy and responsible lending through updated digital conduct codes, particularly as digital products reach first-time borrowers. Additionally, these countries should embed financial inclusion goals into existing prudential regulation, allowing for targeted innovation without undermining systemic stability. Cross-regionally, a harmonized effort is required to close gaps in credit information sharing and digital ID systems. Institutions like the Asian Development Bank or regional forums such as ASEAN could play a critical role in facilitating knowledge-sharing and setting common technical standards for digital finance operations. These actions can help stabilize cross-border digital flows and offer smaller economies a template for managing the risks tied to digital banking growth.

The study also identifies key areas for further research. While it primarily relies on ZS and NPLs as proxies for bank stability, future investigations could integrate other indicators such as Capital Adequacy Ratio (CAR), Net Interest Margin (NIM), and Credit Risk Ratio to provide a more comprehensive analysis. Although this research focuses on Asian economies, expanding the scope to other regions such as BRICS, G8, GCC, or Sub-Saharan Africa would offer comparative insights into how DFI and DE

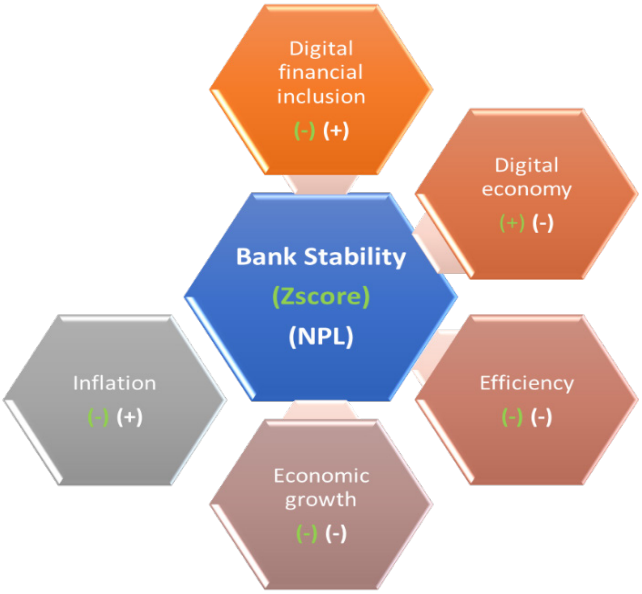

FIGURE 4. Graphical interpretation of the results

interact across varying economic, regulatory, and cultural contexts. Lastly, addressing data granularity and extending the timeframe for analysis would yield more profound insights into the evolving dynamics of digital financial transformation and its implications for banking risks.

This research aligns with the growing interest in understanding the intersection of digital transformation, financial inclusion, and risk management. It provides both theoretical contributions and practical recommendations for navigating these complex interdependencies. By addressing the unique challenges and opportunities posed by DFI and DE in Asia, this study offers valuable perspectives for academics, policymakers, and industry practitioners.

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