The Impact of Bank Competition on Stability in Central Asia: The Moderating Role of Bank Digitalization

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ABSTRACT: This study investigates the impact of bank competition on financial stability in the Central Asian banking sector, with a focus on the moderating role of bank digitalization. The research addresses a critical question—whether digitalization reinforces or weakens the stabilizing effects of competition—in a region characterized by early-stage digital adoption and concentrated markets. Given the growing reliance on technology in banking, understanding its role in shaping risk dynamics is both scientifically relevant and practically important for policymakers and financial institutions. The study employs dynamic panel data analysis using the two-step GMM estimator. Bank stability is measured using the z-score, Competition is assessed through the Panzar-Rosse Model, and digitalization is captured via a composite index. The results reveal that bank competition improves stability, while digitalization alone initially increases risk due to operational vulnerabilities. However, the interaction between competition and digitalization has a positive and stabilizing effect, enhancing risk management and efficiency. These findings highlight the transformational role of digitalization, emphasizing the need for balanced competition policies and support for digital adoption to ensure financial stability in emerging markets.
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Introduction

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The global banking industry is undergoing significant transformations driven by ongoing digital innovations. While these innovations are often associated with the recent rise of financial technology, banks have historically been the leading adopters of digital solutions. Over the decades, bank innovations have dynamically adapted to meet changing consumer and business demands. In a constantly evolving digital landscape, the banking sector is experiencing a new wave of innovations, transforming operational processes and reshaping competitive dynamics (Theiri & Hadoussa, 2024). Digitalization, on the one hand, enhances efficiency by streamlining bank operations and expanding financial services (Chen et al., 2019). Yet, it has also introduced competitive challenges to traditional banks, leading to market fragmentation (Nguyen-Thi-Huong et al., 2023). To withstand competitive challenges, banks digitalize to enhance efficiency, customer experience, and profitability (Chao et al., 2024; Nguyen et al., 2023). However, these efforts might often come with potential risks to bank stability (Khattak et al., 2023).

In Central Asia (CA), the market for digital banking services is projected to grow by approximately eight percent annually between 2024 and 2028, reflecting ongoing bank digital transformations in the region (Statista, 2023). After the fall of the Soviet Union, CA countries initiated financial reforms to create competitive banking systems and integrate into global bank markets. However, the banking sectors of the region have traditionally been characterized by high levels of regulation and concentration, with the top three banks controlling more than 60 percent of total bank assets. In comparison, the top three bank concentration ratios in neighboring China, Vietnam, and Taiwan are significantly lower, at 38%, 37%, and 25%, respectively (the Global Economy, 2022).

While competition is traditionally recognized as a driver of quality, innovations, and efficiency, it continues to be a subject of scholarly discussions in the banking industry (Doku & Nabieu, 2023). Some bank researchers view the lack of competition in the banking sector as leading to high risk (Khattak et al., 2022). Others question the role of competition in the banking industry, claiming that competition might increase bank risks (López-Penabad et al., 2021; Srivastava et al., 2023; Verma & Chakarwarty, 2023).

Amid this debate, digitalization emerges as a potential game-changer, capable of both enhancing efficiencies and stabilizing vulnerabilities. While some studies suggest that digital platforms improve risk monitoring and decision-making (Beck et al., 2020), others highlight the disruptive effects of technology (Gao & Wang, 2023). This duality raises a key question: Does digitalization reinforce or mitigate the effects of competition on stability?

This study seeks to address this question by exploring the direct and interactive effects of bank digitalization and competition on stability in the Central Asian banking sector. Central Asia offers a unique case study, as its banking systems are characterized by market concentration, early-stage digital adoption, and uneven regulatory environments. These features create a natural laboratory for assessing whether technological transformation amplifies or buffers the risks associated with competition.

Against the above backdrop, the current research aims to contribute to the existing body of literature by focusing on several key objectives. Specifically, this research investigates (1) the direct impact of competition on stability, (2) the independent effects of digitalization on stability, and (3) the interaction between competition and digitalization as a moderating factor influencing stability dynamics.

In the context of the CA banking system, several concerns justify the importance of this assessment. First, the existing literature contains few studies that directly evaluate the relationship between bank digitalization competition and stability (Chao et al., 2024; Jia & Liu, 2024). Second, CA countries have faced substantial economic challenges over the past few decades, including political transitions, bank crises, and economic recessions such as those arising from the COVID-19 pandemic and the impact of the Russian-Ukrainian conflict (Batsaikhan & Dabrowski, 2017; Chortareas et al., 2011; Ruziev & Majidov, 2013). Therefore, this research is critically important as countries in the region aim to enhance their financial markets and improve financial accessibility. In addition, this research is the first to empirically estimate the banking system's digitalization and competition in CA, bringing these findings to the attention of an international audience.

The remainder of this paper is organized as follows: Section 2 reviews the literature and outlines the hypotheses. Section 3 discusses the methodology, including data sources, variable definitions, and econometric techniques. Section 4 presents the results and their interpretation and explores robustness tests to validate the findings. Finally, Section 5 concludes with policy recommendations, limitations, and avenues for future research.

Theoretical background

Bank competition and stability

The existing literature presents two contrasting theories regarding the relationship between competition and bank stability. The *competition-fragility* perspective posits that bank competition negatively affects stability (Keeley, 1990). High competition encourages banks to ease their investment and lending policies, which in turn increases asset risk (Srivastava et al., 2023). A rise in competition diminishes market power, reduces profits, and compels banks to bear increased risk (Verma & Chakarwarty, 2023).

Conversely, monopolistic power allows banks to access better lending opportunities, achieve higher profits, enhance capital ratios, and maintain substantial charter values (Sarpong-Kumankoma et al., 2020). Studies supporting these findings found evidence that crises are less likely to occur in more concentrated banking systems (Beck et al., 2013). Banks may loan higher-risk borrowers to attract more consumers under competitive pressures (Srivastava et al., 2023). Additionally, research indicates that banking systems with fewer banks tend to exhibit greater stability, a concept referred to as the *concentration-stability* perspective (Khattak et al., 2022).

In contrast, the *competition-stability* perspective suggests that increased competition fosters bank stability. This perspective is based on the idea that competition mitigates moral hazard and adverse selection issues related to borrowers (Srivastava et al., 2023). To counter competitive pressures and attract more borrowers, banks decrease loan interest rates, reducing the incentive for borrowers to engage in risky projects (Boyd & De Nicoló, 2005).

Furthermore, competition is a crucial external controlling mechanism, disciplining management activities (Singla & Singh, 2019). To remain competitive, bank managers diversify their activities across various fee-based income streams, decreasing risks (Amidu & Wolfe, 2013). While concentrated banking markets often receive government subsidies and guarantees, competition exerts a stabilizing influence and mitigates the "too-big-to-fail" effect associated with the lender of last resort (Soedarmono et al., 2011).

Several studies have provided evidence supporting the hypothesis that competition improves bank stability. Examples include the banking systems of post-Soviet countries (Clark et al., 2018), China (Hussain & Bashir, 2020), and Korea (Jeon & Lim, 2013). In light of these findings, our first hypothesis is:

H1. Higher bank competition improves bank stability.

The effect of bank digitalization and stability

Despite the ongoing digitalization trends in the global banking industry, research in this area remains remarkably limited and sparse (Begimkulov, 2023; Kriebel & Debener, 2019).

Empirical studies report diverse effects of digitalization on bank risk-stability conditions. Some research indicates that overinvestment in digital technology and increased diversification can undermine bank stability, leading to higher risk-taking behaviors (Khattak et al., 2023). Similar findings suggest that digitalization may adversely affect bank stability due to the potential accumulation of risky assets (Carbó-Valverde, 2017). Digital financial solutions simplify and speed up borrower application processing, improving lending efficiency, though they may compromise stability (Fuster et al., 2019).

Studies indicate that digitalization enhances financial stability by optimizing bank operations and fostering greater financial inclusion, particularly in developing regions (Yang et al., 2024). Embracing digital technologies allows banks to improve data collection and processing, leading to accurate customer identification and better risk management practices. (Guo & Liang, 2016). Integrating technology can increase profit margins, providing banks with additional resources to withstand adverse shocks (Lestari et al., 2023). Digitalization in banking reduces risk by lowering marginal costs and improving competitiveness (Jia & Liu, 2024).

Advancements in bank digitalization are anticipated to reduce operational risks and enhance long-term stability (Lestari et al., 2023; Ozili, 2018). Digital solutions enable banks to optimize bank operations, which is expected to reduce operational risks and improve overall stability. Based on these findings, the next hypothesis is formulated as follows:

H2. Bank digitalization leads to the stabilization of banking systems.

The effect of bank digitalization and competition

Bank digitalization boosts competitiveness by allowing banks to better allocate resources and enhance financial products and services in reaction to challenges posed by fintech companies (Zhao et al., 2019). Furthermore, heightened competition prompts banks to view digital technology as a valuable resource and implement digital strategies (Shanmugam & Nigam, 2020). This enables them to effectively address customer needs, improve their market position, reduce systemic risks, and navigate challenges from rival banks (Jia & Liu, 2024; Nguyen et al., 2023). Online enhancements, mobile electronic wallets, and electronic money are redefining banking services by changing the way banks engage with customers and provide services, offering various advantages like convenience, speed, and security (Encalada Encarnación et al., 2020; Khattak et al., 2023; Nair & Emozozo, 2018).

Digitalization lowers marginal costs, allowing banks to provide cost-effective services and further enhancing their competitive positions (Kriebel & Debener, 2019). This, in turn, should improve the bank's financial position and, as a result, bank stability (Shanmugam & Nigam, 2020). Innovations also enable banks to collect, process, and analyze large amounts of data, improving decision-making and risk resilience (Jia & Liu, 2024). As a result of the above, our last hypothesis is:

H3. Bank digitalization has a moderating impact on bank competition

Methodology

Bank stability

To assess bank stability, this study utilizes the z-score, a bank-specific indicator that is broadly recognized and employed in banking research to evaluate financial soundness (Clark et al., 2018; Khattak et al., 2022; Lestari et al., 2023; Sarpong-Kumankoma et al., 2020). The z-score is estimated as follows:

$$z - score = \frac{ROA + Equity/Total\ Assets}{\sigma(ROA)} \quad (1)$$

z-score measures the rate at which a bank's profits could diminish before the bank's capitalization is exhausted. The underlying assumption is that a greater deviation indicates higher stability, with banks defaulting when their capital reaches zero.

To enhance the credibility and robustness of the findings, the study incorporates a widely recognized alternative risk metric, the ratio of non-performing loans to total gross loans, considering that loans are the primary component of bank assets in Central Asia. Banks with higher levels of risk have higher LLR ratios (Aristei & Gallo, 2019).

Bank competition

To assess the level of competition in the banking market, the study employs the Panzar-Rosse Model (P-R) H-statistic. P-R is a comprehensive method frequently used to estimate bank competition across various periods and countries (Varga & Madari, 2022). It measures the transmission of a bank's input prices on its revenues (Panzar & Rosse, 1987; Rosse & Panzar, 1977) and is estimated as follows:

$$\ln(Rev_{it}) = \alpha + \sum_{k=1}^{L} \beta_l log W_{k,it} + \sum_{k=1}^{K} \gamma_k log TA_{k,it} + \varepsilon_{it} \quad (2)$$

where Rev_{it} is the revenue (sum of interest income, commission, fee income, trading income, and other operating income), $W_{k,it}$ is the price of three k inputs labor (personnel expenses to total assets), deposits (interest expenses to total deposits) and capital (other administrative expenses to total assets) (Fungáčová et al., 2014) of bank i at time t.

A weak transmission of input price changes to revenues indicates market power and pricing control, whereas stronger transmission values suggest greater competition. As P-R values increase from 0 to 1, the market transitions from no competition or perfect collusion (P-R = 0) to monopolistic competition (0 < P-R < 1) and to perfect competition (P-R = 1).

For more robust estimations, the study also employs the Herfindahl-Hirschman Index. HHI is a widely used measure to assess the market concentration of banks (Leon, 2014). HHI is estimated as:

$$HHI = \sum_{i=1}^{N} s_i^2 \quad (3)$$

where N represents the total number of banks operating within a market, s_i denotes the market share of the *i'th* bank.

Total assets of banks were used as the primary metric for assessing bank market shares. This allows to focus on the market power of banks based on their actual size and control over resources. Results of HHI tend to be 1 in the case of monopoly and 0 in the case of equally sized companies.

Bank digitalization

The International Monetary Fund defines digital financial services as encompassing traditional banking activities—such as deposits, transactions (including debit and credit cards), and loans—delivered through digital channels (Agur et al., 2020). These digital channels include various electronic tools, such as ATMs, POS terminals, internet banking platforms, mobile applications, and electronic wallets (Versal et al., 2022). In line with this, the Bank Digitalization (BD) level is estimated following the methodology proposed by Versal et al. (2022), which has been slightly adapted to suit the available data specific to the Central Asian banking sector. From the

available data, five main components of the BD index were identified: Payment cards, Electronic money, Electronic facilities, QR systems, and Online platforms, as outlined in Table 1.

Table 1. Components of bank digitalization index

Indicator (h)	Estimation
Payment cards (Cards)	
Payment cards	Total quantity of cards/population
Volume of card payments	Total volume of payments/GDP
Quantity of card transactions	Total quantity of payments/population
Electronic money (EM)	
E-wallets	Total quantity of electronic wallets/population
Volume of EM transactions	Total volume of transactions/GDP
Number of EM transactions	Total quantity of transactions/population
Electronic Facilities (EF)	
ATMs	(Total quantity of ATMs/population) *100,000
POS Terminals	(Total quantity of POS/population) *100,000
QR Systems (QR)	
Volume of QR payments	Total volume of QR payments/GDP
Quantity of QR payments	Total quantity of QR payments/population
Online Platforms (OP)	
Mobile banking	Bank application users/total users
Online banking	Web Index

Source: own editing based on Versal et al. (2022)

To estimate bank digitalization index, first, each variable is normalized within the range of [0:1]:

$$h_{i,t} = \frac{x_{i,t}}{\max(x_{i,t})} \tag{4}$$

Then, the BD index is calculated, which is the sum of all indicators:

$$BD_t = \sum_i h_{i,t} \tag{5}$$

Independent variables

It is crucial to monitor bank-specific factors that could influence bank stability. Consistent with existing research on the determinants of bank stability, we account for several variables.

Given that higher profitability might lead to concerns regarding the potential misuse of market power and increased risk-taking activities by banks, the study controls for Return on Assets as the indicator of profitability (Sarpong-Kumankoma et al., 2018; Tan, 2016)

Assuming that bank digitalization affects bank revenues from non-traditional sources of income, the diversification ratio is integrated (Lestari et al., 2023; Suryanto et al., 2022). Studies also suggest that diversification impacts stability, although the evidence remains inconclusive (Amidu & Wolfe, 2013; Khattak et al., 2023).

Research indicates that larger banks are prone to taking on more risk, and those with higher equity might leverage their capital to extend loans, potentially undermining overall bank stability (Khattak et al., 2022, 2023; Leroy & Lucotte, 2017). Also, some studies indicate that the effect of bank digitalization may vary between large, state-owned banks and smaller counterparts (Chao et al., 2024). Consequently, bank size, represented by the natural logarithm of total assets, is incorporated into the analysis.

Next, the study controls the level of loans within total assets (also known as the credit risk ratio), which indicates portfolio composition, reflecting banks' exposure to credit risk. Higher level of loans increases the potential of default risk (Clark et al., 2018; Liu et al., 2013)

To account for variations in country characteristics, the study incorporates GDP growth rates, considering their impact on banking sector stability (Khattak et al., 2023; Tan, 2016).

Table 2 provides a summary and estimation method of the variables used in the study.

Table 2. Summary of variables used in the study

Variable	Definition	Estimation
Z-score	Distance to default	Equation 1
LLR	Loal loss reserves ratio	Loan loss reserves / Total loans
P-R	Panzar-Rosse Model	Equation 2
HHI	Herfindahl-Hirschman Index	Equation 3
BD	Bank Digitalization Index	Equations 4 and 5
ROA	Return on Assets	Net income / Total assets
Div	Diversification	Non-interest income / Gross revenue
Size	Bank size	Ln(Total assets)
LTA	Credit risk	Loans to assets
GDPG	GDP growth	Annual growth

Source: own editing

Regression model

To achieve the objectives of the study, three regression models are developed. Model 1 (Equation 6) explores the effect of bank competition on bank stability. Model 2 (Equation 7) assesses the impact of bank digitalization on bank stability. Model 3 (Equation 8) investigates the interaction between competition and digitalization as a moderating influence on stability.

$$BS_{bt} = \alpha_0 + \alpha_1 BS_{bt-1} + \alpha_2 BC_{bt} + \alpha_3 BC_{bt}^2 + \alpha_4 BI_{bt} + \alpha_5 GDP_{ct} + \varepsilon_t \quad (6)$$

$$BS_{bt} = \alpha_0 + \alpha_1 BS_{bt-1} + \alpha_2 BD_{bt} + \alpha_3 BD_{bt}^2 + \alpha_4 BI_{bt} + \alpha_5 GDP_{ct} + \varepsilon_t \quad (7)$$

$$BS_{bt} = \alpha_0 + \alpha_1 BS_{bt-1} + \alpha_2 BC_{bt} + \alpha_3 BD_{bt} + \alpha_4 BC * BD_{bt} + \alpha_5 BI_{bt} + \alpha_6 GDP_{ct} + \varepsilon_t \quad (8)$$

In the equations above BS_{bt} is bank stability, BC_{bt} stands for bank competition, BD_{bt} denotes bank digitalization and BI_{bt} includes bank-specific indicators of bank b at time t, GDP denotes GDP growth and is the error term.

To consider the possible endogeneity issues within variables, the instrumental variables method is used together with the Generalized Method of Moments (GMM) estimator. Endogeneity can occur due to the simultaneous determination of variables or reverse causality. Accordingly, the potential endogeneity issue is managed by employing an instrumental variable approach, as suggested by Clark et al. (2018) and Khattak et al. (2023). In line with research on bank competition, digitalization and stability (Clark et al., 2018; Khattak et al., 2023; Verma & Chakarwarty, 2023), this study employs a series of lagged explanatory variables as instruments to resolve the issue of endogeneity. Therefore, BC_{bt-1}, and BS_{bt-1} are one-period lags.

At the same time, to assess the potential non-linear effects and complexities in the relationships, quadratic terms of bank competition BC_{bt}^2 and digitalization BD_{bt}^2 are included following Berger et al. (2017).

Data and sampling

The initial study aimed to include banks from all five Central Asian countries. However, due to data availability issues, only banks from Kazakhstan, Kyrgyzstan, and Uzbekistan were analyzed, totaling 67 banks. The final dataset includes an unbalanced panel of 20 banks from Kazakhstan, 23 from Kyrgyzstan, and 24 from Uzbekistan, presented in Table 3.

Table 3. Number of Banks

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Kazakhstan	16	16	17	17	18	18	20	20	20	20	20
Kyrgyzstan	21	22	22	22	23	23	23	23	23	23	23
Uzbekistan	8	9	11	11	14	14	20	23	24	24	24
Total	45	47	50	50	55	55	63	66	67	67	67

Source: own calculation

Results and discussion

Descriptive statistics

Table 4 provides descriptive statistics of the variables. P-R spans from 0.09 to 0.89, with an average of 0.52, showing that bank competition is strictly between perfect competition and monopoly. In addition, the mean HHI of 0.16 reflects a below-average level of market concentration in all three countries. Overall, this indicates the presence of monopolistic competition, where banks possess pricing power but face competitive pressures that limit excessive profits (Akande et al., 2018).

Regarding bank stability, the Central Asian banking system exhibits a higher risk profile. The mean z-score of 42.5 and LLR of around three percent indicate a stability level that is slightly better than that of banks in the MENA region (Khattak & Ali, 2021; Zoghlami & Bouchemia, 2021) yet lower than in China (Tan, 2016).

Table 4. Descriptive statistics

Variable	Mean	St. deviation	Min	Max
Bank digitalization	17,89	10,63	3,31	52,06
Panzar-Rosse Model	0,52	0,19	0,09	0,89
Herfindahl-Hirschman Index	0,16	0,11	0,08	0,57
Z-score	42,52	78,54	0,98	345,3
Loan loss reserves ratio	0,03	0,06	0,00	0,34
Diversification	0,31	0,07	0,22	0,50
Size	18,64	2,79	14,69	22,70
Loans to assets	0,53	0,07	0,40	0,73
Return on assets	0,03	0,08	-0,01	0,45
GDP growth	4,18	3,26	-7,15	10,92

Source: own calculation

Correlation matrix

Table 5 presents the results of the correlation matrix, which demonstrates the absence of multicollinearity, as no coefficient exceeds 80% (Kennedy, 2008).

Table 5. Correlation matrix

	P-R	HHI	BD	Div	ROA	Size	z-score	LLR	LTA	GDP
P-R	1									
HHI	0,42	1								
BD	0,44	0,14	1							
Div	0,24	0,29	-0,06	1						
ROA	0,27	0,24	-0,11	0,40	1					
Size	0,07	0,33	0,36	-0,11	-0,08	1				
z-score	-0,12	-0,34	-0,40	-0,27	-0,06	-0,39	1			
LLR	0,35	0,42	0,41	0,02	-0,01	0,41	-0,53	1		
LTA	-0,40	0,37	0,38	-0,34	-0,21	0,57	-0,05	-0,25	1	
GDP	0,03	0,37	-0,23	0,21	0,05	0,27	0,19	-0,20	0,29	1

Source: own calculation

Regression results

Table 6 presents the findings from the regression analyses conducted. A series of diagnostics tests were applied to ensure the robustness of the findings. First, insignificant p-values of the J-Test of overidentifying restrictions confirm the suitability of the selected variables and their lagged values as instruments in the models. Next, the Arellano-Bond tests (AR1 < 0.05 and AR2 > 0.05) confirm the absence of first- and second-order serial correlations. Finally, significant values of Wald tests confirm that the variables included are jointly significant, showing robust explanatory power.

Table 6. Competition, digitalization, and bank stability

	(1) Bank competition and stability	(2) Bank digitalization and stability	(3) Moderating effect of bank digitalization
Variables	**z-score**	**z-score**	**z-score**
Lag	0.1428***	-0.1908*	-0.3529*
P-R	0.0346**		0.9414***
P-R2	0.0163**		
BD		-0.4399**	-4.6114***
BD2		0.0312**	
P-R × BD			3.3000**
ROA	0.0007**	-0.0484**	-0.6277***
Div	0.0187**	-0.1706**	-3.1128***
Size	1.4279**	0.8297**	5.6312**
LTA	-0.0418*	0.3556**	1.0832***
GDP	0.2980**	1.0391**	1.6635***
Inst-s	*32*	*32*	*32*
J-Test (p-value)	*1*	*1*	*1*
AR1 (p-value)	*0.0416*	*0.0522*	*0.0325*
AR2 (p-value)	*0.668*	*0.6199*	*0.3804*
Wald test	*345.22****	*674.9****	*877***

Source: own calculation

Bank competition. The first section of Table 6 presents the regression results examining the direct impact of bank competition on bank stability. The lagged dependent variable of the z-score is positive and significant, indicating that past stability positively influences current stability. It shows the path-dependent process in which financially resilient banks maintain stability over time. Indeed, bank

regulatory legislation in CA is becoming stricter, leading to advancements in risk management practices among banks over time (Clark et al., 2018; Yudaruddin, 2022).

The results indicate that bank competition has a positive and significant impact on bank stability. Quadratic effects of P-R on z-score show that competition has a progressively positive impact on bank stability, supporting the competition-stability perspective. The findings support Hypothesis 1 and align with research in emerging and post-communist markets where competition is found to discipline the banking sector by promoting efficiency-driven strategies and risk mitigation tools (Clark et al., 2018; Turk Ariss, 2010; Yudaruddin, 2022).

The control variables provide additional insights into stability dynamics. Profitability has a positive and significant impact, consistent with the notion that profitable banks are better equipped to absorb shocks and invest in risk management systems (Carbó-Valverde, 2017; Sarpong-Kumankoma et al., 2018). Diversification enhances stability due to its role in spreading risk across non-interest income sources (Amidu & Wolfe, 2013; Khattak et al., 2023). However, this effect diminishes in subsequent models, suggesting that diversification strategies may be less effective in digitalized environments. Bank size positively influences stability, reflecting the benefits of resource availability and economies of scale to withstand economic shocks (Clark et al., 2018; Gao & Wang, 2023). In CA, larger banks receive increased state support, providing additional resources to buffer against financial distress, enhance creditworthiness, and foster a perception of "too big to fail" among investors and customers. Also, larger banks have more diverse operations and participate in non-traditional banking activities, which leads to economies of scale (Clark et al., 2018; Khattak et al., 2023). Loan-to-asset ratio further reinforces stability by reflecting effective credit management, while GDP growth highlights the role of macroeconomic expansion in supporting financial soundness.

Bank digitalization. The second section of Table 6 investigates the relationship between bank digitalization and stability. The lagged dependent variable is negative, suggesting that stability declines in banks with the presence of digitalization. This finding reflects the disruptive nature of digital transformation as banks undergo technological restructuring that may initially introduce operational vulnerabilities and adaptation costs (Khattak et al., 2023). Compared to the positive persistence observed in Model 1, the negative coefficient suggests that stability becomes volatile in the context of digital transformation.

The results are corroborated by a negative and significant impact of BD on stability, highlighting the challenges of technological adoption. The result of the quadratic term indicates that as the level of digitalization continues to increase, its effect on bank stability becomes positive. Digitalization, while enhancing efficiency and innovation, is also associated with operational risks and technological challenges that undermine bank stability. This is consistent with findings in other markets where the adoption of digital tools increased risk exposure at the initial stages before stabilizing over time (Kriebel & Debener, 2019; Shanmugam & Nigam, 2020). This is also relevant for developing countries, where digital facilities often require balancing substantial upfront investments with delayed profits (Nguyen-Thi-Huong

et al., 2023). The finding highlights context-specific challenges in Central Asia, where digitalization remains nascent and regulatory frameworks are less developed.

Among the control variables, profitability negatively affects stability, suggesting that profit-driven strategies in digitally transforming banks may prioritize short-term returns over long-term resilience. Similarly, diversification reduces stability due to volatility in non-interest income streams reliant on digital channels. However, size and LTA positively affect stability, underscoring the role of scale advantages and credit management capacity in mitigating transition risks. GDP growth provides macroeconomic stability but suggests the potential for procyclical risk-taking during economic expansions.

Moderating effect of bank digitalization. The third section examines the combined and interaction effects of bank digitalization and competition on stability. The lagged dependent variable is negative, further reinforcing the disruptive impact of digitalization on past stability observed in Model 2. This negative coefficient suggests that banks undergoing simultaneous competition and digitalization pressures face short-term instability as they adapt to technological changes while navigating competitive markets.

The results highlight a positive and significant interaction term (PRM × BD = 3.3000, $p < 0.05$), indicating that digitalization amplifies the stabilizing effects of competition. This finding suggests that, although digitalization alone increases risk, it becomes a stabilizing force when paired with competition, which imposes discipline (Singla & Singh, 2019) and efficiency incentives (Begimkulov, 2024; Srivastava et al., 2023). Indeed, digital systems and infrastructure lower operational costs by automating and facilitating transactions (Carbó-Valverde, 2017; Nguyen et al., 2023; Shanmugam & Nigam, 2020). As a result, increased efficiency leads to overall improvements in financial performance, thereby increasing bank stability.

Robustness test

To validate the main findings, a robustness test was conducted by substituting the dependent variable and key explanatory variables. Specifically, the z-score was replaced by LLR to measure bank risk, and HHI was used instead of P-R to capture market competition.

Overall, the robustness tests in Table 7 confirm the main findings from the primary analysis while offering additional insights. First, HHI has a positive and significant effect on LLR, suggesting that higher market concentration increases risk levels. This result supports the competition-stability hypothesis. Bank size and diversification reduce the risk, highlighting the benefits of economies of scale and income diversification in stabilizing bank operations.

In the second robustness test, the results indicate that BD has a positive effect on risk, confirming the earlier findings. The lagged dependent variable turns positive, indicating that risk persistence increases once banks adopt innovations. This suggests that technological transitions may create short-term vulnerabilities and challenges. Control variables further support this interpretation. Size is positive,

implying that larger banks with higher digital adoption rates may take on greater risks to maintain market dominance. Meanwhile, LTA ratios indicate that higher credit intensity amplifies risk, underscoring the role of loan portfolios in driving instability during technological transitions and supporting our findings.

The final robustness test incorporates the interaction term to assess whether digitalization moderates the impact of competition on risk. The results reveal a negative and significant interaction effect, suggesting that digitalization reduces the risk-enhancing effects of market concentration. This finding validates the moderating role of digitalization observed in the main analysis. Digital tools enable banks to generate stable fee-based income (Lestari et al., 2023), allow for continuous monitoring of customers, and assess for credit repayment to avoid possible defaults (Guo & Liang, 2016).

The direct effects of BD observed in the main analysis are consistent with this robustness test, where BD increases risk when assessed independently. This further supports the notion that digitalization introduces vulnerabilities, but when combined with competition, it acts as a stabilizing force by enforcing discipline and improving transparency. This also shows the reliance of banks on traditional loans and the limited digitalization of loan processes, suggesting room for enhanced digital integration to improve stability.

Control variables provide additional insights. Profitability continues to amplify risk, reflecting profit-driven incentives in competitive environments. Size and loan-to-asset ratios remain positive, emphasizing the role of scale advantages and credit intensity in risk amplification. Meanwhile, GDP reduces risk, highlighting the stabilizing effect of economic growth.

Table 7. Robustness test

	Model 1	Model 2	Model 3
Variables	LLR	LLR	LLR
Lag	-0.0002**	0.0001*	0.0001*
HHI	0.0041 *		0.0001***
BD		0.0001*	0.0003*
HHI × BD			-0.0002*
ROA	0.0003	0.0001*	0.0001*
Div	-0.0005 *	0.0000	0.0000
Size	-0.0006**	0.0042*	0.0039*
LTA	0.0001	0.0001**	0.0001**
GDP	-0.0001*	-0.0108	-0.0104*
Inst-s	*30*	*30*	*34*
J-Test (p-value)	*1*	*1*	*1*

	Model 1	Model 2	Model 3
AR1 (p-value)	*0.0073*	*0.0325*	*0.0328*
AR2 (p-value)	*0.5503*	*0.8373*	*0.2442*
Wald test	*525.6****	*116.8****	*1704.2****

Source: own calculation

Conclusion

This study examines the relationship between bank competition, digitalization, and stability within the Central Asian banking sector, providing empirical evidence on how technological advancements and market structures influence risk and resilience.

First, the results demonstrate that higher competition has a positive linear impact on bank stability. This finding supports the competition-stability hypothesis, suggesting that competitive pressures in Central Asia encourage stability, reduce market power, and discipline risk-taking behaviors.

Second, the study reveals a U-shaped relationship between bank digitalization and stability. While at the initial stage, digitalization negatively affects bank stability due to technological transition costs and operational risks, later the benefits begin to outweigh the initial negative impacts.

Third, digitalization also amplifies the stabilizing effect of competition when combined with competitive pressures. The positive interaction term confirms the moderating effect of digitalization in reinforcing competition's impact on stability, enhancing risk assessment, loan monitoring, and operational efficiency. This evidence highlights the transformative potential of digital technologies to support risk management but underscores the need for regulatory frameworks to mitigate associated risks.

The dual impact of digitalization highlights the need for banks to carefully manage technological transitions. While digital tools enhance efficiency and risk management, their initial adoption may introduce operational vulnerabilities and cybersecurity risks.

The positive effect of competition on stability underscores the importance of fostering competitive banking environments. Regulators should focus on reducing entry barriers and encouraging fintech innovations to sustain market discipline and prevent monopolistic practices that may amplify risk-taking behaviors.

Given the interaction effects between competition and digitalization, regulators should develop adaptive frameworks to monitor and manage risks arising from technological adoption in competitive markets.

This study has several limitations that should be addressed in future research. The study focuses on Central Asian countries despite limiting the generalizability of the results to other regions with different regulatory frameworks, market structures, and technological readiness. Therefore, future studies could focus on regional comparisons to study variations in the competition-digitalization-stability nexus. ■

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