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Digital Finance and Commercial Banks' Risk

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ABSTRACT

China's digital financial growth has advanced rapidly, and the banking sector, which serves as the core of the real economy, is concerned about its capacity to resist the impacts of digital finance. The paper analyzes the impact of digital financing on commercial banking risk-taking via balance panel data from 2013 to 2022 from 160 Chinese banks. The results prove that the impact of digital finance on commercial banks' risk-taking and finds that firstly, in terms of the overall effect, digital finance has a dampening effect on commercial banks' risk-taking; in terms of the structural effect, the risk-dampening effect of the breadth of coverage is the strongest and the breadth of coverage and the depth of use play a significant role in the dampening of commercial banks' risk-taking.

KEYWORDS

Bank Competition, China, Commercial Banks, Digital Finance, Risk-Taking

INTRODUCTION

The origin of digital finance can be traced back to the end of the 20th century, and the introduction of PayPal in the United States in 1998 was the beginning of Internet finance. With the development of Internet finance theory, P2P lending platforms also emerged after 2005.

Internet finance mainly refers to Internet enterprises and traditional financial institutions that carry out financial business based on Internet technology (Dong et al, 2020). Financial Stability Board proposed the concept of financial technology (Fin-Tech) for the first time at the international level, which means "the technology-induced financial market, financial institutions and the way of providing financial services." (Anifa et al., 2022; Mansour, 2023). Internet finance covers a narrower content. It focuses on the scene dimension, while fintech emphasizes the impetus brought to finance by the update of science and technology and focuses on the technical dimension. The concept of digital finance is more neutral and covers a broader scope (Gomber et al., 2017; Bayram et al., 2022).

As an emerging business model, digital finance is bound to impact the stability of commercial banks' operation and development (Khattak et al, 2023). At the same time, digital technology has also brought about new risk exposures, and the problem of risk contagion has increased (Luo, 2022). The downward trend of China's economy is not optimistic; the probability of corporate defaults has increased, and financial risks have accumulated. In this context, it is essential to clarify whether digital

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finance increases or reduces commercial banks' risk-taking, and it is of great significance to enhance the financial risk prevention ability of commercial banks, improve the efficiency of commercial banks' risk management, and promote the smooth operation of the financial system under the new wave.

The Internet environment developed earlier in foreign countries than in China, so foreign research on the relationship between digital finance and commercial banks started earlier (Lee et al., 2023). In recent years, with the rapid development of digital finance in China, studies on digital finance and commercial banks' risk-taking have also emerged, and through the literature, the main points of view are as follows:

First, digital finance promotes risk-taking by commercial banks by eroding the value of their franchises and exacerbating risk contagion (Ajili & Mansour, 2024). With its advantages in customer acquisition, channel operation, information extraction, and capital supervision, digital finance has introduced the core deposit and lending business of commercial banks, affected the monopoly of commercial banks in the financial industry, reduced their franchise value and profitability (Dong et al., 2020; Theiri, & Hadoussa, 2024), and its reduced profitability has increased the risk of banks' operation.

In addition, in the era of digital finance, the introduction of digital technologies such as cloud computing and big data technology by commercial banks will expose them to the data risks of the Internet industry (Cheng et al, 2022; Ha & Nguyen, 2022; Liang et al., 2023; Quach et al., 2022), and immature technology, consumer privacy protection, financial fraud, and liquidity risk contagion problems may increase the risk-taking of commercial banks (Boamah et al., 2023). According to Luo (2022), the risk of financial innovation products has become more hidden, and the risks of technological attributes such as data, network, privacy, and third-party technological dependence are all potential factors for risk contagion, creating a market risk that is more penetrative and contagious.

Second, digital finance inhibits commercial bank risk-taking through technological spillovers. Commercial banks have absorbed new digital finance technologies through the demonstration effect. Khan (2022) found that Internet finance changes commercial bank risk management and operational efficiency, effectively improving it, which makes up for its unfavorable impact on profitability and risk, reduces commercial banks' bankruptcy risk, and improves bank stability. Li et al. (2022) pointed out that the rapid development of digital technology and the digital economy effectively solves the problem of information asymmetry between banks and enterprises and optimizes the structure of the risk-taking behavior of banks in China.

Nasiri et al. (2022) believe that in the late stage of development, the bank's development and use of digital technology tends to be mature, its banking service system is constantly improving and risk control ability is constantly improving, and its risk-taking will continue to decline. It can be found through the review that existing research on the relationship between digital finance and commercial bank risk-taking has various views among scholars (Nguyen & Dang, 2022).

There is still space for research to make more accurate judgments based on the latest indicators of digital finance and the specific situation of Chinese commercial banks. The existing literature has rarely examined the moderating mechanism of the relationship between the two in terms of the external environment. Given this, this paper seeks to make contributions in the following aspects: first, using Peking University's Digital Inclusive Finance Index as a proxy variable for digital finance, we examine its impact on commercial banks in terms of the "overall effect" of digital finance and the "structural effect" of the three dimensions under it, namely, the breadth of coverage, the depth of use, and the degree of digital services. "The second is to examine its impact on commercial banks' risk-taking from the bank size and region perspective. Second, the heterogeneity of digital finance on commercial bank risk-taking is examined from bank size and regional financial regulation perspectives. Third, to explore the mechanism of the external environment on the relationship between the two, this paper examines the moderating effect of the degree of competition in the banking industry and economic policy uncertainty on the relationship between digital finance and commercial bank risk-taking, respectively.

The objective of this study is to offer new ways of examining digitalization in the context of financial performance in the Chinese banking sector. This will allow us to critically assess to what extent and in what ways fintech impacts performance.

Regarding this study's practical contributions, the findings are essential for financial institutions and regulators, as they help explain digital finance's effectiveness. The results prove the impact of digital finance on commercial banks' risk-taking and find that firstly, in terms of the overall effect, digital finance is having a dampening impact on commercial banks' risk-taking; in terms of the structural implications, the risk-dampening impact of the breadth of coverage is the strongest and the breadth of coverage and the depth of use play a significant role in the dampening of commercial banks' risk-taking

Our research paper will first present a theoretical analysis and research hypothesis. Second, we will present research data and study design. Third, we will focus on the empirical findings and regulatory mechanism test, and finally, we will show the conclusion and recommendations.

THEORETICAL ANALYSIS AND RESEARCH HYPOTHESIS

Mechanisms of Digital Finance's Impact on Commercial Banks' Risk-Taking

The Facilitating Effect of Digital Finance on Commercial Bank Risk-Taking

Firstly, digital finance affects commercial banks' traditional deposit and loan business. Overall, under the impact of digital finance, the scale of deposits taken by commercial banks has mostly stayed the same (Ajili & Mansour, 2024). However, the change in deposit structure is more significant: the proportion of customer deposits with lower funding costs has declined, and the proportion of interbank deposits with higher funding costs has risen. The deterioration of the deposit structure and the increase in interest payment costs aggravate the level of risk-taking by commercial banks (Luis et al., 2020; Drehmann et al., 2010). The impact on the deposit and loan business has caused the net interest margin of commercial banks to decline, compressing the traditional on-balance sheet income of commercial banks.

Second, digital finance has facilitated the development of banks' off-balance-sheet businesses, such as wealth management (Qiang et al., 2023). Combined with the background of the rapid development of digital finance, commercial banks rely on digital technology to carry out business diversification, gradually weakening the reliance on the spread; the proportion of on-balance sheet business declined, and the proportion of off-balance sheet business increased, to obtain the deposit and loan business.

However, the existing regulatory policy cannot comprehensively regulate the off-balance sheet business, and a dead zone still exists that is not covered by the regulation. The lack of regulation may make commercial banks bear more risks than their affordable capacity to maximize profits, which may increase the risk of bankruptcy of commercial banks and not be conducive to realizing the long-term sound operation of commercial banks (Ulf, 2023).

Finally, regarding risk contagion, the mutual integration of business and technology between commercial banks and digital finance has inevitably increased the risk exposure of commercial banks, inevitably triggering new risks (Li et al., 2022; Tan,2014). In contrast, changes in risk management and operational efficiency of commercial banks have taken place, thereby significantly increasing the likelihood of their own increased risk-taking. Operational risks, such as the introduction of digital transaction systems by commercial banks, may trigger problems such as unstable data storage and personnel operational errors; technological risks, the integration of digital finance into the management system of commercial banks will bring about security problems caused by network technology, triggering the emergence of risks in the banking system; legal risks, the boundaries between illegal

fund-raising and the financing business of Internet platforms are blurred, and the cooperation of commercial banks with digital financial enterprises is difficult to adhere to the legal principles for the protection of consumer privacy. Therefore, the hypothesis is formulated as H1a: Digital finance facilitates risk-taking in commercial banks.

The Dampening Effect of Digital Finance on Commercial Bank Risk-Taking

In the face of the wave of rapid development of digital finance, the only way for commercial banks to adapt to the impact of digital finance on the traditional business of banks and thus stabilize their own operation and development is to accelerate their own digital transformation and make full use of the technological spillover effect of digital technology.

First, digital finance can effectively alleviate the problem of information asymmetry in commercial banks. The rapid integration of finance with artificial intelligence, big data and other digital technologies enables market participants to mine corporate information more quickly, conveniently and accurately, successfully capturing the behavioral data of different groups in society (Debidutta etal., 2024; Shamima et al., 2022), thus improving the transparency of market information and alleviating the degree of information asymmetry.

From the perspective of information acquisition, the advantages of big data, cloud computing and other technologies in centralized processing of massive data enable commercial banks to obtain a more comprehensive dimension of customer information (Nobanee, et al., 2021), while also combining the advantages of high precision, which greatly improves the efficiency of commercial banks in acquiring information, enabling financial institutions to grasp more observable, high-quality information at low cost before granting credit.

From the perspective of information processing, commercial banks can use digital technology to establish credit risk assessment models for micro and small enterprises, effectively reducing the cost of risk assessment and improving the efficiency and accuracy of risk review (Qi et al., 2022).

Secondly, digital finance can improve the risk identification ability of commercial banks (Yang et al., 2021). The application of big data, artificial intelligence and other digital technologies by commercal banks can increase the breadth and depth of data mining, achieve multi-dimensional interoperability of internal and external data and dynamic interaction of data, establish an efficient, real-time financial risk control model for the whole process, improve the risk identification ability, and strengthen the foundation of risk management.

Finally, digital finance can help commercial banks carry out monitoring activities effectively. From the perspective of ex-ante monitoring, digital finance can effectively reduce the occurrence of adverse selection. In recent years, commercial banks can not only obtain corporate information through corporate accounts, but also rely on digital technology to obtain corporate online transaction data and behavioral data (Akhter, 2023), more dimensional and more comprehensive information makes the accuracy of the risk assessment of the borrowing enterprise increase, in order to avoid lending funds to enterprises with a higher risk of default, resulting in an increase in the rate of non-performing loans. From the point of view of in-between monitoring, digital finance can effectively reduce the occurrence of moral hazard (Momtaz, 2021). The great advantage of digital technology lies in the construction of risk assessment models to accurately track the user's digital behavior and behavioral data, reducing the probability of enterprises making high-risk investments and other behaviors detrimental to the interests of commercial banks due to the pursuit of self-interests, and avoiding to a large extent the losses arising from credit risks suffered by commercial banks. This largely prevents commercial banks from suffering losses due to credit risk.

Therefore, the hypothesis is formulated as H1b: Digital finance has a dampening effect on commercial bank risk-taking.

An Analysis of the Heterogeneity of Digital Finance Affecting Risk-Taking in Commercial Banks

Bank Size Heterogeneity

China's commercial banking industry has a tradition of "large banks serving large customers and small and medium-sized banks serving small and medium-sized customers". Banks with large asset sizes often have customers with good balance sheets, sufficient collateral and low probability of default (Yong, 2016).

Large-scale banks can take advantage of adapting to the wave of digitization more quickly, making it easier to complete the digital transformation and, thus, more easily offset the impact of digital finance on their traditional business (Shanti et al., 2023). They can further take advantage of digital technology's enabling role to help them achieve their business goals.

The empowering effect of digital technology is further utilized to reduce the information asymmetry between banks and enterprises, establish a better risk monitoring system, and improve risk identification capabilities, making the operation of large-scale banks more efficient.

In contrast, small-scale banks' customer base often needs more collateral and even lacks creditworthiness, resulting in higher credit risks. This, coupled with the negative impact of digital finance on their traditional business and the new risk exposures created by digital technology, may make them less adaptable to external factors.

In addition, large-scale banks have invested much more in fintech than small-scale banks, and their original business operation platforms and back-office risk control systems are more sophisticated than small-scale banks, so they may be better able to utilize their advantages fully through digital finance.

Regional Financial Regulatory Heterogeneity

As analyzed in the previous section, commercial banks can strengthen their risk management capabilities and improve financial services through digital finance's technological spillover effect.

However, this does not mean that the inherent risks are eliminated, and the development of digital finance will also bring new risk exposures, such as financial fraud, data loss, and other problems, resulting in a threat to the security of the financial system.

The development of digital finance also brings new risk exposures, such as financial fraud, data loss, and other problems, leading to threats to the security of the financial system, so it is necessary to improve the financial regulatory system to incorporate new risks (Uddin et al., 2023).

The promulgation of the Guiding Opinions on Promoting the Healthy Development of Internet Finance in July 2015 meant that China officially launched the supervision of Internet finance and gradually increased the regulation of digital finance.

Subsequently, the CBRC, the Financial Stability Development Committee of the State Council, and even at the national level have deepened the layout of fintech and digital financial regulation and strengthened the governmental supervision of digital finance in an attempt to prevent the financial risks arising from the brutal development of digital finance and to seek a balance between regulatory rigidity and market-oriented regulation.

Inhibiting the negative effects of digital finance development and promoting the healthy and stable development of the financial market might be more helpful (Jungo et al, 2022; Tay et al., 2022).

In summary, the hypothesis is H2: Digital finance affects commercial banks' risk-taking, with heterogeneity in bank size and regional financial regulation.

RESEARCH DATA AND STUDY DESIGN

Sample Selection and Data Sources

This paper selects the annual data of Chinese commercial banks from 2013 to 2022 and performs the following treatments:

First, policy and foreign-funded banks are excluded because they have different characteristics to commercial banks (Mansour,2023); second, samples with many missing values are excluded; third, samples with missing data for three consecutive years are excluded.

Finally, we obtained the 10-year balanced panel data of 160 commercial banks, including six state-owned banks, 11 joint-stock commercial banks, 85 city commercial banks, and 58 rural commercial banks. The total number of observations is 1600.

Micro-level data were obtained from the Wind database and the annual reports of commercial banks, and a small amount of missing data is made up by looking up the banks' annual reports.

The digital finance index comes from the Digital Inclusive Finance Index compiled by the Digital Finance Research Center of Peking University, which can be obtained from its official website.

It measures the level of fintech development in the provinces where commercial banks are registered. The Digital Inclusive Finance Index is built on the underlying data of Ant Financial Services' transaction accounts (Lv et al., 2022), which can measure fintech development across counties. Chen (2022) built the index based on three dimensions: breadth of coverage, depth of use, and degree of digitization, considering both the population covered by Ant Financial Services and whether the covered population uses Ant Financial Services business. The index can accurately measure the level of fintech development in China.

Other macro data are mainly from the Wind Database, CEIC China Economic Database, and China Urban Statistical Yearbook.

Variable Design

Explained Variable: Commercial Bank Risk-Taking

The weighted risky asset ratio, non-performing loan ratio, and Z-value are used more frequently in the existing studies.

At this stage, the need for more data on risk-weighted assets is relatively severe, and the NPL ratio only represents credit risk, which cannot comprehensively represent the concept of commercial bank risk-taking. Therefore, after comprehensively considering the availability of data and the representativeness of indicators, this paper refers to the research of Mercieca et al (2007), and Laeven & Levine (2009) and selects Z-value as a proxy for the risk-weighted assets of commercial banks in China.

From the perspective of internal governance of banks, the Z value is constructed to measure the probability of bank bankruptcy, and its calculation formula is:

$$Z_{i,t} = \frac{ROA_{i,t} + CAR_{i,t}}{\sigma_{i,t}\left(ROA\right)_{i,t}}$$

where ROA is the bank's return on assets, i.e., net profit after tax/total assets; CAR is the bank's capital-to-assets ratio, i.e., shareholders' equity/total assets; σ (ROA) is the standard deviation of the bank's return on assets; and i and t represent commercial banks and years, respectively. The logarithm of Z is taken for the regression in practical application because of its sharp peaks and tails nature; the larger Z is, the more stable the commercial banking system is, and the smaller the risk-taking of commercial banks is.

Explanatory Variables: Digital Finance

With reference to the existing literature, this paper selects the Peking University Digital Inclusive Finance Index (DIFI) as a proxy variable for digital finance (He et al., 2022), which can reflect the

actual development of digital finance in a more comprehensive and objective way. The index not only reflects the external impact of Internet finance on commercial banks, but also reflects the internal fintech strength of commercial banks, which is authoritative and comprehensive. In order to explore the overall effect and structural effect of digital finance on commercial banks' risk taking, the index and the secondary indicators of digital finance, such as coverage, usage and digitization, are regressed on commercial banks' risk taking. The index contains ten consecutive years of index data from 2013 to 2022, and the higher the digital finance index, the higher the level of digital finance development in the region. In the benchmark regression part of this paper, referring to the study of Liang et al. (2022), provincial-level data are used, and in the robustness test part, municipal-level data are used, and the index is divided by 100 to solve the magnitude problem.

Control Variable

In order to avoid the interference of other factors, the more essential factors were selected as control variables from the factors that could be influenced. At the micro-bank level, asset size, profitability (roe), operating capacity (tat), operating efficiency (cir), and capital structure (lev) were selected as control variables; at the macro-economic level, GDP growth rate (GDPg), inflation rate (cpi) and degree of financial development (findep) were selected as control variables.

According to the content of the previous section, all variables are summarized in Table 1, which is an essential preparation for the subsequent model construction and test analysis.

In order to explore the impact of digital finance on commercial banks' risk-taking, this paper constructs the following benchmark regression model:

Table 1. Variable selection table

Variable type	variable name	Symbol	Variable Definition
explained variable	Commercial bank risk-taking	risk	Z-value
explanatory variable	Digital Finance Index The Coverage Index Usage Depth Index Digitization service level index	Index Coverage Usage Digitization	The Digital Finance Inclusion Index, compiled by the Internet Finance Research Centre of Peking University
		Micro-bank level	
	Asset size Profitability Operating capacity Operating efficiency Capital structure	Size ROE TAT CIR LEV	Logarithm of total bank assets Banks' return on net assets Banks' total asset turnover ratio Bank's cost-to-income ratio Bank's equity to assets ratio
		Macroeconomic level	
	GDP growth rate	GDPg	Nominal GDP growth rate
	inflation rate	cpi	Logarithm of the consumer price index
	Level of financial development	findep	Balance of various RMB loans to financial institutions/ GDP

$$risk_{i,t} = a_0 + a_1 index_t + \sum a_2 CV_{i,t} + \mu_i + \varepsilon_{i,t} \quad (1)$$

In model (1), the explanatory variable $risk_{i,t}$ is commercial bank risk-taking, the core explanatory variable $index_t$ is the digital finance index, and $CV_{i,t}$ denotes the control variables, which include control variables at the micro-level as well as the macroeconomic level of the bank. Referring to previous literature, the base regressions in this paper use the fixed effects approach, μ_i is the individual fixed effects of banks, which is used to control for individual bank characteristics that do not vary over time, and $\varepsilon_{i,t}$ denoting the random term error.

Other things being equal, if the sign of 1 a is significantly positive, hypothesis H1b holds; if the sign of 1 a is significantly negative, hypothesis H1a holds.

In order to further explore the structural effect of digital finance on commercial banks' risk-taking, we test the influence of three sub-dimension indicators, namely, coverage breadth, usage depth, and digital service degree, on banks' risk-taking and establish the following model:

$$risk_{i,t} = b_0 + b_1 covrage_t + \sum b_2 CV_{i,t} + \mu_i + \varepsilon_{i,t} \quad (2)$$

$$risk_{i,t} = c_0 + c_1 usage_t + \sum c_2 CV_{i,t} + \mu_i + \varepsilon_{i,t} \quad (3)$$

$$risk_{i,t} = d_0 + d_1 digitization_t + \sum d_2 CV_{i,t} + \mu_i + \varepsilon_{i,t} \quad (4)$$

In model (2) (3) (4), the explanatory variable, $risk_{i,t}$ is commercial bank risk taking, $covrage_t$ is digital finance coverage breadth index, $usage_t$ is the index of digital finance coverage, $digitization_t$ is the index of digital finance digital support services, $CV_{i,t}$ denotes the control variables, μ_i is the bank's individual fixed effects, and $\varepsilon_{i,t}$ denotes random term error.

Descriptive Statistical Analyses

Table 2 shows the descriptive statistics of the explained, explanatory, and control variables. As seen from the table below, the Core explanatory variable commercial bank risk (risk) has a minimum value of 1.358 and a maximum value of 5.088, a relatively large span indicating significant differences in risk-taking levels between different years and banks.

The range of the explanatory variables is 0.184~4.320 for the index of digital finance and 0.020~4.319 for the coverage index.

Ranges from 0.020 to 3.970, the depth of use index ranges from 0.069 to 4.888, and the digitization index ranges from 0.076 to 4.887.

The range of the digitization index (digitization) is 0.075~4.621; the fluctuation range of the digital finance composite index and the indicators of the three dimensions under it are significant, indicating that there are large gaps in the coverage and permeability of digital finance at different times and in different regions.

In addition, there are apparent differences in asset size, profitability (roe), operational efficiency (cir), and capital structure (lev), indicating that there are significant gaps in the internal resources, business strategies, and operational capabilities of China's commercial banks.

Table 2. Descriptive statistical analysis

Variable Name	Sample Size	Average Value	(Statistics) Standard Deviation	Minimum Value	Maximum Values	Median
Risk	1600	3.444	0.539	1.358	5.088	3.434
index	1600	2.336	0.997	0.184	4.320	2.400
coverage	1600	2.142	0.970	0.020	3.970	2.175
usage	1600	2.380	1.021	0.069	4.888	2.337
digitization	1600	2.896	1.234	0.075	4.621	3.228
Size	1600	11.912	1.681	7.854	17.322	11.664
Roe	1600	14.286	6.046	-1.884	46.832	13.468
Tat	1600	0.032	0.009	0.008	0.091	0.030
Cir	1600	33.628	7.466	16.180	129.085	32.745
Lev	1600	7.508	1.880	2.173	24.870	7.339
GDPg	1600	6.839	1.778	2.240	9.550	6.995
Cpi	1600	4.630	0.010	4.619	4.658	4.628
findep	1600	3.417	1.338	1.528	8.131	3.050

EMPIRICAL FINDINGS

The Aggregate and Structural Effects of Digital Finance on Commercial Bank Risk-Taking

Firstly, the Hausman test is conducted on the sample data, and the results show that the p-value of the Hausman test result is 0.0000, which significantly rejects the original hypothesis. Therefore, this paper selects the fixed effect model to conduct subsequent regression to test the effect of digital finance on bank risk-taking. The test results are shown in Table 3, column (1) shows that under the individual fixed effects of banks, increasing bank-level and macro-level control variables, the overall effect of digital finance on commercial bank risk-taking, the regression results show that the coefficient of the index is 0.0219. It is significantly positive at a 1% confidence level, indicating that the development of digital finance can significantly contribute to the improvement of Z; the more significant the Z value, the lower the risk-taking of commercial banks, i.e., the digital financial development can significantly promote Z worthy of enhancement, the bigger the Z value, the lower the risk-taking of commercial banks; that is, digital finance will significantly inhibit the risk-taking of commercial banks. This confirms the results of the study carried out by Tian & Shao (2023). Hypothesis H1b has been verified.

In order to further test the structural effect of digital finance on commercial bank risk-taking and examine the sub-dimensional impact of digital finance on bank risk-taking, this paper divides the digital finance index into three dimensions: breadth of coverage, depth of use, and degree of digitisation to test the impact of different dimensions of digital finance development on bank risk-taking. The results are shown in columns (2) (3) (4) of Table 3. As can be seen from the table, the coefficients of coverage, usage and digitization are all positive at 1% significance level, indicating that the development of the three major forms of digital finance can significantly inhibit the risk-taking of commercial banks, which further confirms Hypothesis H1b. 0.0202 units; usage every increase of 1 unit, the bank risk-taking decreased by 0.0174 units; for every increase of 1 unit in digitization, bank risk taking decreases by 0.00845 units. As a result, in the impact of the three major forms of

Table 3. The empirical results of digital finance on commercial banks' risk-taking

	(1)	(2)	(3)	(4)
	risk	**risk**	**risk**	**risk**
index	0.0219*** (0.00393)			
coverage		0.0202*** (0.00418)		
usage			0.0174*** (0.00312)	
digitization				0.00845*** (0.00234)
size	-0.0269*** (0.00730)	-0.0247*** (0.00750)	-0.0194*** (0.00644)	-0.0119* (0.00640)
roe	0.00386*** (0.000387)	0.00389*** (0.000390)	0.00361*** (0.000385)	0.00380*** (0.000391)
tat	2.462*** (0.316)	2.438*** (0.317)	2.594*** (0.318)	2.281*** (0.318)
cir	-0.00140*** (0.000266)	-0.00139*** (0.000266)	-0.00141*** (0.000266)	-0.00139*** (0.000267)
Lev	0.103*** (0.00103)	0.103*** (0.00103)	0.103*** (0.00102)	0.104*** (0.00101)
GDPg	0.000301 (0.00115)	-0.0000415 (0.00115)	0.000445 (0.00116)	-0.00171 (0.00107)
cpi	-0.190 (0.134)	-0.320** (0.130)	-0.300** (0.130)	-0.0961 (0.155)
findep	-0.00357 (0.00444)	-0.00406 (0.00446)	-0.00192 (0.00443)	-0.00323 (0.00447)
_cons	3.744*** (0.636)	4.331*** (0.625)	4.165*** (0.625)	3.169*** (0.721)
fixed effect	containment	containment	containment	containment
N	1600	1600	1600	1600
R^2	0.917	0.917	0.917	0.916
Adj. R^2	0.908	0.907	0.908	0.906

Note:***, **, * denote significance at 1%, 5%, and 10% confidence levels, respectively, and the robust standard errors of the regression coefficients are in parentheses. Same as below.

digital finance on commercial bank risk, the breadth of coverage has the strongest risk-suppressing effect, followed by the depth of use, and the breadth of coverage and depth of use play a major role in suppressing the risk-taking of commercial banks, and the degree of digital services also has the same effect, but the magnitude is smaller. The results are consistent with the study by Chengming et al. (2022). The empirical results show that banks rely on digital finance to reduce their risk-taking by improving their operating income and capital adequacy ratio, optimizing their operational performance, and improving their risk control capabilities.

Therefore, from the perspective of preventing systemic financial risks, relevant macro policies should focus on accurately increasing the breadth of coverage and depth of use of digital credit and insurance, helping commercial banks in their digital transformation and enhancing the robustness of their operations.

An Analysis of the Heterogeneity of Digital Finance Affecting Risk-Taking in Commercial Banks

Bank Size Heterogeneity

This paper takes the median total assets of each commercial bank at the end of 2020 as the boundary, groups the commercial banks into large-scale and small-scale banks, and conducts regression tests separately. The test results are shown in Table 4. The regression results show that the regression coefficient of the index of large-scale banks is 0.0136, which is significant at a 1% level. The regression coefficient of the index of small-scale banks is 0.00489, which is insignificant, indicating that digital finance has a significant inhibiting effect on large-scale banks' risk-taking level but no significant effect on small-scale banks. The coefficients of coverage and usage of large-scale and small-scale banks have similar results, indicating that the breadth of coverage and depth of usage of digital finance is significant in large-scale banks but has no significant effect on small-scale banks. The coefficient on digitization, on the other hand, is not significantly positive for both large-scale and small-scale banks, indicating that the degree of digitized digital finance services does not have a significant effect. Thus, the impact of digital finance on commercial banks' risk-taking is heterogeneous, depending on bank size. The results align with those observed by Guo & Shen (2016) in the Chinese market. In fact, regarding the impact of Internet finance on commercial banks' risk-taking, the reaction of large commercial banks is slow, while that of small and medium-sized banks is relatively sensitive. Overall, digital finance has a significant dampening effect on the risk-taking level of large-scale banks, while it has no significant effect on small-scale banks.

Regional Financial Regulatory Heterogeneity

In order to explore whether the different financial regulatory strengths in which commercial banks are located will produce heterogeneity in the relationship between the independent variables and the dependent variable, this paper measures the regional financial regulatory level by the regional financial regulatory expenditure. It takes the median of this value as the boundary to divide the sample data into solid and weak regulatory levels for group regression, and the results are shown in Table 5. As can be seen from the table, the coefficients of INDEX, COVERAGE, USAGE, and DIGITISATION are all significantly positive under both strong and weak regulatory levels. The size of the coefficients under the strong regulatory level is more significant than that under the weak regulatory level as a whole, which indicates that when the financial regulation is more robust, the risk-taking of the commercial banks is more sensitive to the changes in digital finance. The inhibitory effect of the bank's risk is more significant and helps to promote the healthy and stable development of the financial market.

In summary, compared with small-scale commercial banks and commercial banks with weak regional financial regulation, digital finance has a more significant inhibitory effect on the risk-taking of large-scale commercial banks and commercial banks with regional solid financial regulation, indicating that digital finance affects the risk-taking of commercial banks with bank size heterogeneity and regional financial regulation heterogeneity, and hypothesis H2 is supported.

Robustness Check

Substitution of Explanatory Variables

In this paper, the provincial digital finance index and its subordinate indexes are used in the baseline model, which is replaced by the municipal digital finance index (index_c), municipal coverage index (coverage_c), municipal usage depth index (usage_c), and digitization degree index (digitization_c) to re-test respectively. As shown in Table 6, the coefficients of all the explanatory variables are significantly positive at a 1% confidence level, consistent with the original model, indicating that the empirical results have good robustness.

Table 4. Bank size heterogeneity

	1	2	3	4	5	6	7	8
	Large-Scale	**Small-Scale**	**Large-Scale**	**Small-Scale**	**Large-Scale**	**Small-Scale**	**Large-Scale**	**Small-Scale**
	Risk	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
index	0.0136*** (0.00445)	0.00489 (0.00567)						
Coverage			0.0106** (0.00493)	0.00424 (0.00585)				
usage					0.0136*** (0.00331)	0.00257 (0.00476)		
digitization							0.00307 (0.00254)	0.00392 (0.00334)
control variable	containment	containment	containment	containment	containment	containment	containment	containment
	3.511***	6.020***	3.868***	6.172***	3.695***	6.147***	3.509***	5.562***
_cons	(0.675)	(0.946)	(0.663)	(0.923)	(0.659)	(0.929)	(0.752)	(1.074)
fixed effect	containment	containment	containment	containment	containment	containment	containment	containment
N	800	800	800	800	800	800	800	800
R2	0.939	0.930	0.939	0.930	0.940	0.930	0.939	0.930
adj. R^2	0.932	0.921	0.931	0.921	0.932	0.921	0.931	0.921

Table 5. Regional financial regulatory heterogeneity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Intensive Supervision	**Weak Regulation**	**Intensive Supervision**	**Weak Regulation**	**Intensive Supervision**	**Weak Regulation**	**Intensive Supervision**	**Weak Regulation**
	Risk	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**	**Risk**
Index	0.0307*** (0.00509)	0.0243*** (0.00725)						
Coverage			0.0275*** (0.00553)	0.0234*** (0.00741)				
Usage					0.0251*** (0.00387)	0.0117** (0.00537)		
Digitization							0.0101*** (0.00298)	0.0126*** (0.00425)
control variable	containment	containment	containment	containment	containment	containment	containment	containment
4.156***_cons (0.750)		3.683*** (1.053)	4.862*** (0.759)	4.435*** (1.001)	4.921*** (0.749)	4.380*** (1.021)	3.008*** (0.872)	2.806** (1.215)
fixed-effects control		containment	containment	containment	containment	containment	containment	containment
N 797		803	797	803	797	803	797	803
R^2 0.935		0.911	0.934	0.911	0.936	0.910	0.933	0.911
adj. R^2 0.921		0.894	0.919	0.893	0.922	0.893	0.918	0.893

Table 6. Robustness tests-substitution of explanatory variables

	(1)	(2)	(3)	(4)
	Risk	**Risk**	**Risk**	**Risk**
index_c	0.0266*** (0.00555)			
coverage_c		0.0260*** (0.00632)		
Usage_c			0.0191*** (0.00427)	
digitization_c				0.0162*** (0.00366)
control variable	containment	containment	containment	containment
_cons	3.652*** (0.647)	3.789*** (0.647)	4.087*** (0.631)	3.397*** (0.670)
fixed effect	containment	containment	containment	containment
N	1600	1600	1600	1600
R^2	**0.917**	**0.916**	**0.917**	**0.917**
Adj. R^2	**0.907**	**0.907**	**0.907**	**0.907**

Adding Control Variables

This paper tests the original model by adding control variables: the macro control variable interbank, which denotes the annual average of the 7-day interbank lending rate, and the bank micro control variable dpr, which denotes the bank deposit and loan ratio. The test results are shown in Table 7. After adding control variables, digital financial inclusion (index), coverage, usage, and digitization still significantly affect commercial bank risk-taking, indicating robust empirical results.

System GMM Inspection

Because of the continuity of commercial banks' risk-taking (Chengming et al., 2022), the level of commercial banks' risk-taking is not only affected by the level of digital financial development in the current period, the individual characteristics of the bank and other socio-economic variables, but also may be affected by the level of stock risk in previous years. If the existence of lagged variables is ignored, it may lead to model endogeneity problems. Therefore, this paper constructs first-order lagged terms (L.risk) of the explanatory variables, builds a dynamic panel model, and uses a systematic GMM approach to overcome potential endogeneity (Arellano & Bond, 1991).

The test results are shown in Table 8; the AR (2) test of columns (1) (2) (3) (4) are all greater than 0.1, which indicates that there is no second-order serial correlation in the difference of the disturbance terms. The Hansen test is more significant than 0.1, which indicates that all the instrumental variables are valid. The coefficients of index, coverage, and usage are positive at the 1% significance level, and the coefficient of digitization is positive at the 10% significance level, which indicates that both the digital finance index and the subordinate indicators have a significant inhibitory effect on commercial bank risk-taking. The coefficients of digitization are positive at a 10% level of significance, which indicates that the digital finance index and the following indicators have a significant inhibitory effect on the risk-taking of commercial banks, which is consistent with the original model, indicating that the test results are robust.

Table 7. Robustness tests-additional control variables

	(1)	(2)	(3)	(4)
	Risk	**Risk**	**Risk**	**Risk**
index	0.0182*** (0.00413)			
coverage		0.0161*** (0.00436)		
Usage			0.0138*** (0.00340)	
digitization				0.0789*** (0.00230)
control variable	containment	containment	containment	containment
_cons	4.297*** (0.671)	4.837*** (0.651)	4.598*** (0.658)	3.870*** (0.740)
fixed effect	containment	containment	containment	containment
N	1578	1578	1578	1578
R^2	**0.920**	**0.919**	**0.920**	**0.919**
Adj. R^2	**0.910**	**0.910**	**0.910**	**0.909**

Table 8. Robustness Tests - Systematic GMM Tests

	(1)	(2)	(3)	(4)
	Risk	**Risk**	**Risk**	**Risk**
L.risk	0.899*** (0.0200)	0.898*** (0.0199)	0.892*** (0.0204)	0.904*** (0.0192)
index	0.0561*** (0.0115)			
coverage		0.0634*** (0.0120)		
usage			0.0524*** (0.0101)	
digitization				0.0119* (0.00669)
control variable	containment	containment	containment	containment
_cons	-12.01*** (3.416)	-11.93*** (3.403)	-6.790* (3.486)	-12.43*** (3.068)
N	1449	1449	1449	1449
AR(2)	0.625	0.632	0.699	0.357
Hansen test	0.204	0.201	0.187	0.337

REGULATORY MECHANISM TEST

In order to clarify the mechanism behind the impact of digital finance on bank risk-taking and to test the effect of digital financial development on bank risk-taking by the external environment, this paper interprets the regulatory mechanism of the external environment in terms of the degree of competitiveness of the banking sector and economic policy uncertainty.

The Moderating Effect of Competitiveness in the Banking Sector

With the competition in the financial system triggered by the continuous advancement of the interest rate marketization process, the relationship between competition in the financial market and the security of the financial system has become an issue of concern for scholars. Competition in the banking sector puts commercial banks under pressure to make profits. It may cause them to change their business models, so paying attention to the moderating effects of banking competition is valuable. According to the "franchise value hypothesis," increased competition in the banking industry will compress commercial banks' deposit and loan spreads, weakening the monopoly power of commercial banks in the market. Then, commercial banks may take the initiative to increase risk-taking to acquire high-risk assets to compensate for the loss of profits (Chengming et al., 2022). It has also been argued that if the banking sector is too competitive, management's expectations of future revenues decline and thus favor conservative credit and investment policies, thus reducing commercial bank risk-taking. At the same time, when market resources are relatively limited in a highly competitive banking industry, commercial banks will improve their operational efficiency and risk prevention and control capabilities (Kedarya et al., 2023).

In order to test the moderating effect of the degree of competition in the banking sector, the Herfindahl index of the share of the number of branches is selected as a proxy variable for the degree of competition (hhi) in the banking sector, and the following model (5) is developed:

$$\begin{aligned} risk_{i,t} &= \beta_0 + \beta_1 \left(cover_t \, or \, usage_t \, or \, digitization_t \right) + \beta_2 hhi_t \\ &+ \beta_3 hhi_t * index_t \left(hhi_t * cover_t \, or \, hhi_t * usage_t \, or hhi_t * digitization_t \right) \\ &+ \sum \beta_4 CV_{i,t} + \mu_i + \varepsilon_{i,t} \end{aligned} \tag{5}$$

The regression results are shown in Table 9. Column (1) of the table shows that the coefficient of the interaction term hhi × index is 0.122 and passes the 5 per cent significance test, which indicates that the value of the proxy variable hhi is inversely related to the degree of competition in the banking sector.

Since the value of proxy variable hhi is inversely related to the degree of competition in the banking sector, it indicates that for every 1 unit increase in the degree of competition in the banking sector, the overall effect of digital finance development on the inhibition of bank risk-taking decreases by 0.122 units. Columns (2) (3) and (4) of the table show that the coefficients on the interaction terms hhi × coverage, hhi × usage, and hhi × digitization are significantly positive at the 10%, 10%, and 1% confidence levels, respectively, indicating that an increase in the level of competition in the banking sector also has a positive effect on the level of risk taking in banks. In conclusion, the degree of competition in the banking industry will weaken the inhibitory effect of digital finance on commercial bank risk-taking.

Moderating Effects of Economic Policy Uncertainty

The government realizes the purpose of intervening in the economy by formulating and adjusting economic policies, in which the rising frequency of policy introduction and the unclear policy direction

and intensity all lead to increased economic policy uncertainty. Compared with Western developed countries, China's economic policies are more uncertain (Dayong et al., 2019). When economic policies change frequently, the distortion of information transmission will disturb the decision-making of commercial banks and make it difficult to form an opinion about the future. Economic policy changes, misjudge the economic situation, and incorrectly favor enterprises or industries with poor development prospects (Dayong et al., 2019). This will interfere with the level of risk identification when banks lend, which will lead to an increase in the level of uncontrollable risk-taking by banks.

When economic policy fluctuations are large, banks will raise the standard of credit review and reduce the supply of credit to maximize the protection of shareholders' rights and interests.

On the other hand, they will reduce their risk tolerance, creating a tendency of "self-insurance." At the same time, economic policy fluctuations aggravate the uncertainty of banks' external environment.

According to the theory of financial vulnerability, banks will consider the profitability level, and on the other hand, reduce the risk tolerance, and reduce the proportion of risky assets allocated to protect against external risks. At the same time, economic policy volatility increases the unknown nature of the bank's external environment, and according to the theory of financial vulnerability, banks will consider profitability and reduce their risk tolerance and risky asset allocation in order to protect themselves against external risks

Table 9. The moderating effect of banking competitiveness

	(1)	(2)	(3)	(4)
	Risk	**Risk**	**Risk**	**Risk**
index	0.0184*** (0.00463)			
coverage		0.0134*** (0.00512)		
usage			0.0152*** (0.00331)	
digitization				0.00603** (0.00248)
hhi	-0.932* (0.363)	-1.161*** (0.380)	-1.241*** (0.324)	-1.270*** (0.326)
Hhi*index	0.121** (0.0487)			
hhi × coverage		0.0842* (0.0511)		
hhi × usage			0.0895* (0.0466)	
hhi × digitization				0.0954*** (0.0357)
control variable	containment	containment	containment	containment
_cons	2.900*** (0.654)	3.464*** (0.643)	3.203*** (0.643)	2.361*** (0.739)
fixed effect	containment	containment	containment	containment
N	1600	1600	1600	1600
R^2	0.919	0.918	0.919	0.918
Adj.R^2	0.909	0.909	0.909	0.909

In order to test the moderating effect of economic policy uncertainty, this paper selects the monthly arithmetic mean of Baker's economic policy uncertainty index as a proxy for economic policy uncertainty (epu), and the following model (6) is established:

$$risk_{i,t} = \lambda_0 + \lambda_1 index_t \left(cover_t \, or \, usage_t \, or \, digitization_t\right) + \lambda_2 epu_t + \lambda_3 epu_t * index_t \left(epu_t * cover_t \, or \, epu_t * usage_t \, or \, epu_t * digitization_t\right) + \sum \lambda_4 CV_{i,t} + \mu_i + \varepsilon_{i,t} \quad (6)$$

The regression results are shown in Table 10. Column (1) of the table shows that the coefficient of the interaction term epu × index is 0.00522 and passes the 1% significance test, indicating that for every 1-unit rise in economic policy uncertainty, the overall effect of the inhibitory effect of the development of digital finance on bank risk-taking increases by 0.00522 units. Columns (2) (3) (4) of the table show that the coefficients of the interaction terms epu × coverage, epu × usage, and epu × digitization are 0.00610, 0.00344, and 0.00687, respectively. All of them are significantly positive at the 1% confidence level, suggesting that the aggravation of economic policy uncertainty also contributes to reducing the risk-taking of commercial banks by the three primary forms of digital

Table 10. Moderating effects of economic policy uncertainty

	(1)	(2)	(3)	(4)
	Risk	**Risk**	**Risk**	**Risk**
index	0.0156*** (0.00509)			
coverage		0.0141*** (0.00519)		
usage			0.0162*** (0.00375)	
digitization				0.00851*** (0.00242)
hhi	-0.00165 (0.00145)	-0.00180 (0.00148)	-0.00119 (0.00141)	-0.00182 (0.00161)
Hhi*index	0.00522*** (0.00144)			
Hhi*coverage		0.00610*** (0.00134)		
Hhi*usage			0.00344*** (0.000985)	
Hhi* digitization				0.00687*** (0.00169)
Control variable	containment	containment	containment	containment
_cons	6.936*** (1.360)	7.634*** (1.164)	5.931*** (1.087)	9.150*** (1.484)
Fixed effect	containment	containment	containment	containment
N	1600	1600	1600	1600
R^2	0.918	0.918	0.918	0.917
Adj. R^2	0.908	0.908	0.908	0.908

finance. Commercial banks' risk-taking and the effect on the breadth of coverage and the degree of digital services are more pronounced. In conclusion, economic policy uncertainty strengthens the inhibiting effect of digital finance on commercial bank risk-taking.

CONCLUSION AND RECOMMENDATIONS FOR MEASURES

Based on the continuous evolution of Internet finance and financial technology, the concept of digital finance has emerged: It refers to the use of digital technology by traditional financial institutions and Internet companies to achieve financing, payment, investment, and other new financial business models, in which digital technology includes the Internet, cloud computing, big data, blockchain, artificial intelligence, and other new-generation information technology.

Based on the 10-year balanced panel data of 160 commercial banks from 2013 to 2022, this paper explores the impact of digital finance on commercial banks' risk-taking and finds that firstly, in terms of the overall effect, digital finance has a dampening effect on commercial banks' risk-taking; in terms of the structural effect, the risk-dampening effect of the breadth of coverage is the strongest and the breadth of coverage and the depth of use play a significant role in the dampening of commercial banks' risk-taking. Regarding structural effect, the breadth of coverage has the most substantial risk suppression effect, and the breadth of coverage and depth of use play a significant role in the suppression of commercial bank risk-taking. Second, the impact of digital finance on commercial bank risk-taking is heterogeneous in terms of bank size and regional financial regulation. Compared with small-scale commercial banks and commercial banks with weak regional financial regulation, digital finance has a more significant inhibitory effect on the risk-taking of large-scale commercial banks and commercial banks with solid regional financial regulation. Third, under the moderating effect of the external environment, the increase in the degree of competition in the banking sector weakens the inhibitory effect of digital finance on commercial bank risk-taking; the increase in economic policy uncertainty strengthens the inhibitory effect of digital finance on commercial bank risk-taking.

The above conclusions have important policy implications: First, build a perfect digital financial regulatory system and adopt the principle of differentiated regulation. Financial regulators should incorporate digital financial platforms into the financial regulatory framework and combine with the characteristics of the digital financial platforms themselves, targeting the construction of digital financial platforms, external supervision, and industry self-regulation combined with the dual financial constraints system, in order to effectively constrain the over-expansion of the transaction scale of the digital financial platforms, which will help to reduce the negative impact of the digital financial stability of the profitability of commercial banks. In addition, the regulator should also regulate different commercial banks to ensure the stability of their profitability. In addition, the regulatory authorities should also adopt differentiated regulatory principles for different commercial banks, which can better allocate regulatory resources to achieve the most efficiency and thus improve the efficiency and results of financial regulation. Second, commercial banks should be encouraged and guided in their digital transformation to optimize their business strategies and strengthen their risk management with the help of digital technology. On the one hand, commercial banks can use digital technology to improve their operational efficiency, enhance their risk management capabilities, and promote digital product innovation; on the other hand, the development of digital finance promotes the process of interest rate marketization, which has a particular impact on the traditional business of commercial banks, leading to the contraction of banks' credit business and the increase of off-balance sheet business.

Hard and soft infrastructures related to technology research and development and technology application should be improved to create favorable conditions for the digital transformation of commercial banks. Commercial banks should learn advanced technology and management from high-tech enterprises, carry out forward-looking technological research and technological reserves, and at

the same time should be based on the financial origin, strictly abide by the bottom line, ensure that the prudent business policy does not waver, and on this basis, further make use of external scientific and technological resources to accelerate the digital layout. Thirdly, to regulate the degree of competition in the banking industry, the financial regulator needs to scientifically construct a banking access mechanism and reasonably set the access thresholds of foreign-funded banks and the opening-up process to guide the banking industry to compete in an orderly and moderate manner. Fourthly, in order to regulate the uncertainty of economic policies during periods of frequent fluctuations in economic policies, the CBRC should give full play to its role in regulating and resolving significant financial risks, understand the changes in the risk-taking of various types of banks on time, identify the types of risks, and take timely measures to resolve the emergence and transmission of systemic financial risks.

Some limits to our study are as follows. Future studies could incorporate additional qualitative data through interviews to ensure triangulation, particularly concerning policy issues. Additionally, future studies should expand the empirical sample to make comparisons between different countries so that the results can be generalized.

CONFLICTS OF INTEREST

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