

Fintech, Macroprudential Supervision and Systematic Risk in China's Banks

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In recent years, the rapid development of fintech has brought far-reaching changes to the financial sector. At the same time, fintech may cause potential systemic risk in the financial sector, which has aroused special concerns from financial regulatory authorities. Based on the micro data of China's listed banks from 2013 to 2020, this paper analyzes the impact of fintech development on systemic risk in China's banking industry and its mechanism. It reveals that for a micro bank, fintech progress increases its risk-taking and enhances inter-bank linkages, which results in significantly amplified systemic risk, and the impact is time-lagged and persistent. In addition, the heterogeneity analysis shows that the impacts of fintech on state-owned banks and other banks are heterogeneous and the margining risk of state-owned banks is lower when the fintech improves. It is also found that enhancing macroprudential supervision can reduce the systemic risk spillover of fintech. Robustness analyses including GMM regression and the method of instrumental variables prove that the conclusion is robust. This paper is of theoretical and policy significance for the prevention of systemic risk in the banking industry as China develops fintech.

Keywords: fintech, macroprudential supervision, systemic risk

1. Introduction

Industrial restructuring and upgrading needs the financial sector to better serve the real economy since China's economy has moved from high-speed growth to high-quality development. As the fourth industrial revolution and technological revolution are in progress, the emergence of fintech has contributed new ideas to deepening financial reforms and industrial restructuring. Various technologies represented by big data and AI continue to be deeply integrated with financial business scenarios, enabling long-established products and services in the financial sector. Technology-driven

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financial innovation helps to lower transaction costs and alleviate social and financial frictions and exhibits prominent inclusion effect (Ali, 2016). However, fintech is likely to cause new risks while benefiting the efficiency of financial operations. It began to be highly concerned by regulatory authorities as the problems with P2P lenders and the Ant Financial were exposed. In this context, the banking industry, as the leader of the financial system in China, embraces the compliance of individual licensed business and the systematization of supervision, and its wide coverage of customers and business can provide a high-quality application basis for fintech. Compared with other financial institutions, the banking industry is able to keep financial stability while leveraging fintech advantages, and as a result, China has turned to banks as the frontier and mainstay of fintech development.

However, even though banks' internal risk control is stronger and external supervisory system is better than other financial institutions, fintech development and application in the banking industry shows two distinct effects. On the one hand fintech applications such as big data and blockchain have, to a large extent, reduced information asymmetry and transaction costs, facilitated business and increased credit supply to SMEs (Sheng *et al.*, 2020), improving banks' efficiency and lowering non-systemic risk such as the liquidity risk; innovative technology including intelligent algorithms and cloud computing has extended the accessibility and depth of service for inclusive finance (Guo *et al.*, 2020). On the other hand, the fintech development poses new challenges to China's financial supervision, as it increases the risk-taking propensity of banks (Qiu *et al.*, 2018), mounts endogenous risk in the system (Fang *et al.*, 2020), and finally aggravates systemic risk in the banking industry (Liu *et al.*, 2021).

The 14th Five-Year Plan proposes to speed up the reform, opening up and development of the financial sector with six moves, including preventing financial risks and growing the fintech. It sets the tone for preventing and resolving the systemic risk. Therefore, it is critical to find out the impact of fintech development on systemic risk in the banking industry and the supervisory measures.

The major ideas of measuring fintech development in current fintech studies which are based on the banking industry are as follows. One is the Regional Fintech Development Index constructed with the Baidu index of "fintech" keyword or the number of local fintech firms (Wang *et al.*, 2012; Song *et al.*, 2021), and another is the Peking University Digital Financial Inclusion Index compiled by the research team of Institute of Digital Finance, Peking University in cooperation with the Ant Financial (Qiu *et al.*, 2018). Both metrics are essentially based on the financial sector as a whole and measure the regional differences in the level of fintech development, while overlooking potential differences in systemic risk changes brought about by the integration of business products with fintech because of the different conventional characteristics of financial institutions, as well as fintech disparities across commercial

banks for different strengths and business strategy choices. As a result, there might be errors using the above metrics to study the impact of fintech on systemic risk in China's banking industry. Moreover, current studies on fintech and systemic risk in the banking industry have only covered internal mechanism such as the risk-taking, with no literature working on the role of macroprudential policies in fintech supervision; and the literature on fintech and financial supervision that mostly starts from theoretical derivations or case studies to discuss the supervisory challenges brought by fintech development lacks empirical evidence.

To fill the research blank and thus theoretically support financial supervision and guarantee the sound development of fintech, this paper empirically analyzes the impact of fintech development in China's individual listed banks on their systemic risk and its mechanism, as well as the impact of macroprudential supervision on the spillover resulting from fintech systemic risk. The innovations of this paper are as follows. First, it is the first to adopt SRISKv2, based on which Migueis and Jiron's (2021) modified systemic risk metric, for studying the impact of fintech on systemic risk in the banking industry. It is a meaningful marginal addition to systemic risk measure and research in China. Second, based on the essence of fintech—technology-driven financial innovation, and drawing on the measure of corporate innovation capability, this paper uses the sum of patents and software copyrights after excluding design patents and non-fintech utility patents to measure the fintech level of a single bank, so that the heterogeneity of conventional features of different types of financial institutions and the differences in strengths and business strategy choices of commercial banks are taken into account. Third, this paper empirically studies “how the spillover resulting from systemic risk of fintech development changes under macroprudential supervision”. The empirical results and policy proposals are good for further fintech supervision and help China develop fintech over preventing systemic risks of the banking industry.

The rest is arranged as follows: Part 2 covers the theoretical basis and empirical hypotheses; Part 3 introduces SRISKv2; Part 4 is about the model design, variables and sample selection; Part 5 is the empirical test; and Part 6 concludes and makes policy proposal.

2. Theoretical Analysis and Empirical Hypotheses

2.1. Fintech and Systemic Risk

Fintech is a product of the fourth industrial revolution results deeply integrating with financial business scenarios, and its economic impact is a focus of research. Generally speaking, fintech is a double-edged sword at the macro level, the financial sector absorbing technical innovations could enhance its vitality and efficiency

in serving the real economy, and contribute to economic and social development (Chen, 2021). The issues such as “attribute mismatch” in traditional finance have been well corrected following the development of fintech (Tang *et al.*, 2020). At the meso and micro levels, fintech facilitates industrial transformation and upgrading and business innovation (Wang *et al.*, 2012) and increases credit supply to SMEs, so it is inclusive in nature (Sheng *et al.*, 2020). However, the widespread use of technology, while improving the operating efficiency of financial institutions, makes systemic risk more complex, contagious, covert and sudden and endogenous risk accumulated in the system (Fang *et al.*, 2020). Fintech has disguisedly advanced the interest rate marketization, but banks prefer riskier assets to compensate for the losses caused by rising costs on the liability side (Qiu *et al.*, 2018). Overall, fintech has aggravated systemic risk in the banking industry (Liu *et al.*, 2021).

Fintech progress can lift the banking’s marginal contribution to systemic risk through multiple channels. Regarding its own characteristics, fintech is an integrated product of finance and technology, and high-tech may add new risk to original financial risks, so the superimposed effect of technical and financial risks may amplify the system risk (Chen *et al.*, 2020). As for the interfering factors on systemic risk, the application of cutting-edge technology such as big data and blockchain in financial service scenarios is highly segmented and intersecting in business, which could blur the boundaries of different financial institutions. The sustainable penetration of the Internet also makes financial institutions in different areas more closely connected to each other. Fintech development has enlarged the breadth and depth of linkages among financial institutions to amplify the systemic risk (Xiao *et al.*, 2012). Moreover, fintech is low-profit margin and asset-light. This gives micro firms incentives and conditions to expand rapidly, pointing to the key factors which constitute a systemically important financial institution (SIFI): “too big to fail” (Benoit *et al.*, 2017) and “too tightly-connected to fail” (Billio *et al.*, 2012). From the supervisory challenge perspective, fintech products’ high-tech and professional nature makes it harder to detect potential risks brought by fintech. Behind the advantage of “easy compliance” from a micro perspective is the arbitrage space caused by the supervisory lag over Fintech. Drawing from historical practices, the integration of finance and technology in the previous three industrial revolutions frequently led to accumulation and concentrated exposure of risk due to the objective lag of relevant systems and supervision (Chen, 2021).

In summary, the following hypotheses are proposed.

Hypothesis 1: A micro bank’s fintech progress will significantly raise its marginal contribution to systemic risk.

Hypothesis 2: The banking industry’s fintech progress enhances its risk-taking propensity, which further raises its systemic risk.

Hypothesis 3: The banking industry’s fintech progress makes banks more connected

to amplify its systemic risk.

2.2. Role of Macroprudential Supervision

Fintech is double-sided and it means that its positive effect cannot be achieved without proper supervision. Supervisors should treat fintech as a normal phenomenon amidst financial development, be prepared for supervision and keep the balance between innovation and security.

As early as before the 2008 global financial crisis, Borio (2003) distinguished macroprudential from microprudential supervision, and argued that the former could avoid macro-economic damage from financial crises by preventing systemic risk. After the crisis, there was a consensus on the need to enhance macroprudential supervision for the prevention of systemic risk and the financial stability (Maddaloni and Peydró, 2011; Matthew, 2020). Subsequent studies by many scholars have continued to support the effectiveness of macroprudential supervision (Liang *et al.*, 2015). However, as the finance continues to evolve, macroprudential supervision has begun to be constrained, as Hou *et al.* (2020) found that commercial banks have the motivation to transfer funds to shadow banks to evade supervision and supervisory arbitrage weakens the effectiveness of supervisory measures only for commercial banks.

On the one hand, the principal objective of macroprudential policies is to maintain financial stability and prevent systemic risk, mainly featured by the setup of a stronger, counter-cyclical system (Zhou, 2011) that, theoretically, could weaken the negative impact of fintech and keep systemic risk at an acceptable level. On the other hand, however, empirical results of the shadow banking revealed the existence of supervisory arbitrage. While fintech has emerged shortly and progressed at a fast pace, there is a certain lag in the systems and regulations as well as financial supervision. In this context, tightening macroprudential supervision may backfire, causing banks to make non-reasonable use of fintech instruments to circumvent supervision, thereby having the negative effect of fintech amplified. In summary, the following hypotheses are proposed.

Hypothesis 4: Enhancing macroprudential supervision can weaken the spillover resulting from the systemic risk of fintech development.

Hypothesis 5: Tighter macroprudential supervision stimulates banks to make non-reasonable use of fintech instruments to circumvent supervision, increasing the spillover resulting from the systemic risk of fintech development.

3. SRISKv2 Calculation and Banks Ranking according to Systematically Importance

The primary task and prerequisite for financial risk prevention and financial supervision is to accurately measure the marginal contribution of micro financial

institutions to the overall systemic risk. Among the most cited micro-level systemic risk indicators internationally, by a comprehensive comparison, SRISK (Brownlees and Engle, 2016) is more reasonable in setting the crisis conditions as it considers extreme conditions, applies the conditional mean method to work on top-down shocks and directly includes size, leverage and interconnectedness. Thus it is more suitable as a micro-level systemic risk metric in China (Chen *et al.*, 2019).

SRISK measures the value of an institution's potential capital shortfall in the event of a systemic financial crisis. In the original model, capital shortfall (CS) is defined as the capital required to meet supervisory requirements after deducting the firm's market equity from the firm's assets, i.e., $CS_{i,t} = kA_{i,t} - W_{i,t}$, where k , the capital adequacy ratio, is determined by national supervisory requirements, and normally, the prudential capital factor is set at 8% by the minimum capital adequacy ratio under Basel III. $A_{i,t}$ is the quasi assets of firm i at period t and $W_{i,t}$ is the market value of equity of firm i at period t . Then, SRISK is defined as: $SRISK_{i,t} = E_t(CS_{i,t+h} | r_{m,t:t+h} < C)$, where h is the time range, $r_{m,t:t+h}$ is the market return over the measurement range and C is the threshold level of the market return.

However, the above definition of capital shortfall is conceptually flawed. To be specific, "capital shortfall" is the amount of capital by which a firm falls short of meeting a required level of capital. In the definition used in SRISK, a firm's capital shortfall is positive when required capital is larger than its market equity and negative when required capital is smaller than its market equity. By this meaning, when required capital is smaller than market equity, there is no shortfall but surplus, and $CS_{i,T}$ should take the value of 0 instead of a negative value. Thus, a proper definition of capital shortfall CS' is as follows: $CS'_{i,t} = \max(0, kA_{i,t} - W_{i,t})$.

It is easy to see that the previous definition of capital shortfall weakens SRISK as a systemic risk metric: the conditional expected shortfall is lowered by the negative portion of $CS_{i,T} [T \in (t, t+h)]$. Practically, capital surplus in the case of "firms not in distress when subject to severe market shocks" cannot be used to supplement the shortfall in the case of "firms in distress when subject to severe market shocks". Therefore, Brownlees and Engle (2016) minimized the inconsistency of negative "expected shortfall" by setting SRISK to zero, but this does not change that SRISK underestimates systemic risk relative to the conditional expected shortfall metric building upon the proper definition of capital shortfall (CS'). To better measure the systemic risk in financial firms, SRISKv2 (Migueis and Jiron, 2021) is taken as the major micro-level systemic risk indicator. It is defined as:

$$SRISKv2_{i,t} = E_t(CS'_{i,t+h} | r_{m,t:t+h} < C).$$

SRISKv2 is calculated in a similar manner to SRISK, except that the definition of capital shortfall is improved. As the " $LRMES \approx 1 - \exp(-18 \times MES)$ " approximation is not applicable to the financial system in China (Chen *et al.*, 2019), this paper

follows a similar procedure to Brownlees and Engle (2016)¹ in calculating SRISK and SRISKv2 of banks in the banking system with quarterly data and daily stock returns of China's listed banks from 2009 to date. Additionally, by analogy with SRISK, this paper measures marginal contribution to systemic risk by Bank i with $SRISKv2\% = SRISKv2_i \times 100\% / \sum_i SRISKv2$, and then dynamically ranks China's listed banks. Table 1 shows the top 10 banks with marginal contribution to systemic risk from 2011 to 2020. This ranking is almost the same as the annual *Assessment Methodology for Systemically Important Banks*, and SRISKv2 results are credible.

Table 1. Dynamic Ranking of Systemically Important Banks in China (2011–2020)

rank	1	2	3	4	5	6	7	8	9	10
2011	BOC	ABC	BoCOM	SPDB	CCB	ICBC	IB	CITIC	CMB	CMBC
2012	BOC	ABC	ICBC	BoCOM	CCB	SPDB	IB	CMBC	CITIC	CEB
2013	BOC	ABC	ICBC	CCB	BoCOM	SPDB	CITIC	IB	CMB	CEB
2014	CCB	ICBC	BOC	ABC	BoCOM	IB	SPDB	CMB	CITIC	CMBC
2015	CCB	ABC	ICBC	BOC	BoCOM	CITIC	IB	SPDB	CMB	CMBC
2016	ABC	BOC	CCB	ICBC	BoCOM	CITIC	SPDB	IB	CMBC	CEB
2017	ABC	BOC	BoCOM	CITIC	CMBC	IB	CCB	SPDB	ICBC	CEB
2018	BOC	CCB	ABC	ICBC	BoCOM	CMBC	SPDB	IB	CITIC	CEB
2019	ABC	BOC	CCB	ICBC	BoCOM	SPDB	CITIC	CMBC	IB	CEB
2020	BOC	ABC	CCB	ICBC	BoCOM	CITIC	CMBC	SPDB	IB	CEB

Note: Bank of China (BOC), Agricultural Bank of China (ABC), Bank of Communications (BoCOM), Industrial and Commercial Bank of China (ICBC), China Construction Bank (CCB), Industrial Bank (IB), Shanghai Pudong Development Bank (SPDB), China Minsheng Bank (CMBC), China CITIC Bank (CITIC), China Everbright Bank (CEB), and China Merchants Bank (CMB).

¹ For page limitations, SRISK calculation is not described here. If necessary, the authors can be contacted.

4. Model, Variables and Sample

4.1. Model Design

To find out how a micro bank's fintech level impacts its systemic risk, the baseline model is set as follows.

$$\begin{aligned} SystemicRisk_{i,t} = & \alpha + \beta_1 PATSC_{i,t-1} + \sum \gamma Controls_{i,t-1} \\ & + time + bank + \varepsilon_{i,t} \end{aligned} \quad (1)$$

In equation (1), i denotes the individual bank and t denotes the observation time. The explanatory variable *SystemicRisk* is the systemic risk of commercial banks, measured by SRISK and SRISKv2, respectively. The core explanatory variable is the fintech level of banks. *Controls* is a vector of other control variables with potential influence over the systemic risk; $\varepsilon_{i,t}$ is a random error term; and *time* and *bank* are time and individual fixed effects, respectively. The fintech level and control variables are treated with a first-order lag to avoid the influence of potential endogeneity issues on conclusion.

To study the role of macroprudential supervision, this paper relaxes the time fixed effects by adding quarterly growth rate of real GDP and quarterly rate of CPI to control variables to control the macroeconomic impact, and divides the sample into different horizons by macroprudential supervision intensity for grouped regression. On this basis, there introduces the interaction term of macroprudential supervision intensity and fintech level to analyze the moderating effect. The model is as follows.

$$SRISKv2_{i,t} = \alpha + \beta_1 PATSC_{i,t-1} + \sum \gamma controls_{i,t-1} + bank + \varepsilon_{i,t} \quad (2)$$

$$\begin{aligned} SRISKv2_{i,t} = & \alpha + \beta_1 PATSC_{i,t-1} + \beta_2 MPI_B_t + \beta_3 MPI_B_t \\ & \times PATSC_{i,t-1} + \sum \gamma controls_{i,t-1} + bank + \varepsilon_{i,t} \end{aligned} \quad (3)$$

where MPI_B denotes macroprudential supervision intensity at period t , and other variables are defined as above.

4.2. Variable Selection

4.2.1. Systematic Risk

As SRISK is effective in measuring the ability of individual financial institutions to withstand risks over a crisis and identifying the systemic importance, its application to

China has been justified in empirical analysis. SRISKv2 follows a similar procedure in calculating SRISK and avoids underestimating the systemic risk with adjustments to the definition of capital shortfall. It is in line with what required by the macroprudential supervision. Therefore, SRISKv2 is used for the measure of systemic risk of banks and compared with SRISK. The calculation has been described in Part 3, where the crisis is defined as a 40% or more decline in market earnings over six consecutive months.

4.2.2. Fintech Level

Essentially, Fintech is the process of technology driving financial innovation, and its core is that financial institutions innovate their business structure and improve service quality with an integration of technology with scenarios of application. Therefore, in measuring the fintech development of a micro bank, the bank's financial innovations by technical means should be taken into account, i.e., to measure the number of channels based on fintech development in its innovative channels of business development and service provision. It is consistent with the measure of corporate innovation activities. The major proxy variables for innovation activities used in the academic community include: patent copyrights (Shai *et al.*, 2016), R&D investment and intangible assets (Ju *et al.*, 2013). Data availability is inadequate as most listed banks do not disclose R&D expenditures. Intangible assets also include non-proprietary technology, trademark rights and land use rights, which are unable to accurately reflect fintech innovation results. Referring to previous practices of scholars (Li *et al.*, 2016), this paper comprehensively selects the sum (PATSC) of patents (PAT) and software copyrights (SC) among intellectual property rights as the fintech development metric of individual banks. Design patents and non-fintech utility patents are excluded to better fit the measuring of fintech development.

4.2.3. Macroprudential Policy

A macroprudential policy index is constructed upon IMF's integrated Macroprudential Policy (iMaPP) database. To make it targeted, this paper selects 13 variables closely linked to the banking industry, such as capital conservation buffer, the leverage ratio required and loan restrictions, for the MPI_B index construction. The steps are as follows. For each macroprudential policy instrument, a dummy variable is set with a value of +1 when the instrument is tightened, 0 when there is no change, and -1 when the instrument fails or is relaxed. The cumulative value of all policy instrument dummy in the current period is the final macroprudential policy index.

4.2.4. Other Control Variables

Given that large banks with strong capital strength or a high risk appetite prefer to develop fintech for faster expansion, this paper selects control variables with reference to previous studies and the real situation of commercial banks in China. Table 2 shows the variable name, symbol and meaning in this empirical study.

Table 2. Description of Variables

	Variable name	Symbol	Meaning
Explained Variable	Systemic risk of banks	<i>SRISKv2</i>	Value of an institution's potential capital shortfall in the event of a systemic financial crisis
		<i>SRISK</i>	
Explanatory variable	Fintech level of banks	<i>PATSC</i>	Sum of technology patents and software copyrights of banks
	Macroprudential policy index of banks	<i>MPI_B</i>	Summation of dummy values of macroprudential policy instruments for the banking industry
Bank and Macro control variable	Return on total assets	<i>ROA</i>	Net profit/total assets
	Bank size	<i>Size</i>	Natural logarithm of total bank assets
	Capital adequacy ratio	<i>CAR</i>	Net capitalization/risk-weighted assets
	Loan-deposit ratio	<i>LDR</i>	Total loans/total deposits
	Bank efficiency	<i>CIR</i>	$\frac{\text{Overhead} + \text{other business expenses}}{\text{Net interest income} + \text{net fee income} + \text{other business income} + \text{investment income}}$
	Bank profitability	<i>NIM</i>	Net interest income/average balance of interest-earning assets
	Real GDP growth rate	<i>GDP_r</i>	Quarterly growth rate of real GDP
	CPI rate	<i>CPI_r</i>	Quarterly rate of CPI

4.3. Sample Selection and Data Source

This paper selects commercial banks listed on the Shanghai Stock Exchange (SSE) and the Shenzhen Stock Exchange (SZSE) before 2018 as a sample and uses quarterly panel data from 2013 to 2020 for empirical test. The micro bank data used are from Choice Financial Terminal and Wind Financial Terminal, with some missing data added based on the regular disclosure reports of banks. Macroprudential supervision data are calculated by IMF's iMaPP database. The systemic risk metrics, *SRISK* and *SRISKv2*, are calculated using MATLAB.

5. Empirical Study

5.1. The Impact of Fintech on Systemic Risk

5.1.1. Baseline Regression

Table 3 shows the baseline regression results. The coefficient of fintech level is significantly positive at 1% level, and hypothesis 1 is confirmed. That is, while a major goal of fintech applications is to better manage risks, the fintech progress in individual banks will indeed bring about an increase in their systemic risk. The coefficient symbols of other control variables in the estimation results are largely in line with theoretical expectations. If the estimation coefficient of *ROA* is significantly negative, it indicates that the higher the profitability of a bank, the better the quality of its cash flow, the smaller the capital shortfall in a crisis, and the lower its systemic risk.

Table 3. Baseline Model Estimation Results

Variable	(1) <i>SRISKv2</i>	(2) <i>SRISK</i>	(3) <i>SRISKv2</i>	(4) <i>SRISK</i>
<i>L.PATSC</i>	0.04163*** (13.022)	0.04342*** (13.010)	0.03747*** (10.388)	0.04046*** (10.665)
<i>L.ROA</i>			-33.87050*** (-5.771)	-32.55948*** (-5.378)
<i>L.Size</i>			-15.68051*** (-3.590)	-12.99391*** (-2.640)
<i>L.NIM</i>			-2.16516 (-1.648)	-1.34568 (-0.970)
<i>L.LDR</i>			-0.00408 (-0.051)	0.08879 (1.058)
<i>L.CIR</i>			0.05744 (0.487)	0.17656 (1.413)
<i>L.CAR</i>			-0.51249 (-0.994)	-0.65392 (-1.325)
Constant term	Yes	Yes	Yes	Yes
Sample size	589	646	563	616
R ²	0.923	0.894	0.932	0.903
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes

Note: In the brackets are the robust *t*-values, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, and the following empirical results are reported in the same format and notes are not repeated.

5.1.2. Heterogeneity Analysis

On the issue of systemic risk spillover of fintech, interbank heterogeneity could be manifested in two ways. On the one hand, the five state-owned banks (ICBC, ABC, BOC, CCB, and BoCOM), with bigger size and wider business ties with other banks, may lead to larger marginal systemic risk from unit technical progress. On the other hand, the fact that state-owned banks are more rational in application of fintech, because their more transparent disclosure of information, more stringent, extensive supervision and better risk assessment mechanisms could cut down the marginal systemic risk amplification effect resulting from unit technological progress. To explore how the spillover of systemic risk resulting from fintech development in state-owned and other banks actually evolves in the above two potential scenarios, this paper performs grouped regressions on the sample of the five major state-owned banks and other banks to analyze whether there are differences in the impact of fintech on different banks. In particular, previous studies have indicated that with the pandemic hit, the liquidity of the entire financial system and the normal functioning of financial markets have been negatively impacted to some extent, and this impact is heterogeneous across banks (He *et al.*, 2020). For the reliability of the conclusion on heterogeneous discussion over the impact of fintech on systemic risk, this part adopts data from 2013 to 2018 for empirical analysis.

Table 4. Regression Results of Heterogeneous Impact of Fintech on State-Owned Banks and Other banks

Variable	(1) <i>SRISKv2</i>	(2) <i>SRISKv2</i>	(3) <i>SRISK</i>	(4) <i>SRISK</i>
<i>L.PATSC</i>	0.02283*** (2.881)	0.05868** (2.417)	0.02270*** (2.756)	0.05395 (1.718)
Control variable	Yes	Yes	Yes	Yes
Constant term	Yes	Yes	Yes	Yes
Sample size	110	257	115	304
R ²	0.842	0.908	0.850	0.847
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes

Columns (1) and (3) in Table 4 present the regression results for state-owned banks and columns (2) and (4) show the results for other banks. According to the results in columns (1) and (2), the coefficients of fintech level in both regressions for state-owned and non-state-owned banks are significantly positive, indicating that for both state-owned or other banks, the fintech development in individual banks lead to an increase

in their systemic risk. The systemic risk spillover resulting from fintech development in the five major state-owned banks is far smaller than that in other banks. In the case of this paper, the spillover is weakened by more than 50%. It means that the fintech development's amplification effect on systemic risk is heterogeneous across banks and the risk spillover is smaller for state-owned banks when the fintech level is improved.

5.1.3. A Test on Time Lag and Persistence of Fintech Impact

For there is almost no registration threshold for software copyrights, *PATSC*, the indicator measuring fintech level, will increase at the moment of firms developing software. As software is constantly upgraded amidst application, the growth of its user scale will take some time. As a result, this cycle results in a time lag of fintech impact on bank systemic risk. As revealed by the regression results with the lagged term added, the impacts of fintech level on bank systemic risk with two and three lags are significantly positive, and the coefficient values are even larger than that of the baseline regression. It means the fintech level produces time-lagged and persistent impacts on the systemic risk.

5.2. Further Study: Role of Macroprudential Supervision

This part works on the role of macroprudential supervision in the process through which fintech impacts systemic risk, by means of grouped regression and moderating effect analysis.

Table 5. Estimated Results of Grouped Regression and Moderating effect Analysis

Variable	Grouped regression			Moderating effect
	(1)	(2)	(3)	(4)
<i>L.PATSC</i>	0.04568*** (3.522)	0.03172*** (3.879)	0.07562*** (4.884)	0.03987*** (4.910)
Interaction term				-0.00319 (-1.879)
<i>MPI_B</i>				-0.29595 (-1.028)
Control variable	Yes	Yes	Yes	Yes
Constant term	Yes	Yes	Yes	Yes
Sample size	115	145	59	319
R ²	0.874	0.869	0.983	0.870
Individual fixed effects	Yes	Yes	Yes	Yes

In Table 5, the first three columns present the estimated coefficients from the grouped regression, with columns (1), (2), and (3) corresponding to when the macroprudential supervision is tightened, unchanged, and relaxed, respectively. The results imply that fintech progress still raises bank systemic risk at times of tighter macroprudential supervision, but the increase in systemic risk brought about by unit fintech progress drops significantly compared to the times of loose supervision. It suggests that the macroprudential supervision continues to play a role in controlling systemic risk to a certain extent against the new challenges posed by fintech development. Interestingly, compared to tightening or relaxing macroprudential supervision, the spillover of new systemic risk resulting from fintech progress is the smallest when the supervision stays unchanged. This is probably because periods of unchanged macroprudential supervision are usually times of stable and sound economic fundamentals, or because banks do exhibit a tendency to commit regulatory arbitrage with innovative channels such as fintech when faced with more stringent supervision, which has the effect of supervisory policies distorted to some extent. As shown by the results of moderating effect analysis in Column (4), the coefficient of macroprudential policy index is insignificant but has a minus sign, implying the macroprudential supervision is quite likely to mitigate bank systemic risk, and the insignificance here is understandable if it is considered with the grouped regression results. The interaction term's coefficient is negative at 10% significance level, meaning that the macroprudential supervision can diminish the spillover of systemic risk resulting from fintech development. From the above results, tightening macroprudential supervision generally facilitates fintech development whilst preventing systemic risk. In the light of potential supervisory arbitrage, however, abrupt changes in supervisory policies should be avoided as much as possible.

5.3. Robustness Test¹

5.3.1. Robustness Tests for Sample Interval

Given that the liquidity of the entire financial system and the normal functioning of financial markets were negatively impacted and the non-performing loan ratio of the banking industry rose due to setbacks in the real economy under the Covid-19 pandemic, and all banks made some sacrifices on economic efficiency or other aspects for boosting the economy after the pandemic (He *et al.*, 2020), this part discusses again the relationship between fintech and bank systemic risk with data from 2013 to 2018. The results show that the fintech coefficients are all positive at 1% significance level after excluding the sample data for the year before and

¹ For saving space, the test results are not listed here. Please contact the authors if necessary.

after the Covid-19. The previous findings remain robust after removing Covid-19 impacts.

5.3.2. Robustness Test Based on Explanatory Variables

A major difference in the threshold for patent and copyright applications is as follows: software copyrights can be protected as long as they are completed and applied for, without going through the scrutiny; while patents, especially in the software category, are required to be reviewed substantively before becoming effective. In case that the simple addition is unable to form an effective complement to the representation of the two for micro banks' fintech level but blurs the actual relations, the number of technology patents (PAT) and the number of software copyrights (SC), respectively, are used as proxy variables for fintech level to regress the baseline model again. The results reveal that bank systemic risk remains positively correlated with fintech development.

Additionally, considering that the indicator varies widely among individual banks when it is built with the sum of fintech patents and software copyrights, and that the overall banking layout has tilted toward fintech after 2018 to make the indicator increase rapidly thereafter, to make this paper more robust, the logarithm of *PATSC* is taken to derive $\ln PATSC$, which is used as a new proxy variable for fintech level. The previous findings are proved robust in the regression results.

5.3.3. Endogeneity Correction

To address potential endogeneity issues arising from reverse causality, referring to Xie *et al.* (2018), this paper adopts the normalized provincial data on Internet penetration, (*Internet*, data from the *Statistical Report on China's Internet Development* and the sample interval of this regression is 2013–2018 due to the availability of data for the instrumental variable) as an instrumental variable for digital finance development. As shown by the two-stage least squares results, the coefficient of *Internet* in the first-stage regression is significant at 1% level, as required by the instrumental variable correlation, and the *F* value >12, there is no weak instrumental variable. In the second-stage regression, the coefficient of fintech level is significantly positive at 1% level. The conclusion that fintech progress will raise the marginal contribution to systemic risk in banks remains robust.

The potential persistence of systemic risk in banks may also pose endogeneity issues. This paper adds the lagged terms of explained variables to the regression equation, constructs a dynamic panel model, estimates the coefficients with the systematic GMM method, and tests whether the differenced disturbance terms are

second-order autocorrelated and whether the instrumental variables are valid, by which the findings' robustness is further tested. In the results, the AR(2) value >0.1 , i.e., no second-order autocorrelation in the differenced disturbance terms of the regression equation; the p -values for Hensen do not reject the original hypothesis; instrumental variables are valid; and the fintech progress of individual banks continues to result in a systemic risk spillover. The findings remain robust after the potential persistence of systemic risk in banks is taken into account.

In further, it is a common approach to employ the two-way fixed effects model in the regression based on panel data, but there could be an issue of less stringent control for endogeneity. The regression model is estimated again with a high-order joint fixed effects approach, and the previous findings remain robust. The fintech progress of individual banks results in a systemic risk spillover.

5.4. Mechanism Test

The above theoretical analysis and empirical tests find that a micro bank' fintech progress significantly raises its contribution to systemic risk. This part constructs an econometric model as follows to discuss the role of two mechanisms, bank risk-taking and interbank linkages, in the process of fintech exhibiting systemic risk spillover.

$$SRISKv2_{i,t} = a_0 + a_1 PATSC_{i,t-1} + \sum b Controls_{i,t-1} + time + bank + e_{i,t} \quad (4)$$

$$Y_{i,t} = c_0 + c_1 PATSC_{i,t-1} + \sum d Controls_{i,t-1} + time + bank + e_{i,t} \quad (5)$$

$$SRISKv2_{i,t} = m_0 + m_1 PATSC_{i,t-1} + m_2 Y_{i,t-1} + \sum n Controls_{i,t-1} + time + bank + e_{i,t} \quad (6)$$

where Y is the mediator variable. This paper takes the natural logarithm of Z -value, z , as a proxy variable for bank risk-taking¹ and the interbank asset linkage WA and interbank liability linkage WS as the proxy variables for interbank linkages.

¹ $Z_{it} = \frac{ROA_{it} + E_{it} - A_{it}}{\sigma_i(ROA_{it})}$, where E_{it} is the capital asset ratio of the bank and $\sigma_i(ROA_{it})$ is the standard

deviation of ROA over the sample period for that bank. Interbank asset linkage WA = Interbank assets/total assets. Interbank liability linkage WS = Interbank liabilities/total assets.

Table 6. Channel Exploration Results

Variable	Risk-taking			Liability linkage	
	(1)	(2)	(3)	(4)	(5)
	<i>SRISK</i> v2	<i>z</i>	<i>SRISK</i> v2	<i>WS</i>	<i>SRISK</i> v2
<i>L.PATSC</i>	0.03747*** (10.388)	−0.00007*** (−3.368)	0.03592*** (10.053)	0.00005*** (4.669)	0.03605*** (9.555)
<i>L.z</i>			−35.71573*** (−5.516)		
<i>L.WS</i>					25.84090** (2.529)
Control variable	Yes	Yes	Yes	Yes	Yes
Constant term	Yes	Yes	Yes	Yes	Yes
Sample size	563	620	562	632	563
	0.932	0.983	0.936	0.863	0.933
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Individual fixed effects	Yes	Yes	Yes	Yes	Yes

Table 6 shows the results of analyzing the role of mechanisms. Looking at the risk-taking, the coefficient of fintech level in column (1) is positive at 1% significance level, suggesting that fintech progress raises the systemic risk in banks. In column (2) there is a significantly negative relationship between the bank's fintech level and Z-value. It means a bank's risk-taking propensity will increase significantly following the fintech progress. In column (3), the coefficient of Z-value is significantly negative and the coefficient of fintech level is significantly positive and its absolute value is smaller compared to that in column (1). As is revealed, when the risk-taking increases (Z-value decreases), the bank's systemic risk is amplified; while factors such as the risk-taking level measured by Z-value are controlled for, fintech progress still produce a systemic risk spillover. That is, bank risk-taking acts as a partial mediator in the amplification of systemic risk resulting from fintech progress. In a conclusion, fintech progress of a micro bank stimulates it to take more risks to amplify its contribution to systemic risk, and hypothesis 2 is confirmed.

Let's look at the interbank linkages. The coefficient of fintech level is positive at 1% significance level in column (1) and the results in column (4) reveal that a bank's fintech progress deepens its liability linkage with other banks. By the results in column (5), the coefficient of interbank liability linkage is positive at 5% significance level,

i.e., deeper liability linkage significantly amplifies their systemic risk, while the coefficient of fintech level remains significantly positive, implying that the interbank liability linkage acts as a partial mediator in the amplification of systemic risk resulting from fintech. Meanwhile, as revealed by results of the mechanism analysis based on interbank asset linkage,¹ a bank's fintech progress also deepens its asset linkage with other banks, but the coefficient of asset linkage is insignificant in the regression results of equation (6), meaning that the interbank asset linkage is not a mediator in the amplification of systemic risk resulting from fintech. To sum up, a micro bank's fintech development and application will make it more closely linked to the liability side of other banks in the system, amplifying its systemic risk.

6. Conclusion and Policy Proposal

Based on micro data of listed banks in China from 2013 to 2020, this paper probes into the impact of fintech development on systemic risk in China's banks and its mechanism as well as whether tighter macroprudential supervision contributes to the balance between fintech development and systemic risk prevention. The findings are as follows. First, a micro bank's fintech progress significantly raises its systemic risk level, and the spillover is time-lagged and persistent. Second, the impacts of fintech on the systemic risk in five major state-owned banks and other banks are heterogeneous, and the five major state-owned banks' risk spillover is smaller when the fintech progresses. Third, tighter macro-prudential supervision can lower the spillover of systemic risk resulting from fintech development to a certain extent. Fourth, a bank's fintech development can significantly heighten its risk-taking and deepen interbank liability-side linkages, thereby amplifying its systemic risk. The results of multiple robustness tests have proved the excellent robustness of these findings. Accordingly, the following proposals are put forward. First, in view of the risk spillover resulting from fintech, supervisors should raise their concerns over the emerging fintech development, improve the supporting regulations and systems and enhance follow-up studies and risk assessments to identify risks and seek measures as far in advance as possible to minimize the time lag in supervision. Second, given that macroprudential supervision is playing an instrumental role in the systemic risk control, supervisors must work towards financial stability and financial structural optimization by a combination of macro and micro prudence. Third, state-owned banks experience smaller risk spillover resulting from fintech progress because of the heterogeneous amplification of fintech development on systemic risk across banks. Consideration may be given to making state-owned banks an active player in fintech development, so that cutting-edge fruits of fintech can be first applied in state-owned banks and then

¹ For saving space, the results are not listed here. Please contact the authors if necessary.

launched to other banks after a successful pilot, through which financial development and innovation are balanced with financial stability and security.

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