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DIGITALIZATION AND THE "TOO BIG TO FAIL" DILEMMA: MECHANISMS AND ASYMMETRIC EFFECTS OF BANKS' FINTECH INNOVATION ON TOTAL FACTOR PRODUCTIVITY

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Abstract. Fintech is driving the revolution of finance and profoundly affecting the development of the financial sector. However, few studies examined how commercial banks' fintech innovation affects total factor productivity (TFP). To build up the fintech index of commercial banks, we use web crawler technology to accumulate news related to the fintech innovation of commercial banks in Baidu news. We use the panel data of 72 banks in China from 2010 to 2020 to explore the impacts and mechanisms of fintech on commercial banks' TFP. The results show that fintech innovation effectively improves TFP after a series of robustness tests. Further, we find that fintech innovation can improve commercial banks' TFP by promoting innovations of financial products, increasing risk control capability, reducing cost, and improving profit. Also, the utility of fintech is more significant in banks with more assets, facilities, and human capital, which means that fintech innovation creates a "bigger is better" mindset. Meanwhile, the result of quantile regression shows that the higher the fintech innovation, the more significant the increase in TFP, which further reveals that there is 'too big to fail' among commercial banks under digitalization.

Keywords: fintech innovation, total factor productivity, commercial banks, too big to fail, digitalization dilemma, asymmetric effects, quantile regression, web crawler technology.

JEL Classification: E23, G10, G21.

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1. Introduction

At present, digitalization is integrating into all aspects of the economy and society, and accelerating digital empowerment has become a global consensus (Li et al.,2023a; Zhai et al., 2023). In the digtal era, commercial banks are scrambling to carry out fintech innovation to improve their ability to serve the real economy. However, little literature exists about how fintech innovation influences commercial banks' total factor productivity (TFP). Studies show that many factors can affect bank efficiency, including external technology shock (Buchak et al., 2018; Phan et al., 2020), banking competition (Thakor, 2020), service efficiency, and technological advances (Lee et al., 2021), and so on.

The rapid growth of fintech companies has seriously impacted the profitability and position of banks in financial systems. First, the impact of fintech companies on banks is mainly on intermediary services such as payment and settlement. For example, third-party payments

driven by fintech companies have stolen market share from banks in the payment business (Li et al., 2022a), diverted commercial banks' original customers, and intensified market competition. Second, fintech companies are reducing banks' earnings. Due to technological advancement, shadow banks are gradually encroaching on the loan market that used to belong to commercial banks (Buchak et al., 2018), undermining banks' profits. Third, fintech companies exacerbate banks' risk-taking. Studies find that the involvement of technology companies has changed the financial market so that banks must hold more short-dated, high-cost, easy-to-evacuate funds, which weakens the stability of their deposits and raises their risk level. Besides, external fintech innovation may cause systemic financial risk, worsening banks' operations. Based on this analysis, we may find that the emergence of fintech companies has, to a certain extent, reduced the operational efficiency of traditional commercial banks and weakened their dominance. After suffering from external fintech shock, banks must strengthen fintech innovation to improve their business.

From e-finance and online finance to fintech, technological progress is an essential driving force for the development of the financial industry (Li et al., 2023b). During this period, banks apply new technologies to drive their business transformation. To achieve business transformation, commercial banks must integrate new technologies with existing businesses, which changes the banking industry. From the perspective of broadening service channels and improving bank performance, fintech innovation can broaden the business scale and channels and help commercial banks meet customers' more diversified financial needs. At the same time, fintech can ease the cost pressures on banks and improve their profit (Philippon, 2019; Liu et al., 2020). As for increasing service efficiency, fintech innovation can simplify the business approval process, save business approval time, and improve business processing efficiency. For instance, the technical features of blockchain technology and big data can help banks reduce the cost of transactions and the level of information asymmetry in the loan approval and disbursement process (Li et al., 2023c), thus improving the efficiency of loan disbursement. Fuster et al. (2019) found that after combining fintech with loan approval, the approval speed increased by 20%, significantly improving the approval efficiency. When it comes to assessing customers' credit risk by using multi-dimensional information, fintech innovation, represented by machine learning algorithms, can effectively use less structured information such as cell phone bills, subscription records, or browsing history to carry out credit assessment (Philippon, 2019), and then accurately assess the users' credit level. Thus, we may find that fintech innovation in the banking sector can affect profit levels, service efficiency, and risk assessment capabilities, and so improve its TFP. Yet, this is rarely addressed in the literature.

Thus, this paper uses the micro and balanced panel data of 72 commercial banks in China from 2010 to 2020 to investigate how fintech innovation affects commercial banks' TFP and discusses heterogeneity characteristics. The results show that fintech innovation significantly improves the TFP of commercial banks. The results are consistent after being tested in other ways, including winsorizing, using the Solow residual value method (Solow, 1956) and OP (Olley & Pakes, 1992) method to compute the TFP of banks. Application of mechanism analysis finds that financial product innovation, risk control capability innovation, and reducing cost and improving efficiency are the main channels by which fintech innovation affects banks'

TFP. A heterogeneity analysis finds that fintech innovation promotes banks with larger assets, better facilities, and more investment in human capital more effectively, suggesting that commercial banks have a scale advantage in the digital era. Furthermore, the quantile regression results show that with the gradual deepening of fintech innovation, its contribution to banks' TFP becomes increasingly obvious, indicating a scale effect of fintech innovation. In a word, we conceive that commercial banks in the digital age are "too big to fail".

The main contributions of this paper are as follows: First, this paper expands the literature about the impact of fintech on the banking industry. The literature focuses on macro-factors, such as Internet finance, third-party payments (Fuster et al., 2019), shadow banking, regulatory arbitrage, and other emerging business models driven by technological advances (Buchak et al., 2018). However, they ignore the potential impacts of fintech innovation within banks. Thus, this paper enriches the literature about the impact of fintech innovation on the development of the banking sector from the perspective of banks' TFP.

Second, the existing literature is deficient in constructing fintech innovation indicators. For example, Cheng and Qu (2020) used the text mining method to build up the regional fintech innovation index, which was used to measure the level of banks' fintech innovation. Though the regional fintech innovation index is somewhat representative, it ignores individual differences. So, it cannot be used to conduct micro-research. Guo et al. (2020) used Peking University's digital financial inclusion index, which mainly reflects the usage of financial services by users and focuses on the demand side; therefore, it does not apply to measuring the fintech innovation of the banks' supply side. Lee et al. (2021) constructed a fintech innovation index from two dimensions, supply, and demand, where the supply side uses the scale of fintech company financing and venture capital investment to measure the level of fintech innovation. However, this method focuses on fintech companies rather than commercial banks, so it cannot be used in our paper. Also, there some errors in using a scale of financing and venture capital to measure fintech innovation because science and technology innovation activities may easily fail. This characteristic results in R&D inputs that cannot accurately measure the fintech outputs and may overestimate the innovation. Therefore, this paper refers to existing research methods and uses the text mining to construct a micro-level fintech innovation index of banks. When constructing a fintech dictionary, the keywords related to fintech involved in national policy documents, relevant news, and important conferences are cited, and some words in internet finance are absorbed to realize the dictionary innovation under the text mining method. In addition, this paper uses the Scripy crawler framework, adding 'intitle' when sending URL requests to Baidu websites, achieving precise matching at the title level and innovation in dictionary acquisition technology, bridging the gap in the construction of the fintech innovation index.

Third, this paper extends the research on banks' TFP. The relevant literature reveals that studies on the TFP of banks have mainly focused on external and internal influencing factors. Regarding the external influence factors of banks' TFP, the literature primarily discusses the impact of policy reforms, financial liberalization, and natural resources on banks' TFP (Adetutu et al., 2020). As for internal influence factors, most studies explored the impact on TFP of commercial banks from the perspective of operational efficiency and ownership structure. However, the important and immediate factor of technological innovation in banks is over-

looked. From the perspective of bank fintech innovation, this paper can enrich the literature on the factors that influence the TFP of banks.

Fourth, this paper expands the literature on the impact of banks' fintech innovation on operational efficiency. For instance, Wang et al. (2021) and Lee et al. (2021) documented that fintech innovation has a significant positive effect on the improvement of TFP of commercial banks. However, Wang et al. (2021) did not address the mechanism, and Lee et al. (2021) just analyzed the heterogeneous impact caused by ownership structure and do not explore the heterogeneous impact of fintech innovation and its mechanisms. Thus, this paper accounts for the shortcomings of the literature and further explores the mechanism of fintech innovation on banks' TFP. The results show that promoting financial product innovation, improving risk control capabilities, reducing costs, and increasing efficiency are important ways for fintech to improve banks' TFP. Besides this, heterogeneity analysis and quantile regression indicate that fintech innovation has a scaled effect, which means that large commercial banks can use fintech to expand their original advantages in the digital era and thus behave as though they are "too big to fail".

The remaining sections of this paper are as follows: Section 2 provides theory and our hypotheses. Section 3 shows the model, data, and methodology of the study. Section 4 illustrates the empirical results and robustness tests. We provide the mechanism analysis in Section 5 and the heterogeneity analysis in Section 6. At last, we summarize this paper and give recommendations. The research framework of this paper is as follows (see Figure 1).

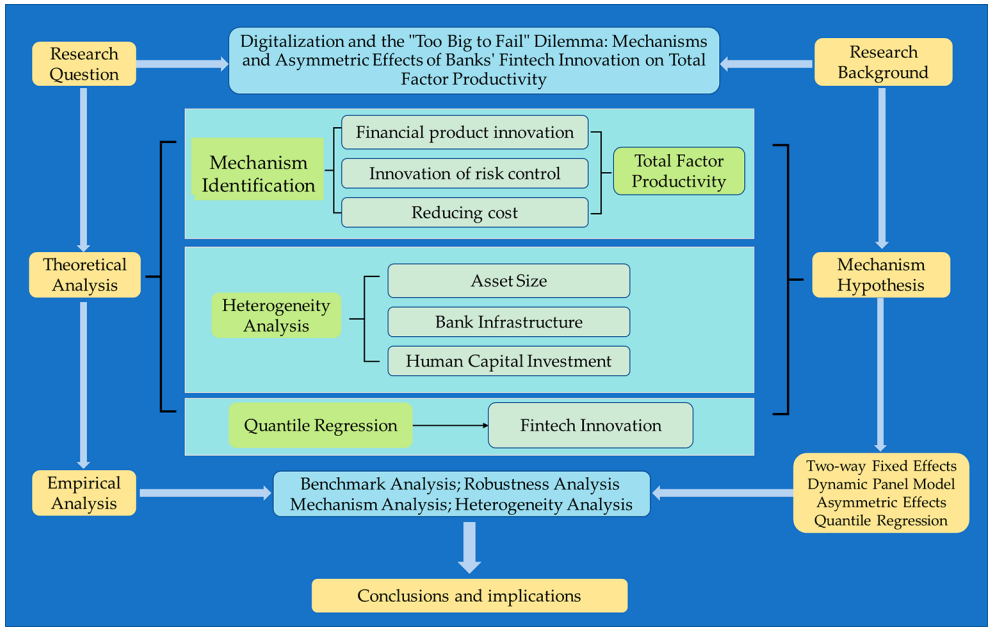


Figure 1. Research framework

2. Theory and hypotheses

2.1. Fintech innovation, financial product innovation, and the TFP of banks

According to Schumpeter's innovation theory, innovation is the creation of a new production function, and introducing a new combination of production factors and conditions into the production system. The process of applying fintech innovation to the banking business is applying the innovation of production conditions caused by technology push to the production system of commercial banks.

After integrating fintech with the banking business, financial products have achieved innovation. Financial product innovation has promoted the diversification of banks' financial products and expanded the boundaries of financial services by accelerating the development of intermediate business and other means, thus improving bank productivity (Lee & Shin, 2018). For example, JPMorgan launched online banking with Finn, which can help customers create accounts in less than four minutes, and Ondeck provided emergency funds for large corporations and enables users to make same-day payments. Another example is Property, powered by the Commonwealth Bank of Australia, which combines its financial services with real estate. Users can directly search the location information of the house and experience integrated lending in the property. This application significantly improved the interaction between customers and banks and achieved a 109% return on revenue.

As for commercial banks in China, the increase in intermediate business income owing to financial product innovation is important in improving banks' income structure and efficiency. At present, the intermediate business of Chinese commercial banks mainly includes payment and settlement businesses, bank card businesses, guarantee businesses, custodian businesses, and wealth management businesses. Fintech innovation can provide technical support to carry out these intermediary businesses better. For instance, in the payment and settlement business, an online payment platform based on fintech can meet the personalized payment needs of customers in different scenarios and realize the leap of bank payment service from offline to online. In the wealth management business, a data center built on a data warehouse and other technologies can help banks get multi-dimensional and fine-grained data, and then accurately identify customers' financial needs, provide corresponding financial products, and achieve accurate customer-oriented push and marketing. The application of big data technology can also analyze the changing pattern of customers' risk appetite and realize dynamic tracking. A robo-advisor can provide timely investment advice after capturing these changes and meet customers' financial needs with innovative products. These product innovations, driven by fintech, can improve customer stickiness and customer retention and increase the income of banks' intermediate business, which in turn improves banks' profitability and benefits TFP.

Based on the above analysis, the following hypothesis is proposed:

H1. *Banks' fintech innovation enhances their financial product innovation capabilities, which in turn improves TFP.*

2.2. Fintech innovation, innovation of risk control, and the TFP of banks

According to comprehensive risk management theory, the assessment and management of risk are important elements of commercial banks' business management, especially credit risk. From the principle of operation, achieving reasonable risk control and ensuring operation safety are prerequisites to achieving excellent profit and the basic guarantee for promoting efficiency. There are many sources of risk in the bank's business, such as credit risk. If the borrower cannot repay the loan, the bank will write off the defaulted loan directly from its profits, affecting the bank's operating performance. Thus, improving the control capability of risk is an important mean to improve the bank's profit level, increase the return on capital, and thus improve the bank's operational efficiency.

If banks apply fintech, such as AI technologies, into their credit operations, banks' information screening capabilities and accuracy of risk control will be improved significantly. Meanwhile, the credit risk will be reduced (Gu et al., 2020; Li et al., 2022b). First, fintech innovation can help banks access information and alleviate information asymmetry (Li et al., 2024). Specificly, fintech can help banks transform "soft" information, which is difficult to measure quantitatively, into measurable "hard" information that can be used as a reference for decision-making. The transformation may enhance the ease of information delivery so that data resources can be mined and used effectively. Then, fintech can help banks access "soft" information more easily and quickly. Besides, with the improvement of "soft" information processing capabilities, bank data dimensions have been enriched, data granularity has been gradually refined, and data coverage has been broadened. This lets banks make more accurate and effective decisions when approving loans. For example, Lin et al. (2013) found that besides traditional lending information, the applicant's social network connections can be used to determine creditworthiness. The application of social network connections can increase the probability of successful borrowing and be used for post-loan management for lending platforms, thus reducing the risk of default. Huang et al. (2018) document that Anthem takes into account some non-financial information beyond the traditional auditing information when approving loan applications, which may reduce the level of information asymmetry, facilitate loan origination, and decrease default risks. Second, fintech innovation can help banks improve the security of transactions. For instance, the application of centralized machine learning algorithms can detect financial fraud through text analysis, thus ensuring the security of transactions (Glancy & Yadav, 2011). Due to technical features such as tamper-evident information, smart contract event triggering, and distributed fault tolerance, blockchain technology can improve transaction security (Chiu & Koeppl, 2019; Wang et al., 2022). The application of big data and cloud computing can optimize banks' risk management models, improve the accuracy of models, and enhance the security of transactions (Wang et al., 2021).

In short, financial technology innovation can increase banks' access to information, improve the granularity of the information, alleviate the information asymmetry between banks and lenders, and thus help banks make more accurate assessment and management of lenders' credit risks, achieve reasonable control on risk, and improve banks' operational efficiency. Also, the technical features of the relevant applications guarantee the security of transactions,

reduce transaction risks (Dynan et al., 2006), and improve the bank's ability to prevent and resolve transaction risks.

Based on the above analysis, we propose the following hypothesis:

H2. *Fintech innovation can improve banks' risk management capabilities and thus increase TFP.*

2.3. Fintech innovation, reducing cost and prompting profit and TFP

In terms of reducing costs, the unit cost of financial institutions has remained at an average of 2% for the past 130 years (Philippon, 2019), and the emergence of fintech can drive further reduction in transaction costs. Fintech innovation can help financial institutions meet customers' more diversified financial needs while relieving the cost pressures of institutions (Palmié et al., 2020; Liu et al., 2020). Further, fintech innovation can reduce verification costs (Xu & Li, 2023) and lower banks' information acquisition costs (Thakor, 2020). In general, fintech's "cost reduction" function is mainly expressed in the decreasing marginal cost of business. For example, banks will inevitably pay higher costs to obtain sufficient data when developing AI and related technologies to improve the algorithms and computation force. However, as banks expand their business types and scale, the cost of technology development will be spread over many asset businesses, eventually showing a trend of decreasing marginal cost (Thakor, 2020; Lee et al., 2021).

From the perspective of improving banks' operational profit, fintech innovation has a strong technology spillover effect, which can promote banks' technological innovation and progress and thus gain benefits. Studies find a strong positive correlation between commercial bank productivity and information and communication technology (ICT) investment, which can expand the overall size of banks' deposits and loans, expand their business, and thus significantly improve operating efficiency. In addition, fintech can enhance network externalities, which can help banks achieve revenue growth. Network externalities mean that the value of connecting to a network depends on the number of people already connected to that network. The development of technology has helped banks expand their services, and the services network is gradually reaching more customers. According to network externalities theory, banks' revenue will increase as people increasingly access the financial services network, showing increasing marginal returns.

Based on the above analysis, we propose the following hypothesis:

H3. *Fintech innovation can help banks "reduce costs and prompt profit" and thus improve the TFP.*

2.4. Fintech innovation, bank heterogeneity, and TFP

Due to different endowments, the impact of fintech innovation will vary from bank to bank. First, banks' size is an important consideration in deciding whether to develop fintech such as AI (Sheng, 2021). According to the theory of scale economy, the unit cost of a product produced will decrease with the increase of the absolute quantity of goods in a specific period, i.e., the average cost can be reduced by expanding the scale of operation, thus increasing the profit level of the enterprise. Commercial banks laying out fintech have high fixed costs.

However, as the scale of business development gradually expands, the fixed cost is spread to an infinite number of businesses, making the unit cost and marginal cost gradually decline. Thus, in the long run, as the financial business increases, its economy of scale effect will be more and more prominent. Large banks have a wider range of businesses and a larger market size to effectively share the cost of fintech innovation, so fintech shows the scale effect. As for medium and small-sized banks, the amount of data accumulated in the course of operations is relatively small, and thus the benefits generated by fintech innovation are relatively weak. Due to distinctions in banks' asset size, fintech innovation will have different impacts on different banks. Second, the essence of fintech is "technology + finance". From the technological perspective, the development of fintech usually relies on technological advances in non-financial areas such as computer science, software technology, and internet technology (Chen et al., 2019). From the perspective of finance, matching the corresponding technology to the financial application scenarios is important to make full use of technology. After making technological advances, commercial banks should provide supporting infrastructure such as software and hardware so that technology and finance can be fully integrated, thus stimulating the growth of the banking business. There are significant differences in technology levels and service scenarios among banks, and thus, fintech innovation will have different impacts on distinct banks. Third, human capital investment is an important factor affecting the role of fintech. Fintech innovation improves production conditions, and the utility of fintech depends on a good combination of production conditions and factors of production. The combination may stimulate the growth of productivity. Thus, combining labor factors and production conditions is crucial for TFP improvement. Based on Lucas' human capital model, it can be known that a worker's human capital level affects not only his or her labor productivity but also the productivity of society as a whole, i.e., human capital has positive externalities. The theory suggests that sectoral economic output is positively correlated with the growth rate of human capital. This can result in different impacts of fintech innovation for different banks due to the differences in human capital investment. Fourth, differences in the degree of fintech innovation can have heterogeneous effects. Studies have shown that the use of technology can increase the productivity of banks (Berger, 2003). At present, there are large differences in the fintech innovation among banks; some banks have achieved a deep integration of technology and business and can use fintech to empower business growth. Other banks lacking internal resources find their technology is limited, so fintech innovation has not yet worked. Like the "flywheel effect", fintech innovation is relatively weak initially; as fintech innovation continues to deepen, its role in promoting TFP in banks will become increasingly significant. In a word, the contribution of fintech innovation is greater for banks with larger assets, better infrastructure, and higher investment in human capital. There is a scale effect of fintech innovation, i.e., the higher level of fintech innovation, the greater its contribution to TFP; thus, being "too big to fail" becomes a typical phenomenon in the digital era.

Based on the above analysis, we propose the following hypothesis:

H4. *There is such a phenomenon as "too big to fail" in the digital age. That is, there is a scale effect of fintech innovation on banks' TFP.*

3. Model, data, and methodology

3.1. Empirical model

This paper constructs the dynamic panel model (1) to explore the impact of fintech innovation on banks' TFP:

$$TFP_{it} = \alpha + \beta Fintech_{it} + \delta TFP_{it-1} + \gamma Control_{it} + \mu_{it} + \varepsilon_{it}. \quad (1)$$

The explanatory variable TFP_{it} is the TFP of commercial bank i in year t, calculated using the LP (Levinsohn & Petrin, 2003) method.The core explanatory variable $Fintech_{it}$ is the level of fintech innovation of commercial banks i in year t, constructed using the annual advanced search results of Baidu News. TFP_{it-1} is the lagged period of TFP_{it}. $Control_{it}$ mean control variables, including deposit-to-loan ratio (*Pod*), risk-weighted assets ratio (*Rwa*), listing (*SS*), capital adequacy ratio (*Car*), profit level (*Roa*), number of bank employees (*Person*). μ_{it} denotes a two-way individual and time-fixed effect. ε_{it} means random error term. The coefficient β of the core explanatory variable $Fintech_{it}$ indicates the direction and magnitude of the impact of fintech innovation on banks' TFP. Based on the previous description, we expect the coefficient β is significantly positive.

3.2. Definition of control variables

3.2.1. Total Factor Productivity (TFP)

There are three main methods for estimating TFP (parametric, non-parametric, and semi-parametric), of which the semi-parametric methods include the OP method and the LP method. The advantage of the parametric method is that the dispersion is small, the degree of accuracy is high, and allows for the existence of random error terms. However this method requires high accuracy for the model and has poor applicability. The advantage of the non-parametric method is that it does not require high accuracy for the model, it has strong applicability, and the results obtained are more comprehensive; however, the results are difficult to use for prediction and analysis. Semi-parametric methods, represented by the OP and LP methods, integrate the advantages of parametric and non-parametric models, in which the parametric component can analyze deterministic influences, i.e., influences that can be represented by a deterministic functional relationship equation. The non-parametric component allows for the portrayal of the effects generated by random disturbances, i.e., the effects generated by secondary factors. The semi-parametric methods that combine parametric components with non-parametric components can describe productivity more realistically. The semi-parametric method both enhances the credibility of the model and reduces the simultaneity bias and sample selectivity bias present in the TFP calculation process.

In line with the literature, we use operating income as output (Kamarudin et al., 2017), view the number of employees (Ray & Das, 2010), operating expenses (Kamarudin et al., 2017), and the net value of fixed assets (Ray & Das, 2010) as inputs, and then use LP method to calculate the TFP of the banks.

3.2.2. Fintech innovation

Because fintech innovation in the banking industry is still developing, there is no unified standard to measure fintech innovation. There are three academic methods: First, directly using the China Digital Inclusive Finance Index, compiled by Peking University's Digital Finance Research Center, as an indicator of fintech innovation (Guo et al., 2020; Yu et al., 2022). We argue that this approach focuses more on the inclusiveness of fintech rather than technology, and this index pays attention to the demand side instead of the supply side, so it does not apply to the study of bank fintech. Second, using the ratio of the size of third-party payments to online payment transactions as a proxy indicator. This method focuses on third-party payments such as WeChat and Alipay, which cannot represent the fintech innovation of the banking industry. Third, building an initial dictionary related to the research topic and using the text mining method to construct a fintech development index based on the number of terms searched by Baidu News (Cheng & Qu, 2020; Lee et al., 2021; Zhao et al., 2022). This method can portray a micro-fintech innovation of banks and meet the research needs of this paper, so we adopt the text mining method to construct the indicators of the fintech innovation of banks.

In finance, scholars have widely used the text mining method to construct some indicators, such as using it to portray the attention paid to something, corporate financial constraints, and innovation indicators (Bellstam et al., 2021). The main application of the text mining method is to construct a new index, and the key is to construct or select a suitable dictionary. Based on government policies, annual reports of banks, and relevant key news and conferences, this paper extracts the keywords related to fintech, including *fintech*, *digital inclusive finance*, *digital currency*, *online payment*, *cross-border payments*, *mobile payment*, *third-party payments*, *mobile wallet*, *online banking*, *e-banking*, *smart banking*, *mobile banking*, *intelligent customer service*, *smart finance*, *smart investment*, *intelligent risk control*, *regulatory sandbox*, *regtech*, *compliance technology*, *digital signature*, *online loans*, *crowdfunding*, *online money management*, *credit score*, *online financing*, *online investment*, *big data*, *cloud computing*, *artificial intelligence*, *blockchain*, *biometrics*, *internet of things*, *quantum computing*, *distributed architecture*, *virtual reality*, *5G*, and *financial cloud*, a total of 37 keywords. Because the development of fintech in China's banking industry can be seen as an extension of internet finance, some keywords from internet finance have been added to the dictionary (Luo et al., 2022), such as "mobile payment" and "third-party payments". After completing the dictionary, we use web crawler technology to obtain the frequency of each commercial bank's corresponding keywords in *Baidu News*, sum them up, and give equal weight to each keyword, so as to construct the micro-fintech innovation index of commercial banks. Increases in this index indicate the higher level of fintech innovation in commercial banks. In the process of fintech development, due to the obvious difference in capital investment, the fintech innovation index among banks may not belong to the same magnitude, and this index is a right-hand bias. Therefore, we log-transformed this index to keep the differences within a reasonable range and make them comparable.

3.2.3. Control variables

The deposit-to-loan ratio (*Pod*) is an important indicator of banks' liquidity risk. In the course of daily operations, banks need to keep a certain amount of cash on hand for customers' daily cash withdrawals and settlements. If the deposit-to-loan ratio is too high, it means that banks will disburse more funds in the form of loans, so there may be a shortage of funds for daily operations, which may lead to a potential risk of liquidity crisis. We refer to the method of Wang et al. (2021), viewing the deposit-to-loan ratio as a proxy variable of bank liquidity, to explore the impact of liquidity risk on TFP.

The risk-weighted asset ratio (*Rwa*) measures the willingness and ability of banks to take proactive risks. From the regulatory perspective, the higher the percentage of risk-weighted assets, the greater the risk the bank faces. From the profitability perspective, the higher the percentage of risk-weighted assets, the greater the likelihood that the bank will be profitable. We refer to the method of Delis and Kouretas (2011), using the risk-weighted asset ratio as a proxy variable of banks' risk-taking, so as to discuss the impact of risk-taking on bank TFP.

The listing (*SS*) of banks can affect their operating conditions and, thus, TFP. First, appearing on the market can replenish capital, enhance risk tolerance, and significantly increase total assets (Allen et al., 2014). Second, after going public, banks need to disclose operational and financial information regularly. So, risk control managers will be introduced to control the bank's operational risks. Thus, this paper introduces a binary dummy variable for bank listing to explore the impact of listing on TFP.

Safety, liquidity, and efficiency are the principles that commercial banks should abide by in their operation. To protect the safety of commercial banks, the Basel Accord imposes some requirements on commercial banks' capital adequacy ratio (*Car*). A reasonable capital adequacy ratio is a reflection of safety for banks, and thus, this paper chooses the bank's capital adequacy ratio as a proxy variable for the operating robustness.

The return on assets (*Roa*) is an indicator of the banks' profitability, the higher the indicator, the more efficiently the bank is able to use its assets to generate income. It has a positive impact on TFP. So, this paper refers to the existing literature (Wang et al., 2021) approach and uses the return on assets as a proxy variable for profitability.

The size (*Person*) of the business is an important factor affecting the efficiency of business operations. Larger banks tend to have stronger business operations and are more inclined to invest in fintech innovation. When it comes to business size, the literature usually uses total asset size (Pan et al., 2020; Wang et al., 2021) or the number of employees (Ayandibu & Houghton, 2017). As for commercial banks, the labor force is also an important factor of production. So, this paper selects the total number of employees at the end of the year to measure business size.

3.3. Data sources and descriptive statistical analysis

This paper uses balanced panel data for 72 commercial banks in China from 2010 to 2020, including 5 large state-controlled banks, 11 joint-stock banks, 51 urban commercial banks, and 5 rural commercial banks, for a total sample of 792. The criteria for sample selection in this paper are as follows: First, representativeness. The selected sample basically covers different

types of commercial banks in China; Second, importance. The large state-owned commercial banks, some joint-stock banks and city commercial banks in the sample are all located in the list of systemically important banks, which have a significant position in the Chinese banking industry and the financial system; Third, data availability. The selected sample has been established for a long time, and the information and relevant financial data are relatively complete.

The indicators used to measure the fintech innovation of commercial banks are constructed by web crawlers. The financial indicators of commercial banks are obtained from the CSMAR and Wind databases, and some financial indicators with missing values are supplemented by using linear interpolation or manually checking the corresponding annual reports. Table 1 shows the definition of variables and their descriptive statistical analysis.

Table 1. Definition of variables and descriptive statistical analysis

Variables	Definition	Number	mean	sd	min	max
TFP	Calculated by LP method	792	5.276	1.039	1.054	7.937
Fintech	Fintech innovation	792	2.385	1.786	0	7.045
TFP-OLS	Calculated by Solow residual value method	792	–1.44e-10	0.195	–1.317	0.952
TFP-OP	Calculated by OP method	792	5.375	1.041	1.101	8.042
Pod	Deposit to Loan Ratio	792	0.722	0.111	0.429	0.987
Rwa	Risk-weighted assets ratio	792	63.88	9.944	5.185	98.18
SS	Listing	792	0.264	0.441	0	1
Car	Capital adequacy ratio	792	13.01	1.705	9.140	18.64
Roa	Return on assets	792	0.957	0.387	0.0483	2.297
Person	Number of employees (in thousands)	792	30.92	87.04	0.637	462.3
Nplra	Non-Performing loan ratio	792	1.393	1.318	–0.420	28.44

4. Empirical results

4.1. Baseline regression results

To investigate whether the effect of fintech innovation on TFP of commercial banks' is facilitative or inhibitory, this paper using OLS for regression and the results are presented in column (1) (2) of Table 2. Meanwhile, in order to reduce the errors in the estimation results arising from endogeneity, this paper uses model (1) for regression, and the results are presented in column (3).

From column (1) and (2), we find that the coefficient of the key explanatory variable, fintech innovation, is significantly positive regardless of whether control variables are included. The coefficient of fintech in column(3) is positive and significant, at the same time, the value of AR (2) is greater than 0.1, indicating that there is no second-order differential autocorrelation. The p-value of Hansen's test is about 0.123, implying that there is no over-identification problem. The above results suggest that fintech will contribute to the commercial banks' TFP, which is consistent with Luo et al. (2022).

Table 2. Baseline regression results

Variables	(1)	(2)	(3)
	TFP	TFP	TFP
L. TFP			0.7272***
			(10.68)
Fintech	0.2614***	0.2393***	0.0605***
	(28.28)	(19.08)	(2.77)
Pod		–1.2569***	–0.3630***
		(–9.52)	(–3.29)
Rwa		0.0102***	–0.0014
		(6.77)	(–1.18)
SS		0.1255**	0.1638***
		(2.41)	(2.75)
Car		–0.0465***	–0.0112**
		(–6.58)	(–2.17)
Roa		0.4408***	0.2209***
		(11.43)	(4.77)
Person		0.0052***	0.0011***
		(10.81)	(3.40)
Constant	4.6522***	4.9481***	1.5969***
	(62.26)	(30.79)	(4.69)
Observations	792	792	720
Number of Banks	72	72	72
Hansen			0.123
AR (1)			0.001
AR (2)			0.106

Notes: z-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

When it comes to the effects of control variables, the regression coefficient of the deposit-to-loan ratio is significantly negative because as banks' deposit-to-loan ratios increase, the liquidity risk gradually rises, which may make it difficult to meet the needs for daily operations, thus leading to a decrease in TFP; The coefficient of the risk-weighted assets ratio is negative, which means excessive risky assets may harm bank returns. The coefficient of the dummy variable for the bank listing is significantly positive at the 1% level, indicating that the listing of banks is beneficial to TFP, which is consistent with Allen et al. (2014). The coefficient of the capital adequacy ratio is significantly negative, illustrating that banks may tend to operate conservatively and fail to achieve a reasonable allocation of risk assets. Excessive capital adequacy ratios lead to poor effectiveness and impair operational efficiency. The regression coefficient of ROA is significantly positive, which means that the more profitable the bank is, the more efficient its operation. As for those banks with sufficient capital, they are able to engage both in the main business and R&D innovation or other efficient production activities, which will increase the TFP. The regression coefficient of the number of employees is significantly positive, which means with the expansion of the number of employees and departments in banks, the productivity has been improved.

4.2. Robustness tests

4.2.1. Excluding extreme values

From Table 1, we can see significant differences in TFP and fintech innovation among the banks. To reduce the error caused by extreme values, the continuous variables such as bank TFP and fintech innovation are subjected to a 1% tail shrinkage. From Table 3 column (1), we find that after excluding extreme values, the effect of fintech innovation is still significantly positive, consistent with the previous conclusion.

4.2.2. Solow residual value method for calculating total factor productivity

To ensure the robustness of the regression results, we replace the TFP measuring method in the following and use the Solow residual method (Solow, 1956) to calculate the TFP of each commercial bank. The theoretical basis for applying this approach lies in the fact that traditional TFP is understood as the level of productivity after deducting the contribution of factors of production such as capital, labour, and land. The TFP can measure the productivity growth resulting from non-factor inputs such as technological advances and improvements in organizational structure. After calculating TFP by the Solow residual value method, we bring it into the model (1) and carry out the regression. The result is shown in column (2) of Table 3.

4.2.3. OP method for calculating total factor productivity

We also use the OP method (Olley & Pakes, 1992) to compute the TFP. This approach assumes that firms' investment decisions are made based on current productivity conditions, and thus firms' current investment can be used as a proxy variable for productivity shocks due to unobservable factors. This addresses simultaneity bias to some extent. We bring it into the model (1), and the result is shown in column (3) of Table 3.

From columns (2) (3) of Table 3, we may find that after replacing the measuring method, the results are still consistent with the previous, indicating that fintech innovation has a significantly positive and effective influence on banks' TFP.

Table 3. Robustness tests

Variables	(1)	(2)	(3)
	Winsor 1%	TFP-OLS	TFP-OP
L.TFP	0.8137*** (7.70)	0.0904 (1.22)	0.8891** (2.49)
Fintech	0.0541* (1.87)	0.0570** (1.98)	0.2240*** (5.47)
Constant	1.5453*** (2.98)	–0.8092*** (–4.08)	5.7162*** (13.50)
Controls	Yes	Yes	Yes
Observations	720	720	720
Number of Banks	72	72	72
Hansen	0.188	0.134	0.258
AR (1)	0.011	0.066	0.068
AR (2)	0.201	0.197	0.380

Notes: z-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5. Mechanism analysis

This paper uses the intermediary effects approach to explore the mechanism about fintech innovation affects TFP, and the model is set as follows:

$$TFP_{it} = \alpha + \beta Fintech_{it} + \delta TFP_{it-1} + \gamma Control_{it} + \mu_{it} + \varepsilon_{it}. \quad (2)$$

$$Inter_{it} = \eta_0 + \eta_1 Fintech_{it} + \eta_2 Inter_{it-1} + \gamma Control_{it} + \mu_{it} + \varepsilon_{it}. \quad (3)$$

$Inter_{it}$ means intermediary variables. The direction and significance of the coefficients η_1 are the key items to explore as to whether the intermediary effect holds. If the coefficients β and η_1 are both significant, it indicates that fintech innovation can have an impact on banks' TFP through intermediary variables. Conversely, if β or η_1 are not significant, it indicates that fintech innovation cannot affect TFP through intermediary variables.

5.1. Financial product innovation

After being significantly shocked in the traditional credit business, banks began to actively adjust development strategies and resource orientation, eager to seek new potential growth points from the intermediate business. In the process of broadening the scope of intermediate business, commercial banks can provide customers with more personalized and diversified financial products, thus increasing operational efficiency (Liu et al., 2020). To explore whether fintech innovation will enhance TFP by way of improving the innovation capabilities of financial products, we use the net profit from handling fees and commission income (*Fee*) as the proxy variable for the bank's ability to create financial products. Also, we introduce the *Fee* as the intermediary variable to model (3).

The result is shown in column (1) of Table 4. After taking product innovation into account, we find that fintech innovation contributes positively to the intermediary variable, and thus increases TFP. In summary, we can conclude that fintech innovation can promote the innovation of financial products, increase commercial banks' intermediate business income, and enhance TFP, confirming hypothesis H1.

5.2. Innovation of controlling risk

The non-performing loan ratio (NPL) has always been an important indicator in the field of bank risk management because it measures the bank's potential credit losses. Non-performing loans are the main factor that erodes financial institutions' business income. We refer to Cheng and Qu (2020)and view NPL as the proxy variables for a bank's ability to control risk. If the NPL ratio is low, it indicates that the bank faces less credit risk, which is evidence of its strong risk control ability. If the NPL ratio is high, it proves that the bank's risk control capability is relatively weak, resulting in higher credit risk.

We introduce NPL as an intermediary variable into the model (3) and carry out the empirical test. From column (2) of Table 4, we will find that the regression coefficient of fintech is significantly negative at the 10% level, which means fintech innovation can reduce the rate of non-performing loans. Based on this, we can conclude that a weaker risk control capability may impair operational efficiency and thus harm TFP. Fintech innovation can help

banks improve their risk control capabilities, achieve accurate risk control and governance, reduce the potential losses that may be caused by many risks, and improve TFP, confirming hypothesis H2.

5.3. Reducing cost and prompting profit

Fintech innovation can contribute to increasing marginal revenue and reducing marginal costs, which can improve TFP. The increase in profit is the direct result of "reducing cost and prompting profit". Therefore, this paper takes bank profit growth rate (*Profit*) as the proxy variable. If the profit growth is fast, it means that the effect of "reducing cost and prompting profit" of fintech is significant. However, if the profit growth is slow, it means that the effect is weak.

We use the profit growth rate as an intermediary variable and make estimates. The result is illustrated in column (3) of Table 4. We discover that the coefficient of fintech is significantly positive at the 1% level, which means fintech has a significant effect on "reducing cost and prompting profit", contributing to the increase of banks' operating profit and improving their TFP, proving hypothesis H3.

Table 4. Mechanism analysis

Variables	(1)	(2)	(3)
	Fee	Nplra	Profit
L. Fee	0.8386*** (18.62)		
L. Nplra		–0.6722*** (–8.90)	
L. Profit			0.2974** (2.33)
Fintech	0.0592** (2.01)	0.0162* (1.79)	0.3773*** (4.98)
Constant	2.3743*** (6.18)	0.6476*** (5.43)	4.6062*** (5.45)
Controls	Yes	Yes	Yes
Observations	720	720	720
Number of Banks	72	72	72
Hansen	0.102	0.178	0.172
AR(1)	0.012	0.085	0.073
AR(2)	0.342	0.403	0.308

Notes: z-statistics in parentheses;*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

6. "Too big to fail?" The heterogeneous impact of fintech innovation on TFP

6.1. Heterogeneity of bank characteristics

To further explore whether the impact of fintech innovation varies depending on the nature of individual banks, this paper constructs model (4) and analyses it in terms of asset size, bank infrastructure, and human capital investment.

$$TFP_{it} = \eta_0 + \eta_1 Fintech_{it} + \eta_2 Moderator_{it} + \eta_3 Fintech_{it} * Moderator_{it} + \gamma Control_{it} + \mu_{it} + \varepsilon_{it}. \quad (4)$$

6.1.1. Asset size

To explore whether the effects of fintech innovation depend on banks' asset size, we introduce the interaction item (*Fintech*Size*) regarding fintech innovation and the banks' asset size into the model (4). The result is displayed in column (1) of Table 5.

We discover that the coefficient of interaction is significantly positive at the 5% level, indicating that the contribution of fintech innovation is greater for larger banks. One possible reason is that large banks have a broader scope of operations and more diverse business units and can split the cost, thus creating significant economies of scale. From the cost perspective, there is a negative correlation between the unit cost of fintech innovation and bank size (Philippon, 2019; Thakor, 2020). From the benefit perspective, the benefit of fintech applications is related to the richness of the data. Larger banks have an advantage in both the unit cost and the benefits of fintech. So, fintech will have a more positive impact on larger banks.

6.1.2. Bank infrastructure

Some hardware facilities, such as a one-stop smart financial services counter, are necessary to utilize fintech fully. However, due to the gap in the funds, some medium and small-sized banks may not be equipped with the hardware facilities of large banks. To investigate whether fintech innovation is heterogeneously affected by differences in amenities, this paper uses the growth rate of banks' net fixed assets (*Fixedassets*) as the proxy variable for the degree of amenity construction. If the growth rate is high, it means that the bank has invested more in infrastructure, and thus, its supporting facilities are relatively well developed.

The result in column (2) of Table 5 shows that the coefficient of interaction (*Fintech*Fixedassets*) is significantly positive, which means there is heterogeneity in the impact of fintech innovation on TFP. A more significant boost will be created for banks with a relatively well-developed infrastructure. The reasons for this may be as follows: in terms of software facilities, banks with sufficient budgets can develop or purchase mobile terminal applications with relatively complete functions, attractive interactive interfaces, and relatively stable operations to provide customers with diversified financial services. The improvement of the bank's internal operating system is also an important factor affecting the efficiency of employees. In terms of hardware facilities, banks with a good infrastructure will have equipment capable of providing additional financial services, such as cash smart counters and smart card issuers, to provide relatively complete financial services to customers. However, banks with limited capital budgets may only have equipment that provides basic financial services, such as ATMs and smart counters. Based on the above analysis, the differences in the type and number of software and hardware facilities of banks ultimately result in the heterogeneous impact of fintech innovation.

6.1.3. Human capital investment

Sustainable input of production factors is an important factor for economic development. The sustainable input of labor factors is crucial for enterprise development. Investment in human capital may lead to the sustainable growth of the labor factor, thus increasing the firm's productivity. In recent years, banks have set up fintech departments or subsidiaries to absorb digital talents and strengthen their talent resources. Due to different investments in human capital, there may be differences in the impact of fintech innovation on the TFP of banks.

This paper uses the growth rate of employee salary (*Salary*) as the proxy variable for human capital investment and introduces the interaction (*Fintech*Salary*) into the model. A high growth rate of employees' salaries indicates that the bank is investing more in human capital; conversely, the input is less. The result is shown in column (3) of Table 5. From the result, we discover that the coefficient of interaction is significantly positive at the 1% level, which means that as banks invest more in human capital, the boosting effect of fintech on TFP becomes more pronounced.

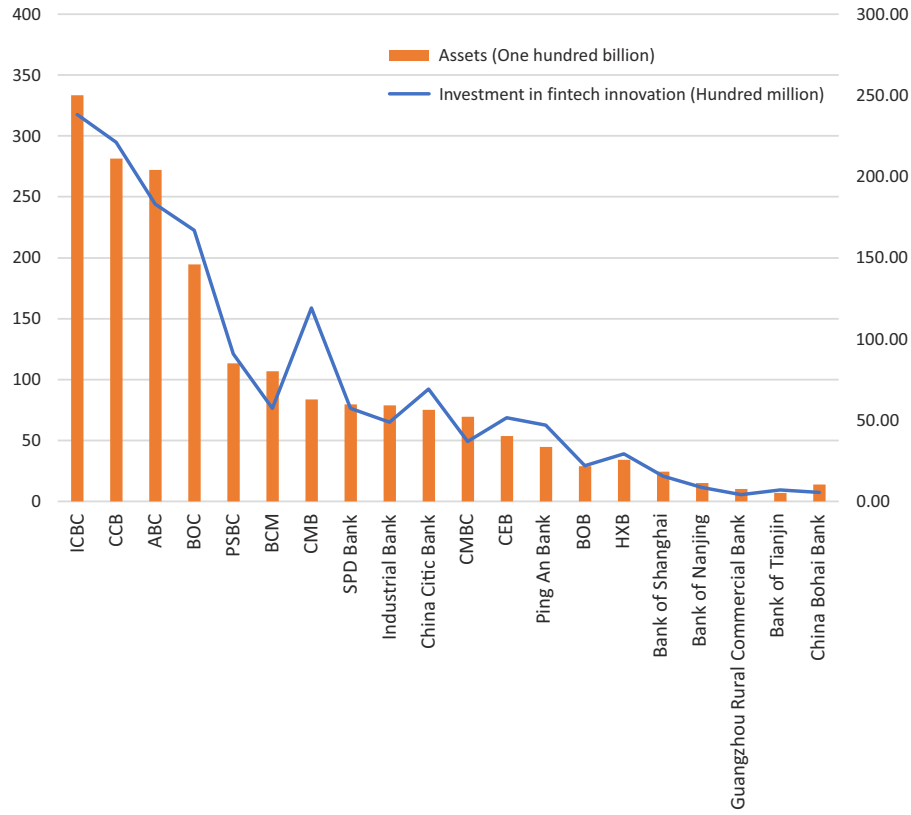
Table 5. Heterogeneity analysis

Variables	(1)	(2)	(3)
	TFP	TFP	TFP
L. TFP	0.8109*** (10.72)	0.8476*** (16.33)	0.8240*** (13.88)
Fintech	0.0273 (1.06)	0.0486*** (2.90)	–0.0509 (–1.34)
Size	0.0571* (1.65)		
Fintech*Size	0.0291** (2.11)		
Fixedassets		–0.0447* (–1.89)	
Fintech*Fixedassets		0.0096* (1.67)	
Salary			–0.1756*** (–5.69)
Fintech*Salary			0.0477*** (4.29)
Constant	0.8965** (2.30)	1.0014*** (3.72)	1.3650*** (5.74)
Controls	Yes	Yes	Yes
Observations	720	720	720
Number of Banks	72	72	72
Hansen	0.279	0.267	0.188
AR(1)	0.001	0.002	0.019
AR(2)	0.236	0.183	0.109

Notes: z-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

6.2. Heterogeneity of fintech development: based on quantile regression

The results of the previous analysis show that when the business scale reaches a certain level, banks can split the cost of fintech innovation, in turn reducing unit costs and thus achieving economies of scale in fintech innovation. From the fintech innovation development practices of China's commercial banks, we find that there is a significant positive correlation between banks' fintech R&D investment funds and their asset size (see Figure 2). The economies of scale in fintech innovation will stimulate large commercial banks to compete for R&D in related technologies, thus realizing the transformation from technological advantage to capital advantage, which in turn will drive banks to invest more funds in R&D to maintain technological leadership (Goldfarb & Trefler, 2018). Eventually, there is the positive cycle of technological and financial advantages. Based on this, large commercial banks will invest more in technology and achieve higher levels of fintech innovation.



Notes: For the sake of space, we use the abbreviated name of some banks. The meaning of abbreviations is as follows: ICBC, Industrial and Commercial Bank of China; CCB, China Construction Bank; ABC, Agricultural Bank of China; BOC, Bank of China; PSBC, Postal Savings Bank of China; BCM, Bank of Communications; CMB, China Merchants Bank; SPD Bank, Shanghai Pudong Development Bank; CMBC, China Minsheng Banking; CEB, China Everbright Bank; BOB, Bank of Beijing; HXB, Huaxia Bank.

Figure 2. Total bank asset size and fintech investment

To explore the possible distinct effects caused by differences in fintech innovation, this paper uses a quantile regression model for our analysis. The quantile regression model can be seen, to some extent, as an extension of mean reversion and can be used to estimate the effect of the explanatory variables on the explained variables at each quantile. At the same time, this model can reduce the bias brought by extreme values and more accurately describe the relationship between explanatory and explained variables. Therefore, we use quantile regressions to explore the heterogeneous impact of fintech innovation, and the result is illustrated in Table 6.

After obtaining the quantile regression results, this paper tested for coefficient differences between groups. The result shows that the p-value is approximately 0.0606, so we see there are differences in distinct quantiles at the 10% level. Furthermore, we derive the results from Stata to show the relationship among the quantile regression coefficients. The details are shown in Figure 3.

Table 6 and Figure 3 show that fintech innovation significantly improves TFP at the 25th, 50th, and 75th quartiles. With the continuous development of fintech innovation, it will have a more significant promotion effect on banks' TFP, i.e., fintech innovation has a scale effect, indicating that fintech innovation of banks strengthens the phenomenon of "too big to fail" in the digital era, and further proving hypothesis H4.

Table 6. Quantile regression

Variables	(1)	(2)	(3)
	25th percentile	50th percentile	75th percentile
Fintech	0.2390*** (14.80)	0.2528*** (17.49)	0.2877*** (12.89)
Pod	–1.3545*** (–5.25)	–1.3130*** (–5.31)	–1.2436*** (–5.03)
Rwa	0.0083*** (4.08)	0.0042*** (2.11)	0.0025*** (1.03)
SS	0.7369*** (10.33)	0.8435*** (9.81)	0.7928*** (7.38)
Car	–0.0644*** (–4.20)	–0.0536*** (–4.29)	–0.0507*** (–4.83)
Roa	0.3239*** (5.62)	0.4116*** (6.25)	0.4189*** (5.20)
Person	0.0041*** (21.68)	0.0034*** (12.76)	0.0034*** (12.68)
Constant	5.1382*** (26.01)	5.0292*** (25.05)	0.2877*** (12.89)
Observations	792	792	792

Notes: t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

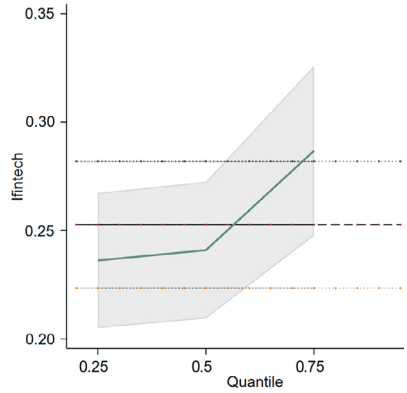


Figure 3. Quantile regression

7. Conclusions and policy implications

7.1. Conclusions

This paper collects the amount of news about the keywords related to fintech innovation of commercial banks in *Baidu News* through web crawler technology, and based on this constructs the micro-fintech innovation index of banks. We use the annual financial index data of 72 commercial banks in China from 2010 to 2020 to construct balanced panel data to examine the impact of the fintech innovation of commercial banks on their TFP and its mechanism.

The study found that: (1) At this stage, fintech innovation has already had a significantly positive effect on banks' TFP. In addition, a series of robustness tests such as data tailoring, replacing the TFP measure method, and changing the regression model, provide results consistent with the baseline regression results, proving that the conclusions of this paper are consistent and valid; (2) Mechanism analysis shows that fintech innovation affects the TFP through three paths: enhancing the ability to innovate financial products, strengthening the ability to control risks, reducing cost and prompting profit; (3) The results of the heterogeneity analysis show that fintech innovation has a more significant impact on those banks with larger assets, relatively better facilities, and faster growth in human capital investment; The quantile regression results discover that with the deepening of fintech innovation, its contribution is more significant, i.e., the greater the fintech innovation, the greater the contribution utility to banks' TFP. This strongly proves fintech innovation has a scale effect, which is consistent with the topic of this paper, i.e., in the context of fintech innovation, the larger banks can rely on capital, brand, and other resource advantages to seize the opportunity to achieve technological leadership. Then, they may convert the technological advantage into the financial advantage, consolidating their leading position in the banking industry. As for medium and small-sized banks, they may face tough development prospects due to limited resources. Therefore, medium and small-sized banks should choose a different development strategy to cope with the possible future drastic changes in the financial system. This means fintech innovation has further strengthened the "too big to fail" phenomenon in the banking industry.

However, there are some limits in this paper. First, due to the limited availability of data, the proportion of urban commercial banks in this paper's sample is relatively high, while the samples of joint-stock commercial banks and rural commercial banks are relatively small; the portrayal of the current development of the banking industry may not accurate enough; Second, in the construction of fintech innovation index, because there is no unified measurement standard in the industry and academia, so this paper adopts the textual mining method to indirectly construct the fintech innovation index of banks. In the future, there is a need to further collect data about banks' actual investment in fintech innovation to measure their fintech innovation more directly. Third, this paper focuses on the impact of fintech innovation on banks' TFP. Due to the length of the article, this paper does not explore the long-term impact of fintech innovation on the overall development of the banking industry, such as whether medium and small-sized banks will be marginalized due to the squeeze of large banks or whether bank fintech innovation brings efficiency gains at the expense of some customers' interests. These questions should be further discussed in the future.

7.2. Policy implications

Based on the above conclusions, this paper puts forward the following recommendations, which are expected to help commercial banks allocate technology resources rationally, fully exploit the utility of the technology, and properly apply fintech innovation to achieve transformation.

First, a fintech development strategy based on status should be completed. For commercial banks, future investment and research of fintech is inevitable. Still, there are many distinctions in the capital, employees, organization structure, and the like that will give rise to different fintech development strategies. For example, large commercial banks often have abundant capital, so various intelligent equipment will appear in their offline outlets. Therefore, digital outlets can meet multiple customer needs and improve service efficiency. Large banks can also provide customers and employees with a more stable online app and internal operating system, thus improving service and operational efficiency. Besides this, large banks are more likely to leverage brand advantages, attracting more business and technology talent and improving operational efficiency. As for medium and small-sized banks, the limited business scope not only hinders the "scale effect" but cannot support the high cost of fintech innovation. Therefore, if banks blindly ignore the heterogeneous impacts of fintech innovation and pursue digital transformation, fintech cannot play a positive role and may even increase the cost and undermine banks' efficiency. So each commercial bank should develop its technology development program based on its positioning.

Second, banks should strive to integrate technology and business more deeply. Technology development is only the means, business development is the purpose, and all technology applications ultimately come down to value growth. Therefore, commercial banks should penetrate big data, blockchain, AI, and other technology tools into core businesses, such as credit risk control and intermediate businesses, to reduce marginal costs, improve marginal profits, and increase the TFP.

Third, governments should strengthen support for medium and small-sized banks, actively address the polarization brought about by fintech, and promote the development of the global financial system in a sustainable direction.

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Author contributions

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