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Is Fintech good for green finance? Empirical evidence from listed banks in China

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ABSTRACT

Green finance has been regarded as an important strategy for the Chinese government to develop a green economy. Few studies have investigated the relationship of bank-level Fintech development in promoting the growth of green finance. To address this research gap, we have developed a bank-level Fintech index based on text mining and entropy methods using panel data from 59 Chinese listed banks from 2011 to 2020. We find that Fintech development can significantly promote the growth of green finance. In addition, the effect of Fintech development on banks with high net income or located in the eastern region is significantly larger than others, indicating that this influence has significant heterogeneity. Finally, we find that Fintech facilitates the growth of green finance by improving banks' risk management capability and operations capability.

1. Introduction

China's economy has grown significantly during the last 10 years as a result of the government's aggressive promotion of real economic growth across a range of industries. The GDP of the nation increased from 53.9 trillion yuan in 2012 to 114.4 trillion yuan in 2021, while the per-capita GDP doubled from 39,800 yuan to 81,000 yuan (Dai et al., 2022). But the environment has paid a heavy price for this quick economic growth. China's economic development model urgently needs to shift from extensive to sustainable development (Zhou et al., 2022). The Chinese government has realized the impact of environmental issues and proposed the targets of reaching a carbon peak by 2030 and carbon neutrality by 2060 at the 75th General Assembly of the United Nations. To support this economic transformation, the Chinese government has launched a series of green financial instruments such as green bonds, green stocks, and green insurance to encourage businesses to actively participate in this green revolution.

Green finance is an emerging field, and researchers regard it as an important solution for achieving energy security and sustainable development objectives. In contrast to conventional finance, green finance requires lenders to consider environmental protection during the loan decision-making process as well as in post-monitoring and risk management. Unlike the proper noun ``Internet finance,'' ``Fintech'' downplays the significance of the Internet and emphasizes applying new technology in traditional financial operations (Goldstein et al., 2019). The Financial Stability Board (FSB) defines Fintech as technologically driven financial innovation that significantly impacts financial markets, institutions, and services by introducing novel applications, processes, or products (Zhou et al., 2022). Fintech is currently being applied across six key financial sectors: payment processing, loan financing, wealth

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management, retail banking, insurance, and transaction settlement. These cutting-edge financial technologies encompass artificial intelligence, blockchain, cloud computing, big data, and more.

The terminologies ``green finance'' and ``financial technology'' are both relatively new and have not been extensively explored within the academic community. Moreover, there is a noticeable dearth of direct research papers investigating the relationship between these two concepts. However, it is imperative to acknowledge the critical role of green finance in China's pursuit of a sustainable, environmentally friendly economic transformation. To achieve this transition successfully, it is essential to gain a comprehensive understanding of the factors that drive the development of green finance.

On the other hand, financial technology, often referred to as Fintech, comprises a suite of cutting-edge scientific and technological applications integrated into the financial industry. A comprehensive exploration of how Fintech influences green finance not only addresses this research gap but also carries substantial practical implications. Such an inquiry has the potential to significantly inform government policy formulation pertaining to sustainable finance and guide the strategic development of the banking sector.

In this paper, we propose that Fintech has the potential to positively influence the advancement of green finance. Our assertion stems from a dual perspective. Firstly, Fintech plays a pivotal role in enhancing banks' customer identification processes, thereby mitigating information asymmetry and enhancing risk management capacities within the banking sector (Wang et al., 2023a). Secondly, it significantly amplifies banks' outreach by providing diversified marketing channels to tap into new customer segments (Hornuf et al., 2021) and concurrently curtails their operational expenses, leading to a noteworthy augmentation in the banks' overall profitability (Wang et al., 2021b). Consequently, these dynamics are compelling banks to increasingly extend credit loans towards environmentally sustainable ventures. To prove this hypothesis, we employ a two-way fixed effects regression model, utilizing panel data obtained from 59 Chinese listed banks spanning the years 2011 to 2020.

This paper contributes to the literature in the following ways: (1) Novelty of the Topic. This study contributes a unique perspective to the existing literature. While some studies have explored the impact of Fintech development on environmental protection or the green economy, few quantitative research studies have specifically examined the relationship between Fintech and green finance, particularly from the viewpoint of banks (Zhou et al., 2022). (2) Creation of a bank-level Fintech development index. So far, existing researches on the Fintech index mostly adopt the Peking University Digital Inclusion Index (Deng et al., 2021; Qiu et al., 2018) or Baidu Index (Wang et al., 2021a). However, their samples are either at city level or country level respectively, hence potentially leading to inaccurate and unreliable data results for analyzing individual bank samples. Only a small number of researchers use the bank-level Fintech index, although they use text mining method to collect the original data of Fintech, their result is not accurate as they do not lock the keywords in the headline of the news and they are directly using the number of relevant news searches provided by Baidu (Cheng and Qu, 2020; Pin and Yue, 2016; Li et al., 2022). Our index construction method is based on existing text mining methods and has been improved on them. Firstly, we limit the keywords to the title of the search news, rather than being able to be retrieved as long as the keywords appear anywhere in the main body of the news. Secondly, we manually collect the release time of each news and categorize it into each year, instead of directly using the search news quantity provided by Baidu, which is not accurate. The accuracy of the Fintech index constructed by the improved text mining method will be much higher than before, making our research results more trustworthy. (3) Investigating the influential mechanism of Fintech on green finance. In addition to endogeneity and robustness tests we also tested the influential mechanism and heterogeneity to better measure the impact of Fintech development on the growth of green finance. We discovered that Fintech impacts the growth of green finance by enhancing banks' capacity for risk management and operational efficiency.

The paper is structured as follows: Section two outlines the theoretical framework and research hypotheses after conducting a review of pertinent literature. Section three presents the construction of the Fintech index, while section four details the research design, encompassing the sample, data source, variable selection, and econometric modelling. Section five presents the research results. Lastly, section six summarizes the research findings and implications.

2. Literature review and hypotheses development

2.1. Green finance

The idea of green finance was originally proposed in Sweden and Germany in the 1970s as people there progressively understood the importance of environmental preservation for long-term economic growth (Irfan et al., 2022). With the adoption of a series of agreements, including the Paris Agreement, the Sustainable Development Goals (SDGs), and the Sendai Framework for Disaster Risk Reduction, more and more academics believe that green finance could be an effective strategy for addressing the problems associated with global climate change. According to the conception proposed by the People's Bank of China in August 2016, green finance refers to the financial services for investments, operations, and risk management in areas like energy conservation, environmental protection, clean energy, and green infrastructure. The goal is to support environmental enhancement, address climate change, and optimize resource usage.

Existing theoretical and empirical research have examined the macro- and micro-level influential factors of green finance. In terms of macro-level factors, researchers have examined the government supervision, legislation, policy and financial market. Strict government supervision of the green financial market can reduce information asymmetry and moral risk. Government supervision can require companies to disclose accurate and reliable information about environmental impact, sustainability practices, and green investments. This disclosure enables investors to make informed decisions and reduces information asymmetry between companies and investors (Li et al., 2020b). In addition, green finance is significantly impacted by governmental legislation. For example, China's ``Green Credit Guidelines'' legislation has severely reduced the capacity of high-polluting companies to finance their debt, increasing approval requirements for green credit (Liu et al., 2019). The central bank's mandate to incorporate green finance policies into bank legislation will greatly promote sustainable economic development and decrease climate risk (Dikau and Volz, 2021). Furthermore, China's green credit policy plays a significant role in the development of green finance, enabling China to emerge as a global leader in this field. It has facilitated the integration of environmental considerations into the lending decisions of financial institutions, fostering the transition to a low-carbon and sustainable economy (Zhang et al., 2021a). From the perspective of the total loan amount, the green credit policy enables green enterprises to obtain more credit resources than polluting enterprises (Zhou et al., 2022). The progress of green finance is significantly impacted by financial markets, including commodities and the US securities market. Returns and fluctuations within these financial markets play a crucial role in influencing the trajectory of green finance (Naeem et al., 2022). Furthermore, Karim et al. (2022a) have posited that green bonds, being one of the pivotal green financial tools, exhibit a consistent positive correlation with financial markets, playing a prominent role both before and after the onset of the COVID-19 pandemic.

Compared to the macro-level factors, some studies have found that there are still some micro-level factors influencing the development of green finance, such as technology innovation, green technology and collaboration among investors. Financial science and technology innovation plays a significant role in improving the development level of green finance financial science and technology and has great reference significance for most countries (Zhou et al., 2022). Information and communication technology such as digital platforms, crowdfunding portals, and mobile applications can connect investors directly with green projects, stimulating the growth of the green finance market and increasing its stability (Zhang et al., 2022). In addition, distributed ledger technologies improve transparency in green finance, which is important since green finance is connected to a series of sustainable development objectives (Taghizadeh-Hesary and Yoshino, 2019). Green technology innovation is also very important for financial development, including financial structure, financial scale, and financial efficiency (Lv et al., 2021).

In short, the development of green finance is affected not only by macro factors such as government regulation, government policies, and green credit but also by micro factors like basic technology and investor cooperation. As a result, the government needs to pay attention to the many factors that could shape the future of green finance.

2.2. Fintech

The development of emerging Fintech technologies such as big data, cloud computing, blockchain, and artificial intelligence is developing fast and changing the way people learn, live, and work. An increasing number of academics have started looking at the development of Fintech and its effect on individuals, companies and societies.

According to Thakor (2020), individuals can now use robo-advisors and wealth management software, resulting in more efficient investment/saving decisions and lower transaction costs as well. Bollaert et al. (2021) argued that Fintech has opened up new investment opportunities for individuals in loan areas and enabled consumers to make transactions seamlessly. Erel and Liebersohn (2022) and Balyuk (2023) stated that Fintech has made it possible for underserved populations to access financial services that were previously unavailable to them through mobile payments, digital lending, and other innovative financial products that cater to the needs of a broader customer base. In conclusion, with the advancements in technology, Fintech has created a convenient and accessible environment for individuals to manage their wealth, ultimately affecting their daily lives.

Fintech can also improve corporate financing efficiency and business processes by bringing emerging digital technologies into traditional financial companies. Bollaert et al. (2021) proposed that Fintech can aid enterprises in achieving their financing goals in the primary and secondary markets. In addition, Wang and Tan (2021) claimed that Fintech can utilize cutting-edge technologies such as artificial intelligence, big data, cloud computing and blockchain technologies to enhance financial service efficiency. Zheng et al. (2020) claimed that blockchain technology as one of the financial tools of Fintech can be utilized to construct a smart contract system to realize automatic execution of accounts payable, which can significantly improve operating efficiency and reduce operating cost. Karim et al. (2022b) believes that Fintech offers effective solutions for small and medium-sized enterprises (SMEs) in ASEAN countries. Particularly during the pandemic, Fintech has alleviated financial constraints for SMEs, expanded marketing channels for online goods, and diversified payment methods for the digital economy.

Fintech possesses the potential to influence for our society, such as job opportunity, cost-efficiency, financial access, social connectivity, and financial biases (Lagna and Ravishankar, 2022). However, the advancement of Fintech is accompanied by several societal challenges, encompassing privacy concerns, cybercrime, financial disruption, widening economic disparities, and complexities related to regulatory compliance (Naz et al., 2022).

2.3. The influence of Fintech on green finance

Existing research provides limited evidence regarding the relationship between Fintech and green finance. Given the pivotal role of the banking industry in finance and its support for Fintech development, this study delves into understanding how Fintech has impacted green finance, particularly from the perspective of banks. Among the array of green finance instruments, green credit holds paramount significance in China due to its substantial transaction volumes and rapid growth rate. In 2021, the scale of green credit in China had surged to US$227.1 billion, marking a fivefold increase from the levels observed in 2012 (Shao et al., 2021). Governments employ green credit to channel funds into green industries and incentivize financial institutions to allocate resources appropriately (Zhang et al., 2021b). Given the significance of green credit as a primary green financial tool, this paper endeavors to unravel the progression of green finance by studying the evolution of green credit.

The impact of Fintech on banks encompasses two primary theoretical foundations: competitive effects and technology spillover effects. As for competitive effects, the proliferation of Fintech companies has significantly intensified competition for banks, as they offer a diverse range of appealing products such as mobile banking services, digital wallets, peer-to-peer lending platforms, and robo-advisory services. For instance, Boot et al. (2021) highlighted that Fintech has effectively lowered the barrier to entry for financial services, enabling new competitors to emerge and capture market share from established players in the banking sector, based on their survey of German households. Li et al. (2020a) suggest that Fintech may elevate the risk levels for traditional financial institutions, potentially resulting in systemic risk. Consequently, banks are confronted with various challenges and have to reduce green credit issues to ensure sustainable operations.

However, Fintech has its technology spillover effect and prompts the development of green finance. For example, Le et al. (2021) believed Fintech, as a new market participant, can play a unique and positive role in promoting green bond development, which is essential for portfolio diversification. Goodell et al. (2022) found that financial technologies, such as machine learning and artificial intelligence, can promote funds allocated into green projects and concluded that Fintech is strongly correlated with green indices.

The theory of technology spillover effect can shed light on the intricate relationship between Fintech and the development of green credit within the financial landscape. The spillover effect is a phenomenon where advancements in one sector or domain inadvertently benefit or influence another sector positively (Ning et al., 2023). In this context, advancements and innovations within the Fintech sector spill over into the realm of green finance, particularly green credit.

Firstly, Fintech excels in utilizing advanced analytics and data-driven insights to assess risks and make informed decisions. This expertise spills over into green credit operations, allowing banks employ data analytics for precise risk assessment in the context of green credit projects (Hung et al., 2020). This also can mitigate information asymmetry and significantly reduces credit risk in Chinese commercial banks (Cheng and Qu, 2020; Wang et al., 2023b; Demir et al., 2022). This helps banks identify ``dyed green'' or ``fake green'' projects, thereby accelerating the allocation efficiency of green credit and improving the service quality of green credit (Yuan et al., 2021).

Secondly, Fintech often introduces innovative services and products enabled by technology, such as mobile payments, peer-to-peer transfers, or robo-advisors (Ding et al., 2022). Traditional banks, recognizing the demand for these services, incorporate similar offerings into their portfolio and amplifies their outreach by providing diversified marketing channels to tap into new customer segments (Hornuf et al., 2021). For example, Fintech can expand marketing channels for online goods, and diversify payment methods for the digital economy to remain competitive and meet evolving customer expectations (Karim et al., 2022b). These emerging customer segments are expected to augment the bank's sales revenue. This will make banks more capable of issuing green credit.

Lastly, Fintech innovations often result in cost reduction due to automation and streamlined processes. This spillover effect contributes to making green credit more accessible by minimizing administrative costs and rising overall profitability (Wang et al., 2021b; Lee et al., 2021; Demir et al., 2022). Reduced operational expenses enable banks to offer green credit at competitive rates, encouraging greater participation from both businesses and individuals in environmentally friendly ventures.

Therefore, although the competitive effect has significantly intensified pressure on banks, compelling them to scale down high-risk green credit projects in order to sustain their operations. The technology spillover effect has catalyzed enhancements across various capabilities within banks, spanning risk management, market sales, operations, innovation, and more. Consequently, this positive influence instils greater confidence and capacity in banks to proactively engage in and expand their portfolio of green credit projects. Based on these characteristics, we propose the following hypothesis:

Hypothesis 1. Bank Fintech can significantly facilitate the growth of green finance.

2.4. Influence mechanism

With the help of Fintech tools, banks can now analyze vast amounts of customer data and financial transactions to identify patterns, trends, and anomalies that might pose a risk to their operations. Fintech can also enable banks to monitor risks by implementing fraud detection algorithms, to identify and prevent fraudulent activities such as phishing, hacking, or identity theft in real-time (Hung et al., 2020). Moreover, Fintech solutions can automate many of the risk management processes, making them faster, more accurate, and less prone to errors. This, in turn, can reduce the need for human intervention in decision-making, thereby minimizing the possibility of human error or bias (Das, 2019). Further, Fintech can reduce information asymmetry and improve the identification ability for green credit projects since information disclosure can effectively reduce risks and improve risk control ability (Cheng and Qu, 2020; Wang et al., 2023b; Demir et al., 2022). Banks with enhanced risk management capabilities excel in assessing the creditworthiness and credit risk associated with green projects, effectively discerning between low-risk and high-risk ventures (Bruns and Fletcher, 2008). For instance, banks with enhanced risk control capabilities demonstrate a greater ability to identify `dyed green' or `fake green' projects. Consequently, Fintech has the potential to enhance the efficiency of allocating green credit and improve the overall service quality in the realm of green credit (Yuan et al., 2021). Thus, based on this premise, we propose the following hypothesis:

Hypothesis 2. Fintech can promote the growth of green finance by enhancing banks' risk management capability.

Fintech plays a crucial role in enhancing a bank's operational capabilities by significantly reducing operational costs and driving sales. Through process automation, such as loan underwriting and compliance checks, Fintech greatly improves operating efficiency, minimizing the time and labor costs required for transaction processing (Wang et al., 2021b; Lee et al., 2021; Demir et al., 2022). These cost efficiencies enable banks to extend green credit at competitive rates, thereby encouraging greater participation from both businesses and individuals in environmentally sustainable initiatives. Furthermore, Fintech empowers banks to provide personalized products and services, extending their outreach through diversified marketing channels to tap into new customer segments (Hornuf et al., 2021; Karim et al., 2022b). By broadening sales channels and expanding outreach, Fintech assists banks in reaching a wider customer base, allowing for the issuance of more green credits to individuals and businesses previously unaware of such offerings. Therefore, we propose the following hypothesis:

Hypothesis 3. Fintech can promote the growth of green finance by boosting banks' operation capability.

Building upon the proposed assumptions 2 and 3, along with the analysis provided above, we have developed Fig. 1 to illustrate the transmission path depicting how Fintech influences green finance.

Considering the pressing concerns of climate change and environmental challenges, in-depth Fintech research on green finance is imperative. Our objective is to bridge this research gap by examining three hypotheses related to Fintech and green finance. By advancing our comprehension of this subject, these hypotheses have the potential to shape policies and practices in China, expediting the journey towards a sustainable financial system. We aspire that the insights from our study will effectively guide key stakeholders, thereby playing a vital role in propelling the ongoing transition towards a sustainable financial landscape in China.

3. Construction of Fintech index

This section explains the construction method of the Fintech index. We utilise data mining techniques to extract information from unstructured text data sources through the web crawler method. Firstly, we identified 30 keywords of Fintech. Next, we count the annual number of news whose headlines comprise key phrases from the Baidu site because the number of Fintech-related news can directly reflect the importance of enterprises on Fintech. Finally, we calculate the weight of each keyword indicator and construct the Fintech index using the entropy approach.

3.1. Selection of Fintech keyword phrases

According to the definition of the Basel Committee on Banking Supervision (BCBS, 2018) and the development situation of the Chinese market, we collected 30 keywords about Fintech and divided them into five categories. The detailed keywords are shown in Table 1:

Next, we combined these 30 keywords with each of the 59 banks, one by one, to form 1770 keyword phrases. All bank names are listed in Appendix A.

3.2. Refining search

In the second step, we type the keyword phrase in the Baidu search engine and tick ``news'' to filter out non-news search results, such as pictures, videos, forums, text libraries, etc. For example, we type the following words "intitle: Industrial and Commercial Bank of China +Big Data" into the Baidu search engine and tick the "news" and "search" icons. Then we will get relevant search results which are similar to Google. The word ``intitle'' is added to limit the keyword group in the news to only appear in the title. In other words, when the keyword group only appears in the news body, not in the title, such news will not be retrieved. The symbol "+" is added to ensure the news headline contains both the keyword of Fintech and the bank name.

To automatically finish the above job, we write code and use Python to search for news, extract the release time of news, divide news by year, and compute the number of news each year to get the annual data of 1770 keyword groups between 2011 and 2020. The web crawler program is edited and debugged through 86 lines of code. We have used Python official modules and third-party modules, including Requests, Urlib, Beautiful Soup, Random, Time, Pandas, and others.

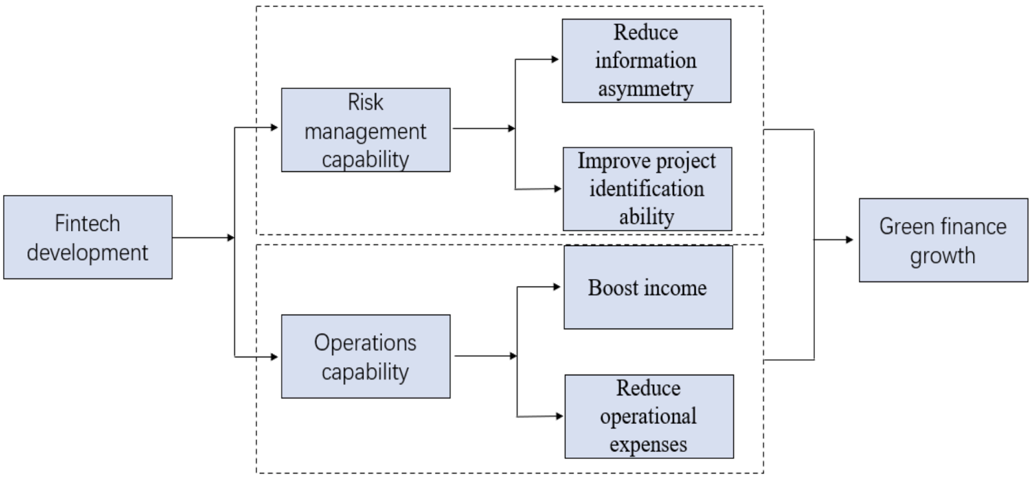

Fig. 1. The influence path of Fintech development on green finance growth.

Table 1
Keywords of Fintech.

Fields	Keywords					
Basic technology	Big data	Fintech	Cloud computing	Blockchain	AI	Digitisation
Technology application	Face recognition	QR code	Intelligent investment advisor	Intelligent robot	Intelligent risk control	Digital currency
Application platform	Mobile bank	Smart bank	Internet bank	Cloud platform	Internet	Mobile internet
Payment settlement	Phone payment	Online payment	Mobile payment	Cloud flash payment	Third-party payment	WeChat payment
Deposits, loans, and insurance	Online loan	Network finance	Supply chain finance	Online finance	Inclusive finance	Online insurance

We have employed the Requests module to send HTTP requests and receive a Response Object containing response data such as content, encoding, and status. This module effectively emulates a user's request to access a website from a web server. Additionally, we have utilized the Urllib package, which is a Python module for URL handling, to fetch Uniform Resource Locators (URLs). The package is used to encode Chinese keywords into binary code for subsequent data analysis. For parsing HTML and XML documents from websites, including those with malformed markup, we have utilized the Beautiful Soup Python package. This package creates a parse tree that enables data extraction from HTML, making it valuable for web scraping purposes.

To circumvent the Baidu website's defence mechanism, an anti-crawler program is set up using the Random and Time modules. This program randomly specifies a sleeping task for a certain number of seconds before sending the next request. The Time module provides functions for handling time-related tasks, while the Random module generates random numbers within Python. Finally, we employed the Pandas Python package to facilitate the transformation of data results from Pycharm format to Excel format. Pandas module is known for its efficiency, flexibility, and support for working with labelled and relational data, making data manipulation more intuitive.

3.3. Build the Fintech index

Measurement of indicator weight is very important for building the index. The common measurement methods include the entropy method, principal component analysis, analytic hierarchy process, and expert consultation method. The entropy method is more objective and reliable compared to other methods since the method measures the indicator weight by calculating their degree of dispersion and entropy value, it gives greater weight to the indicators with greater dispersion and smaller entropy value. Therefore, we used the entropy method to measure the weight of 30 indicators and calculate the Fintech score. Besides, Entropy serves as a metric of uncertainty in information theory. The influence of the indicator on the overall assessment is stronger when information volume increases, uncertainty decreases, and entropy decreases. The entropy approach involves the following specific calculation steps:

(1) in the sample, we assume that the number of the year is h, the individual is m, the evaluation indicator is n, and X_{tij} is the value of the indicator j of the city i in the year t.
(2) Standardize the data using the minimum-maximum method. Given that all 30 indicators are positive, there is no consideration for standardizing negative indicators in this context.

$$Z_{tij} = \frac{\left(X_{tij} - X_{\min}\right)}{\left(X_{\max} - X_{\min}\right)} \text{ (Positive indicators)}$$

In the formula, the value of t is equal to 1, 2, 3, …, h and the value of i is equal to 1, 2, 3, …, m. h and m are the total number of the time and the individual respectively. X_{tij} and Z_{tij} are the value of indicator i before and after the normalization process, respectively.

(1) Use the method of normalization with dimensionless parameters to process all the indicators.

$$P_{tij} = Z_{tij} \bigg/ \sum_{t=1}^{k} \sum_{i=1}^{m} Z_{tij}$$

(2) Identify each indicator's entropy value.

$$E_j = -k \sum_{t=1}^{k} \sum_{i=1}^{m} lnP_{tij}$$

$$k = 1/m(h \times m)$$

(3) Determine each indicator's redundancy.

$$D_j = 1 - E_j$$

(4) Determine each indicator's weight.

$$W_j = D_j \Bigg/ \sum_{j=1}^{n} D_j$$

(5) Calculate each indicator's yearly value after the weighting adjustment.

$$C_{tij} = P_{tij} \times W_j$$

(6) Add up the values of all indicators of one individual in one year to get the panel data of Fintech.

$$Fintech_{ti} = \sum_{j=1}^{n} C_{tij} \times 100$$

4. Study design

4.1. Sample and data source

We used panel data from all mainland Chinese and Hong Kong listed banks from 2011 to 2020. There are a total of 59 banks here, 15 of which are listed in both the Chinese Mainland and Hong Kong, 27 in the former, and 17 in the latter.

There are two key reasons for selecting these 59 Chinese listed banks as research samples. Firstly, these 59 banks are all listed banks in China, accounting for 83 % of total assets and 91 % of net profit in the banking industry. They can represent the overall development of China's banking industry, and they are the core components of China's financial system. Most of the current papers only study the banks listed in Chinese Mainland, and do not take into account the banks listed in Hong Kong. Therefore, this study contributes to a more comprehensive study of the impact of Fintech on China's banking industry. Secondly, China has one of the largest and most diversified banking systems in the world, and the Chinese government has been encouraging the development of green finance by promoting the active participation of financial institutions in sustainable development through policies, guidance, and incentive measures. Therefore, studying listed banks in China can help explore the contribution of Fintech development to global sustainable development.

We manually collected the data for the green finance variable from Environmental, Social and Governance (ESG) Reports posted on 59 banks' official websites. For the Fintech index, we used Python to obtain the original data and employed Stata to construct the index. Section 4.2.2 provides a detailed description of the construction method. Additionally, we obtained the banks' patent information from the Chinese Research Data Services (CNRDS) database. We also acquired data for the control variables from the IFIND and WIND databases. To handle missing data, we used the linear interpolation method, which estimates the original function by calculating known points on the line to obtain the approximate value of the missing data. We then used the Winsorize method to alleviate the problem of extreme values greater than 97.5 % or less than 2.5 %.

4.2. Variable selection

4.2.1. Green finance

We use green credit to represent green finance because green credit has the largest trading scale and the most mature trading system compared to other green financial instruments, like green bonds, green stocks, and green insurance (Shao et al., 2021). In addition, as compared to the insurance and securities industries, banks have a far more prominent position in China's green financial system. When it comes to green finance, the degree of development is directly proportional to the amount of green credit offered by banks. The unit of measurement of green credit is 1 billion yuan.

4.2.2. Fintech

We used a Python-based web crawler to collect keyword frequencies and construct the Fintech index as this text-mining method can extract precise and valuable information from unstructured data sources. Specifically, we first identified 30 Fintech keywords and matched them with the 59 banks' names, resulting in 1770 pairs of keyword phrases. We then counted the number of news articles related to these keyword phrases on the Baidu website. To ensure relevance and effectiveness, we only considered keyword phrases that appeared in news headlines. Next, we measured the level of attention that the 59 banks paid to Fintech using the number of news articles with key phrases. After obtaining the frequency of each of the original keyword phrases, we computed the weight of each keyword indication and developed the Fintech index via the use of the entropy approach. The appendix provides a detailed description of the construction steps for the Fintech index.

4.2.3. Mediator variable

We use the capital adequacy ratio (CAR) which is measured by the ratio of total capital to total risk-weighted assets to reflect banking risk management capabilities since it reflects the extent to which a commercial bank can bear losses with its own capital before the assets of depositors and creditors suffer losses (Cummings and Durrani, 2016). A greater CAR suggests that a bank has a stronger capital cushion to absorb losses and is less likely to fail in the face of unfavourable economic circumstances. The CAR also has the backing of the regulatory framework that was developed by the Basel Committee on Banking Supervision. This framework establishes minimum capital requirements for banks depending on the risks that those banks are exposed to. Given that banks with greater levels of capital are better equipped to absorb losses and preserve financial stability, the framework mandates banks to keep larger amounts of capital for riskier assets.

In addition, we use the net profit ratio (NPR) to represent banking operations capability, because it can measure how effectively a company can convert its sales revenue into net profit. The NPR is calculated by dividing a bank's net profit by its revenue. According to the Resource Based View (RBV) theory, a company's operations capability refers to its ability to manage resources, control costs, and maximize revenue over a period of time (Nath et al., 2010). Therefore, NPR is directly related to the company's operation capability, as it reflects how efficiently the company manages its resources, controls its costs, and maximizes its revenue streams. A high net profit ratio indicates that the company is operating efficiently and effectively, utilizing its resources to generate maximum profits. In contrast, a low net profit ratio suggests that the company may have operational inefficiencies, such as high operating costs, low sales volume, or inadequate pricing strategies. Therefore, the net profit ratio is a useful measure of a company's operations capability.

4.2.4. Control variable

Previous studies have identified several factors that affect the development of green finance, including bank size, leverage level, business diversification, and customer concentration. To sharpen the estimates of our variables of interest, we controlled for the above factors. Firstly, we controlled for total assets to mitigate the effect of bank size differences on green finance (Cubillas and González, 2014). Further, we regulate the equity multiplier to alleviate the influence of varying financial leverage on green finance. This ratio is calculated as the total assets divided by the total equity (Berger and Bouwman, 2017; Diamond and Rajan, 2012). Next, we controlled for the non-interest income rate to alleviate the impact of varying business diversification capability of banks on green finance (Demirgüç-Kunt and Huizinga, 2010). Finally, we incorporate the variable of the concentration ratio of loans from the top ten customers of the bank into the regression model to prevent the customer concentration ratio from affecting the outcome of our regression.

4.3. Econometric model

We adopted three tests to determine a suitable method for the regression analysis, including the Fisher test, the Lagrange Multiplier test, and the Hausman test. Since the findings show the *P*-value for the F test, LM test, and Hausman test are all smaller than 5 %, we opted for the fixed effect model rather than the random effect model or pool regression model. In order to test the effects of Fintech on green finance and to verify hypothesis 1, we developed the following regression model 1:

$$\mathrm{GC}_{it} = \alpha + \beta_1 \mathrm{FT}_{it} + \beta_2 \mathrm{SIZE}_{it} + \beta_3 \mathrm{EM}_{it} + \beta_4 \mathrm{NIIR}_{it} + \beta_5 \mathrm{CCR}_{it} + \mathrm{Bank}_i + Y_{\mathrm{ear}} + \varepsilon_{it} \tag{1}$$

In this regression model, we use the term GC_{it} to represent the amount of green credit for bank *i* in the year *t*, while FT_{it} refers to the Fintech development level for bank *i* in the year *t*. Additionally, the term α represents the constant term, and it represents the value of GC_{it} when all of the independent variables are zero. β1, β2, β3, β4 and β5 are the regression coefficients for each of the independent variables, and they represent the adjustment in GC_{it} caused by a shift of one unit in each independent variable while maintaining all other variables constant. ε_{it} is the random error term that captures the variability in the data that is not explained by the independent variables in the model.

Table 2
Descriptive statistics.

Variable	Observation	Mean	Std. Dev.	Minimum	Maximum
GC_{it}	590	67.46	184.02	0.00	896.80
FT_{it}	590	5.06	8.13	0.00	34.22
CAR_{it}	570	13.20	1.52	10.60	16.88
NPR_{it}	567	34.53	7.54	5.53	48.40
$SIZE_{it}$	585	6.41	1.63	4.03	10.00
EM_{it}	585	14.71	2.66	10.52	21.49
$NIIR_{it}$	574	16.02	11.21	0.13	42.29
CCR_{it}	497	27.51	12.47	8.53	59.20

Note: The descriptive statistics are provided for the dependent, independent and control variables and cover the period from 2011 to 2020. All variables are defined in Appendix B.

5. Test result and analysis

5.1. Descriptive statistics

The descriptive statistics for the variables are summarised in Table 2, which includes the average, standard deviation, minimum, and maximum values for each category.

Table 2 presents descriptive statistics on nine variables, namely GC_{it}, FT_{it}, CAR_{it}, NPR_{it}, $Size_{it}$, EM_{it}, $NIIR_{it}$, and CCR_{it}. The mean values of these variables demonstrate a wide variation, with FT_{it} having the lowest mean of 5.06, and GC_{it} having the highest mean of 67.46. Furthermore, the standard deviations of these variables also display a large variance, with CAR_{it} having the smallest standard deviation of 1.52 and GC_{it} having the largest of 184.02. Also, the minimum and maximum values for green credit and Fintech are very different. For Fintech, the minimum value is 0 and the maximum value is 34.22, while the minimum value for green credit is 0 and the maximum value is 896.8. These figures suggest an imbalance in the structure of green credit and Fintech and significant variation in these variables across different banks. Therefore, it is valuable for us to conduct a heterogeneity test to examine the distinct impacts of Fintech on green credit in banks.

5.2. Benchmark regression result

We used a method of gradually adding control variables to the original model and obtained three regression results, which are presented in Table 3. In the first regression model (column 1), we did not add any control variable. In the second regression model (column 2), we added balance sheet items such as asset size and equity multiplier as control variables. Finally, in the last regression model (column 3), we continued to add the non-interest income ratio and customer concentration ratio as our control variables. To minimize the influence of heteroscedasticity, we also used robust standard error in all three regression analyses.

In column (1), without control variables, FT_{it}'s coefficient is 8.73 and highly significant at the 1 % level. This means that Fintech development has a positive and significant effect on green finance. After the control variables SZ_{it} and EM_{it} are added to the model, the result is unchanged and is shown in column (2). From the fitting result of column (3) after further adding control variables $NIIR_{it}$ and CCR_{it}, the result remains unchanged. The green credit of banks tends to increase by 7.97 % for the rise of 1 % Fintech development level. This is because, on one hand, Fintech can enhance banks' ability to identify customers, reducing information asymmetry and improving the banks' risk management capabilities (Wang et al., 2023a). On the other hand, Fintech can broaden banks' marketing channels to reach new customers (Hornuf et al., 2021), and decrease their operating costs, ultimately boosting the banks' profits (Wang et al., 2021b). Due to these factors, banks are increasingly inclined to extend credit loans to green industries. Overall, All three columns' results in Table 3 show that the development of Fintech significantly boosts the expansion of green credit.

5.3. Endogeneity test

The initial regression results point to a positive influence of Fintech on green finance. However, recent studies have revealed a reciprocal relationship, wherein green finance can also impact Fintech and technological innovation. For example, Guo et al. (2023) argued that bank credit can mitigate both internal and external financing constraints for companies, consequently fostering their technological innovation. Additionally, Du et al. (2022) observed that green finance plays a constructive role in stimulating the technological innovation and enhancing the financial performance of green enterprises, especially in regions marked by high levels of green development or marketization. Furthermore, due to challenges related to data availability, the Fintech variable may contain

Table 3
Benchmark regression results.

Variable	(1) GC_{it}	(2) GC_{it}	(3) GC_{it}
FT_{it}	8.73***	7.63***	7.97***
	(4.38)	(4.45)	(4.25)
$SIZE_{it}$		−86.63***	−96.09**
		(−2.83)	(−2.64)
EM_{it}		−1.49	0.66
		(−0.60)	(0.37)
$NIIR_{it}$			−0.95**
			(−2.12)
CCR_{it}			0.13
			(0.42)
Constant	11.87	527.25***	532.96***
	(0.87)	(3.24)	(2.90)
Bank FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observation	590	585	489
Adj.R^2	0.39	0.42	0.50

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses represent the value of *t*.

measurement errors, potentially establishing a connection between Fintech and unobservable variables affecting green credit. Hence, a potential endogeneity concern arises from the possibility of a reverse causality relationship between Fintech and green finance. Therefore we employ the instrumental variable method and utilize a lagging term of the Fintech variable to replace the original one, in order to mitigate the potential endogeneity problem.

The requirement of instrumental variables estimation is that they must be related to explanatory variables, but not to random error terms or control variables. Following Ding et al. (2022), we selected geographic location as the instrumental variable. Instead of using the distance between cities, we focused on the average distance between the bank headquarters and the top 3 Fintech companies in China, including Baidu, Alibaba, and Tencent. These three Fintech companies are collectively referred to as BAT. This peer-to-peer relationship makes the data more reliable and effective (Ding et al., 2022). BAT has played a pivotal role in driving the development and growth of Fintech (Fintech) in China. BAT has not only facilitated the transition from cash-based to digital payments in China but has also driven innovation in various Fintech areas, including digital banking, AI-powered financial solutions, and wealth management. Their diverse digital ecosystems, strong technological capabilities, and vast user bases have been instrumental in shaping the Fintech landscape in China and have allowed them to become major players in the country's Fintech landscape. BAT is crucial for banks as they enable better risk assessment, fraud detection, and personalized services, and they have leveraged their strong market position to promote technologies to banks. As a result, banks closer to BAT should benefit more from the Fintech spillover effect. The driving distance data between each bank and BAT were manually collected from the Amap database, a top provider of digital maps, navigation, and location services in China.

The fundamental samples of this article are data that varies with time and bank, however, the average distance between banks and BAT is a constant variable. To make the instrumental variables meet the characteristics of time and bank, we have established a novel instrumental variable, which is calculated as the average distance between the target bank and the three BAT (Baidu, Alibaba, Tencent) companies, multiplied by the reciprocal of the number of internet broadband users in the city where the target bank is located (Zhou et al., 2022; Luo et al., 2023). We used the reciprocal of internet broadband subscriptions to multiply by the distance term, so that both variables are negatively correlated with the development of Fintech. Essentially, the number of broadband subscribers can help financial institutions to process transactions faster, manage risks more effectively, and also provide faster and more convenient financial services (such as mobile payment and transfer). Therefore, internet broadband subscribers can affect Fintech development and cannot directly affect the growth of green credit. The results are shown in columns (1) and (2) of Table 4.

According to Kennedy et al. (2019), we also adopt the average driving time from BAT to bank headquarters to replace the term driving distance. Because driving time is also related to Fintech but not relevant to green credit, we set up another instrumental variable, which is calculated as the average driving time between the target bank and the three BAT (Baidu, Alibaba, Tencent) companies, multiplied by the reciprocal of the number of internet broadband users in the city where the target bank is located. The results are presented in columns (3) and (4) of Table 4.

In addition to employing the instrumental variable method, we also utilize 1-year lagged Fintech variable to replace the original Fintech variable to mitigate the endogeneity problem, aiming to mitigate the endogeneity issue. The rationale behind this approach lies in the fact that the current term of green finance is unlikely to influence the previous term of Fintech, whereas the previous term of Fintech can indeed influence the current term of green finance (Zhou et al., 2022). The corresponding results are presented in column (5) of Table 4.

Columns (1) and (3) of Table 4 show that the coefficient estimates of the instrumental variable (IV) are significant at the 1 % level, indicating that both IVs significantly negatively impact the development of Fintech. Column (2) and (4) of Table 4 shows that after dealing with the endogeneity problem, Fintech can still significantly positively promote the growth of green credit at the level of 1 %.

Furthermore, all 2sls regression results have successfully passed the underidentification and weak instrumental variable tests. Initially, they clear the underidentification test, as indicated by the Chi-square (χ^2) statistics with *P*-values of 0.0000, showcasing significance below the 0.01 threshold. Moreover, the Cragg–Donald Wald F statistics for the weak instrumental variable test are notably high, surpassing the critical value of 8.96, representing the 15 % maximum IV size for the Stock–Yogo weak ID test. This

Table 4
Endogeneity test result.

Variable	(1) FT_{it}	(2) GC_{it}	(3) FT_{it}	(4) GC_{it}	(5) GC_{it}
IV_{it}	−0.0014***		−0.1346***		
	(−3.80)		(−3.80)		
FT_{it}		27.2216***		26.9822***	
		(4.48)		(4.53)	
$L.FT_{it}$					6.3255***
					(3.38)
$Controls_{it}$	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observation	489	489	489	489	453
Kleibergen–Paap rk LM statistic *P*-val	0.0000	0.0000	0.0000	0.0000	
Cragg–Donal Walf F statistic	28.92	28.917	29.05	29.046	

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses in columns (2) and (4) represent the value of *z*, while the numbers in parentheses in columns (1), (3) and (5) represent the value of *t*.

unequivocally affirms their adherence to the criteria of the weak instrumental variable test.

5.4. Robustness analysis

To assess the robustness of the regression findings, we modified the sample interval and variables and regressed the data again. Firstly, we changed the sample interval from 2011 to 2020 to 2013 to 2020. In China, the development of green credit has a relatively brief history. The concept of green credit first emerged in 2007, but it was not until 2013 that the Banking Regulatory Commission began mandating that China's state-owned banks collect statistics and report green credit data biannually. Consequently, the green credit data for banks in 2011 and 2012 is largely missing. To mitigate the effects of missing data, we excluded sample data from 2011 to 2012 and conducted a regression analysis on 59 bank samples from 2013 to 2020. The result is shown in Table 5.

Based on the results from Table 5, we can infer that, after excluding the samples from 2011 to 2012, which had significant data gaps, Fintech consistently exhibits a positive impact on the development of green finance across three different sets of control variables, significant at the 1 % level. This further corroborates our fundamental regression findings.

Considering that our sample consists of 42 banks listed on the mainland and 17 banks listed in Hong Kong, we acknowledge that the regulatory framework, green finance policies, customer base, and other factors for banks listed in Hong Kong significantly differ from those listed on the mainland. These distinctions may potentially influence our regression results. Therefore, we conducted a new regression analysis after excluding the 17 banks listed in Hong Kong. Table 6 presents the updated regression results.

After excluding the Hong Kong-listed banks that could potentially affect the regression outcomes, we conducted an analysis focusing on the 42 banks listed in mainland China, and the results are presented in Table 6. The findings from all three columns continue to support our research hypothesis, affirming that Fintech has a positive promoting effect on the development of green finance.

Considering the potential for biases that may arise from the Fintech indicator developed in this study, we chose to incorporate the total number of patents obtained by banks in a given year as an alternative measure to assess the extent of Fintech development in the banking sector. This choice is driven by the understanding that FinTech essentially encompasses financial innovation propelled by technology. Evaluating the level of technological innovation within the financial sector can provide valuable insights into the degree of FinTech advancement (Lai et al., 2023). To mitigate concerns related to heteroscedasticity and the time lag effect associated with patent applications, we opted to utilize the natural logarithm of one plus the FinTech patent applications from the preceding year for each bank. This approach offers a more accurate measurement of the level of FinTech adoption within banks. The outcomes are summarized in Table 7.

From Table 7, we observe that by substituting the original FinTech variable with a FinTech indicator measured using patents, the coefficients for FinTech remain significantly positive across three different control variable scenarios. This further substantiates the reliability of our fundamental regression results and supports our research hypothesis 1, indicating that the development of FinTech can facilitate progress in green finance. According to the results in Table 5, Fintech (FT_{it}) has a significant and positive impact on green credit (GC_{it}) at the 1 % level with coefficients of 6.51 and 0.79, respectively. These figures indicate that banks with a higher Fintech development level tend to provide more green credit, hence supporting Hypothesis 1.

5.5. Heterogeneity analysis

While all the samples in this empirical study are from China's listed banks, there exists a significant variance in bank profitability and bank location among them. To learn more about how Fintech development affects the growth of green credit, this section will look

Table 5
Robustness analysis: different sample intervals.

Variable	(1) GC_{it}	(2) GC_{it}	(3) GC_{it}
FT_{it}	6.91***	6.15***	6.51***
	(4.12)	(4.15)	(3.89)
$SIZE_{it}$		−88.93***	−80.42***
		(−3.09)	(−2.87)
EM_{it}		−1.34	−0.04
		(−0.64)	(−0.02)
$NIIR_{it}$			−0.59*
			(−1.75)
CCR_{it}			−0.18
			(−0.80)
Constant	21.34*	578.40***	507.74***
	(1.80)	(3.44)	(3.27)
Bank FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observation	472	472	409
Adj.R^2	0.37	0.41	0.50

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses represent the value of *t*.

Table 6
Robustness analysis: excluding banks listed in Hong Kong.

Variable	(1) GC_{it}	(2) GC_{it}	(3) GC_{it}
FT_{it}	8.66***	7.22***	7.44***
	(4.33)	(4.34)	(4.40)
$SIZE_{it}$		−125.31***	−121.64**
		(−2.76)	(−2.58)
EM_{it}		−3.23	−1.22
		(−0.88)	(−0.48)
$NIIR_{it}$			−2.21**
			(−2.43)
CCR_{it}			0.82
			(1.15)
Constant	17.82	826.03***	740.18***
	(0.95)	(3.19)	(2.88)
Bank FE	YES	YES	YES
Year FE	YES	YES	YES
Observation	420	420	357
Adj.R^2	0.41	0.45	0.54

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses represent the value of *t*.

Table 7
Robustness analysis: alternative measure of FinTech development.

Variable	(1) GC_{it}	(2) GC_{it}	(3) GC_{it}
FT_{it}	24.97**	21.16***	17.04**
	(2.64)	(2.71)	(2.25)
$SIZE_{it}$		−142.69***	−164.84**
		(−2.72)	(−2.64)
EM_{it}		−1.56	0.57
		(−0.58)	(0.27)
$NIIR_{it}$			−1.29*
			(−1.91)
CCR_{it}			0.40
			(0.91)
Constant	17.58	850.68***	915.73***
	(1.19)	(3.07)	(2.84)
Bank FE	YES	YES	YES
Year FE	YES	YES	YES
Observation	590	585	489
Adj.R^2	0.18	0.28	0.31

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses represent the value of *t*.

at how bank profitability and region differences affect the relationship between Fintech and green credit.

To deal with the disparity of bank profitability, we first categorized the banks into three groups based on their net profit level in 2020. Specifically, the sample is divided into three groups: low net income (low NI), medium net income (medium NI), and high net income (high NI), as shown in columns (1) to (3). Using a two-way fixed effect model, we analyzed the impact of Fintech on green credit across banks with different net income (NI) levels. The regression results are presented in Table 8.

Results in Table 8 show that the level of Fintech development in the high profitability bank group is statistically significant at the 1 % level of confidence. However, the panel regression of the low and medium profitability banks does not show any significant results for the Fintech development level. Overall, the results suggest that the impact of Fintech innovation on green financing varies considerably among banks in terms of their relative profitability.

There are several reasons why Fintech has a greater influence on green credit in banks with high net profit levels than in banks with low or medium net profit levels. Firstly, banks with high net profit levels have more financial resources, enabling them to invest more funds in the research and development of Fintech (Chen et al., 2021). In our sample, the average level of Fintech development in the high-profit banking group is 12.68, significantly higher than 0.96 in the low-profit banking group and 1.91 in the medium-profit banking group. Secondly, banks with high-profit levels have greater capacities to absorb risks associated with green credit due to better customer quality, hardware facilities, and employee quality. Thirdly, they often face greater regulatory pressure from the government, as the shares of these high-profit banks are often controlled by the state. Finally, they pay more attention to the management of their brand image and reputation, so they are more inclined to issue green credit which can effectively showcase and enhance their reputation. Based on the above reasons, every advancement in Fintech of high-profit banks can be more effectively

Table 8
Profitability heterogeneity test.

Variable	(1) Low NI	(2) Medium NI	(3) High NI
FT_{it}	0.05	0.16	4.25***
	(0.33)	(0.83)	(3.33)
SZ_{it}	3.63*	8.57	−241.31
	(1.87)	(1.26)	(−1.71)
EM_{it}	−0.18	−0.54	0.79
	(−0.91)	(−1.15)	(0.08)
$NIIR_{it}$	0.02	−0.06	−6.87**
	(0.62)	(−0.97)	(−2.60)
CLC_{it}	0.06	−0.02	5.44*
	(1.54)	(−0.39)	(1.90)
Constant	−15.07*	−0.02	1890.99*
	(−1.88)	(−0.39)	(1.99)
Bank fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Observation	155	185	149
Adj.R^2	0.35	0.41	0.65

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses represent the value of *t*.

transformed into the driving force for the development of green credit.

To deal with the disparity of bank profitability, we first categorized the banks into three groups based on their net profit level in 2020. Specifically, the sample is divided into three groups: low NI, medium NI, and high NI, as shown in columns (1) to (3). Using a two-way fixed effect model, we analyzed the impact of Fintech on green credit across banks with different net income (NI) levels. The regression results are presented in Table 9.

Additionally, there are notable variances in the scope of Fintech and green finance due to China's unequal economic growth in the eastern, central, and western regions. As a result, the effects of Fintech on banks may vary significantly amongst various regional banks. To handle the heterogeneity of bank regions, we categorized the banks into three groups based on their location in China. Specifically, the sample is divided into three groups: the western region middle region, and eastern region, as shown in columns (1) to (3). We examined the influence of Fintech on green financing across banks with various regions using a two-way fixed effect model. Table 9 displays the results.

Fintech development in the eastern and middle regions of the country significantly has an influence on green finance at the confidence level of 5 %. According to the regression findings for the eastern region, a 1 % increase in Fintech development has resulted in a 7.80 % increase in green credit growth. In contrast, the western region panel regression result is not statistically significant. The overall conclusion is that the impact of Fintech development on the growth of green finance varies widely across different regions.

Table 9
Regional heterogeneity test.

Variable	(1) Western part	(2) Middle part	(3) Eastern part
FT_{it}	0.34	−0.92**	7.80***
	(1.78)	(−3.29)	(4.28)
SZ_{it}	6.35*	−4.56*	−126.38**
	(2.31)	(−2.42)	(−2.45)
EM_{it}	0.08	−0.04	0.11
	(0.19)	(−0.24)	(0.04)
$NIIR_{it}$	0.02	−0.07*	−1.75**
	(0.31)	(−2.23)	(−2.04)
CLC_{it}	0.01	−0.12**	0.31
	(0.05)	(−2.76)	(0.67)
Constant	−30.29*	27.35**	763.52**
	(−2.02)	(3.64)	(2.70)
Bank fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Observation	82	59	348
Adj.R^2	0.57	0.78	0.53

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses represent the value of *t*.

Fintech has a more positive and significant impact on green credit in banks located in the eastern part compared to others for two reasons. Firstly, regulatory frameworks in eastern and middle regions could be more conducive to Fintech development, allowing for more experimentation and rapid adoption of new technologies. Secondly, the level of technological infrastructure in eastern and middle regions could have more advanced technological infrastructure, which could promote banks to leverage the benefits of Fintech, such as faster payment systems and better risk management tools. Based on the above reasons, every advancement in Fintech of eastern banks can be more effectively transformed into the driving force for the development of green credit.

5.6. *Influence mechanism discussion*

To understand how Fintech development impacts green finance, it is essential to further test the impact mechanism of them. To conduct the mechanism test, we select risk management capability and operations capability as the mediator variables of the growth level of green finance. In terms of risk management capability, it is measured by capital adequacy ratio (CAR_{it}) and it reflects the extent to which banks can withstand losses with their capital when loans turn into non-performing assets (Baldwin et al., 2019). Operations capability is measured by the net profit ratio (NPR_{it}), and it can indicate the percentage of business income that can genuinely convert into net profit (Xu and Liu, 2021). In order to clearly assess the impact of Fintech innovation on green growth, we use a causal steps-based method, other than the Sobel test or the bootstrap test. Because the causal steps approach is easy to understand and does not require a normal distribution sample. We established the following recursive equations from model 2 to model 6 to test the mediating mechanism of Fintech development on green finance growth. In these equations, β1 represents the overall influence of Fintech on green credit, while β2 illustrates the impact of Fintech on the mediator variable. If both β2 and β4 are statistically significant in the regression results, it suggests that Fintech influences green credit through the mediator variable. Conversely, if one of them is not statistically significant, it implies that the mediator variable is not valid.

$$GC_{it} = \alpha + \beta_1 \cdot FT_{it} + \sum \beta \cdot Controls + Bank_i + Year_t + \varepsilon_{it} \tag{2}$$

$$CAR_{it} = \alpha + \beta_2 \cdot FT_{it} + \sum \beta \cdot Controls + Bank_i + Year_t + \varepsilon_{it} \tag{3}$$

$$NPR_{it} = \alpha + \beta_2 \cdot FT_{it} + \sum \beta \cdot Controls + Bank_i + Y_{ear} + \varepsilon_{it} \tag{3}$$

$$GC_{it} = \alpha + \beta_3 \cdot FT_{it} + \beta_4 \cdot CAR_{it} + \sum \beta \cdot Controls + \varepsilon_{it} \tag{4}$$

$$GC_{it} = \alpha + \beta_3 \cdot FT_{it} + \beta_4 \cdot NPR_{it} + \sum \beta \cdot Controls + \varepsilon_{it} \tag{4}$$

Table 10
Risk management capability mechanism test.

Variable	(1) GC_{it}	(2) CAR_{it}	(3) GC_{it}
FT_{it}	7.97***	0.03***	7.68***
	(4.25)	(2.97)	(4.34)
CAR_{it}	–	–	9.45**
	–	–	(2.31)
SZ_{it}	−96.09**	−1.11**	−85.56**
	(−2.64)	(−2.58)	(−2.62)
EM_{it}	0.66	−0.33***	3.81*
	(0.37)	(−7.55)	(1.85)
$NIIR_{it}$	−0.95**	−0.01	−0.94**
	(−2.12)	(−0.12)	(−2.12)
CIC_{it}	0.13	−0.04***	0.46
	(0.42)	(−3.00)	(1.16)
Constant	532.96***	25.96	287.74**
	(2.90)	(11.12)	(2.21)
Bank FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observation	489	489	489
Adj.R^2	0.50	0.54	0.51

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses represent the value of *t*.

Table 11
Operations capability mechanism test.

Variable	(1) GC_{it}	(2) NPR_{it}	(3) GC_{it}
FT_{it}	7.97***	0.11*	7.82***
	(4.25)	(1.75)	(4.32)
NPR_{it}	–	–	1.30*
	–	–	(2.00)
SZ_{it}	−96.09**	1.39	−97.82**
	(−2.64)	(0.45)	(−2.65)
EM_{it}	0.66	−0.14	0.62
	(0.37)	(−0.52)	(0.33)
$NIIR_{it}$	−0.95**	−0.01	−1.01**
	(−2.12)	(−0.14)	(−2.06)
CIC_{it}	0.13	−0.13*	0.36
	(0.42)	(−1.47)	(0.88)
Constant	532.96***	36.51**	487.61***
	(2.90)	(2.18)	(2.85)
Bank FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observation	489	480	480
Adj.R^2	0.50	0.35	0.50

Notes: The symbols ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The numbers in parentheses represent the value of *t*.

Firstly, we discussed the capital adequacy ratio as an intermediate variable in the transmission path. The capital adequacy ratio is the ratio of total capital to total risk-weighted assets. It indicates how much loss commercial banks can handle with their own capital before depositors' and creditors' assets face unexpected losses (Baldwin et al., 2019). Table 10 shows the results of the mechanism test for the capital adequacy ratio.

Columns (1) and (2) reveal that Fintech significantly enhances banks' green credit and capital adequacy ratio. Moreover, as depicted in columns (3), Fintech combined with CAR can jointly promote green credit development. Since β1 to β4 in the intermediate effect models are all significant, it confirms that the capital adequacy ratio can play a partial mediating effect in this relationship. The results of Table 10 support hypothesis 2, which posits that Fintech affects the development of green finance by enhancing banks' risk management capability. This optimization occurs because Fintech assists banks in improving identification ability and reducing information asymmetry to identify green projects, resulting in a better understanding of the risk profiles of green projects (Wang et al., 2023a). With enhanced risk management capability, banks are more inclined to allocate loans to green enterprises, despite green credits typically having higher risk and lower returns.

Secondly, we test the mechanism path of net profit ratio (NPR_{it}) as an intermediary variable. The net profit ratio is the proportion of net profit produced from operations in sales that may effectively measure a company's operational performance. Table 11 displays the net profit ratio mechanism test findings.

The results of Table 11 show that β1, β2, β3 and β4 are all significant. This suggests that operations capability plays a partial mediating effect on the impact of Fintech development on the growth of green finance. Hypothesis 3 (i.e., Fintech impacts the development of green finance by improving banks' operations capability) is therefore supported. NPR_{it} functions as an intermediate variable in this transmission mechanism for two reasons. First, banks can boost their income by leveraging new business channels and services introduced by Fintech (Hornuf et al., 2021). Second, Fintech can reduce operational expenses through the use of financial technologies, including intelligent devices, big data inspections, and blockchain smart contracts. As a result, Fintech can help banks to optimise operating income and expenses, thereby improving banks' operations capability (Wang et al., 2021b). With enhanced operations capability, banks are more inclined to issue green credit despite their low returns.

6. Discussion

The development of Fintech significantly enhances the efficiency and scope of financial services that support the real economy, thereby playing a pivotal role in promoting green economic development and attracting substantial academic attention.

However, existing research primarily concentrates on the effects of external Fintech on the banking sector, leaving a dearth of studies examining the influence of bank-driven Fintech. In addition, previous research overlooked the relationship between Fintech and green finance. Consequently, this paper holds theoretical implications for academics and research scholars to explore and investigate the impact of Fintech growth on green finance. This study seeks to delve into this unexplored territory, shedding light on not only the potential influence of bank Fintech development in green finance but also how Fintech development influence the green finance in China.

6.1. Conclusion

In this study, we use a two-way fixed effect model to investigate the influence mechanism of Fintech development level on green finance growth and produce a bank-level Fintech index. We build a panel regression model utilising panel data from 59 Chinese banks to investigate the influence of Fintech development on green finance growth. Our results show that banks' Fintech development level significantly contributes to the growth of green finance by enhancing banks' operations capability and risk management capability. To address the endogeneity concerns, we use the driving distance and driving time between Baidu Company and the headquarters of various banks as instrumental variables and conducted a two-stage least squares estimation on the original model, yielding consistent results. We also confirm the robustness of our conclusions by testing samples from different periods and replacing the original Fintech variable with the number of patents. Finally, heterogeneity tests reveal that the promotional effect of Fintech on green credit is more pronounced in banks with higher profitability levels or located in the eastern regions of China.

6.2. Implication

Apart from the theoretical implications for academics and research scholars, our findings hold significant value for policymakers and banks. Our results affirm that Fintech significantly accelerates the progress of green finance. Therefore, governments should incentivize banks to embrace Fintech by offering financial incentives such as tax credits, subsidies, and grants. These incentives can effectively mitigate the investment costs associated with Fintech adoption and fuel the progress and implementation of Fintech. Additionally, governments should proactively facilitate the development of Fintech infrastructure, encompassing 5G base stations, big data centers, artificial intelligence, and more. This strategic investment will provide a robust foundation for the seamless integration of traditional finance with cutting-edge technologies.

However, it's crucial to acknowledge that Fintech also presents certain challenges for commercial banks, notably technical and privacy risks. To mitigate these risks, we propose some measures for oversight and control within the realm of bank-driven Fintech. On one hand, governments should establish comprehensive regulatory frameworks that encourage the development and adoption of Fintech, encompassing regulatory requirements and streamlined loan approval processes. On the other hand, commercial banks should vigilantly monitor and mitigate new Fintech-related risks by bolstering employee training, standardizing employee behaviour, and formulating effective contingency plans. Overall, our findings underscore the pivotal role of Fintech in propelling the growth of green finance, presenting substantial implications for academics, research scholars, governments, and banks alike.

6.3. Limitation and future direction

We acknowledge three limitations in our study. Firstly, our analysis was confined to Chinese publicly listed banks, and we did not extend our investigation to privately held banks. In future research, incorporating data from non-listed banks would be beneficial to comprehensively validate the robustness of the reported results. Secondly, in measuring the Fintech indicator, our approach primarily relied on an index constructed using text mining and entropy methods. While this methodology provided valuable insights, there exist potentially more authoritative indicators, such as the Fintech development metrics provided by the People's Bank of China, which should be considered for a comprehensive assessment of Fintech development levels. Lastly, due to data constraints, we were unable to delve into certain intermediary processes that illustrate Fintech's influence on green finance, such as the bank's innovation capability. Future research should endeavor to explore additional relevant intermediary variables to thoroughly investigate this mechanism.

Declaration of Competing Interest

We declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Listed banks in China

Industrial and Commercial Bank of China	China Construction Bank
Agricultural Bank of China	Bank of China
China Merchants Bank	Postal savings bank of China
China CITIC Bank	Shanghai Pudong Development Bank
Bank of communications	Industrial Bank
Ping An Bank	Minsheng Bank
Everbright Bank	Huaxia Bank
Bank of Beijing	Bank of Jiangsu
Bank of Shanghai	Zheshang Bank
Bank of Ningbo	Bank of Nanjing
Chongqing rural commercial bank	Bank of Hangzhou
Shanghai Rural Commercial Bank	Bank of Changsha
Bank of Chengdu	Guiyang bank
Bank of Zhengzhou	Bank of Chongqing
Bank of Qingdao	Bank of Suzhou
Qingdao rural commercial bank	Qilu bank
Bank of Lanzhou	Changshu bank
Bank of Xi'an	Bank of Xiamen
Zhangjiagang rural commercial bank	Zijin rural commercial bank
Wuxi rural commercial bank	Suzhou rural commercial bank
Jiangyin bank	Ruifeng Rural Commercial Bank
Guangzhou rural commercial bank	Dongguan Rural Commercial Bank
Bohai bank	Shengjing Bank
Bank of Guizhou	Huishang bank
Jiujiang bank	Jinzhou bank
Zhongyuan bank	Bank of Tianjin
Bank of Jiangxi	Weihai bank
Bank of Gansu	Harbin Bank
Shanxi commercial bank	Bank of Luzhou

Appendix B. Variable definitions

Role	Variables	Symbol	Measurement
Explained variable	Green finance	GC_{it}	Balance of bank green credit
Explanatory variable	Fintech development level	FT_{it}	Fintech score The number of patents
Mediator variable	Risk control capacity	CAR_{it}	$\frac{\text{Net Capital}}{\text{Risk} - \text{Weighted Assets}} \times 100$
	Operational capacity	NPR_{it}	$\frac{\text{Net Profit}}{\text{Revenue}} \times 100$
Control variable	Bank size	$SIZE_{it}$	$\ln(\text{Total Asset})$
	Financial leverage	EM_{it}	$\frac{\text{Total Asset}}{\text{Total Equity}}$
	Business diversification capability	$NIIR_{it}$	$\frac{\text{Non} - \text{Interest Income}}{\text{Operating Income}} \times 100$
	Customer concentration ratio	CCR_{it}	$\frac{\text{Top ten customers}' \text{ loan}}{\text{Net capital}}$

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