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Unleashing Fintech's potential: A catalyst for green bonds issuance

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ABSTRACT

Financial technology, also known as fintech, is transforming daily lives and revolutionising the financial industry. However, there is currently no consensus regarding the effect of fintech on the green bond market. Using novel Chinese data, this study provides robust evidence that fintech development can significantly boost green bond issuance. Further analysis suggests that this promotional effect occurs by empowering intermediary institutions and increasing social environmental awareness. Additionally, we investigate the heterogeneous effect and find that the positive relationship is more pronounced for bonds without high ratings and whose proceeds are not used for refinancing. This effect is also stronger for non-state-owned issuers and in cities connected with High-Speed Railway networks or located in the eastern region of China. These results call for attention from policymakers and security managers to take further notice of fintech utilisation in green finance products.

1. Introduction

Among various financial instruments, green bonds are emerging as a fast-growing type of fixed-income security, and the proceeds are committed to financing climate change solutions and other green projects (Tang and Zhang, 2020). The market volume of green bonds reached over half a trillion dollars (USD 517.4 billion) in 2021, according to Climate Bonds Market Intelligence. However, the green bond market still holds substantial potential for growth, largely due to the future necessity of a carbon–neutral society and the inadequate supply of green bonds in recent years (Sangiorgi and Schopohl, 2023). The primary reason for the latter is the complexity involved in their issuance and the uncertainty and high risks in verifying and evaluating the underlying projects. Furthermore, monitoring and regulating these emerging assets can be difficult (Flammer, 2021). Therefore, green bonds face various issuance challenges.

Given these obstacles, it is crucial to gain a deeper understanding of the factors that encourage and assist organisations in offering green bonds to expand the green bond market. Most of the existing research on the determinants of green bond issuance focuses on firm attributes (Dutordoir et al., 2023) or issuer motivations (Flammer, 2021; Sangiorgi and Schopohl, 2023). However, there is a dearth of literature on the role of regional factors in green bond issuance. A deeper understanding of how regional characteristics affect green

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bonds is crucial as it can directly inform policymakers about future regulation strategies. In this study, we attempt to fill the research gap by asking whether – beyond corporate attributes and investor attitudes – the advancement of fintech in a region would also facilitate the issuance of green bonds. This leads us to formulate our first research question: (1) *What is the effect of fintech on green bond issuance?*

We focus on regional fintech development because it is closely connected to green bonds. Fintech, also known as financial technology, is revolutionising the financial industry through innovative solutions and cutting-edge technologies (Ding et al., 2022). By facilitating data sharing, advocating market competition, improving allocation efficiency, and creating an excessive credit supply (Allen and Gale, 1994; Grinblatt and Longstaff, 2000; Houston et al., 2010; Brunnermeier, 2009), the global development of fintech may offer solutions to the challenges faced by green bonds. Governments have recently promoted green bond issuance using fintech. For example, in February 2023, the Hong Kong SAR Government tokenised green bonds using blockchain technology, which is the first tokenisation attempt for green bonds worldwide, and commented on the potential enhancement of the 'efficiency, transparency and security of green bonds transactions'.[1] However, there is currently a lack of consensus in the literature regarding the effects of fintech on green bond issuance (Qin et al., 2022).

Fintech may accelerate green bond issuances. As previously mentioned, green bond issuance and development present various challenges. By introducing innovative digital solutions, financial institutions can streamline and expedite bond issuance, facilitate data sharing, reduce the potential for fraud, and enhance trust with the advent of blockchain and smart contracts (Shin et al., 2020; Monrat et al., 2019; Cong et al., 2020). This can increase the transparency and efficiency of green bond issuance, while decreasing risks, thus promoting issuance (Quddus, 2020; Dorfleitner and Braun, 2019). In addition, fintech platforms provide user-friendly interfaces, educational resources, and effect-measurement tools, enabling investors to easily align their financial objectives with environmental goals, which raises the demand for green products and benefits green bond issuance (Eyraud et al., 2013; Liao, 2018). However, fintech infrastructure may also prevent new green bond issuance by increasing the transparency of immature Environmental, Social, Governance (ESG) portfolios (Dorfleitner and Braun, 2019), followed by the divestment of several financial products owing to environmental regulatory risks (Heinkel et al., 2001), which in turn prevents new green bond issuance. In conclusion, to enrich our understanding of the channels through which fintech affects green bond issuance, we pose our second research question: (2) *How does fintech affect green bond issuance through possible channels?*

To unveil these puzzles empirically, we combine China's city-level fintech index and green bond issuance data. China is at the forefront of fintech (Goldstein et al., 2019; Guo et al., 2023) and can therefore provide detailed fintech data that other countries currently lack. China also plays a vital role in the global goals of sustainability and carbon emissions reduction.[2] Moreover, green bonds are especially prevalent in China (Flammer, 2021),[3] providing us with a good opportunity to investigate the relationship between fintech and green bond development. We begin our empirical analysis by showing that fintech development positively affects green bond issuance. We then use several identification strategies to validate the causal effect, such as the instrumental variable (IV) approach, staggered Difference-in-Difference (DiD) model, and Heckman two-stage model. Next, we examine the underlying mechanisms. The results show that fintech can empower financial institutions and enhance social environmental awareness, thus increasing green bond issuance. Finally, we conduct cross-sectional partition tests and find that the positive effect is more pronounced for bonds without high credit ratings and whose proceeds are not used for refinancing. This effect is more pronounced for issuers that are not state-owned, cities linked to the High-Speed Railway (HSR) network, and those located in the eastern region of China.

This study contributes to two strands of literature. First, we contribute to the literature on how fintech is related to green projects. The existing literature generally focuses on the positive effects of fintech on sustainability-oriented ventures (Calic and Mosakowski, 2016; Vismara, 2019; Ding et al., 2022), green education programmes (Savelyeva and Park, 2022; Yin et al., 2019), and land restoration (Zhang et al., 2021). This study extends the discussion of fintech to green bonds, which are a new investment instrument, with dramatically increasing sales in recent years (Pham and Huynh, 2020). For issuers, green bonds may expand the investor base with a lower cost of capital and longer term. For investors, green bonds improve ESG performance (Tang and Zhang, 2020).

This study also contributes to existing literature on green bonds. The rapid growth of the green bond market has left behind research on its determinants and consequences (Wang et al., 2020). Current research has mainly focused on the motivation or determinants of issuing green bonds (e.g. Flammer, 2021; Dutordoir et al., 2023; Sangiorgi and Schopohl, 2023), green bond pricing (e.g. Larcker and Watts, 2020; Flammer, 2021; Tang and Zhang, 2020), and the impact of green bonds on issuers (Tang and Zhang, 2020; Flammer, 2021); there is no literature attributed to the offering of regional development factors. We shed light on the regional development factors by analysing how regional fintech innovation could help in green bonds issuance process, thereby accelerating green bond issuance, and in which situation the effect is more pronounced.

Finally, our findings have important implications for nations pursuing their environmental goals. Progress in fintech can provide

[1] Source: Hong Kong Monetary Authorityhttps://www.hkma.gov.hk/eng/news-and-media/press-releases/2023/02/20230216-3/.

[2] See 'Climate change: China's green power surge offers hope on warming,' BBC, June 29, 2023https://www.bbc.com/news/science-environment-66043485.

[3] China's green bond market has grown rapidly since its inception in 2016. Driven by its 'dual carbon' goals – reaching peak carbon emissions by 2030 and carbon neutrality by 2060 – Chinese issuers, including government-backed entities, financial institutions, and corporations across various sectors, have issued green bonds totalling $199.2 billion as of 2021, making China the second largest issuer of green bonds around the world. Particularly, China's green bond market saw a year-on-year increase of $44.4 billion (RMB 286.3 billion) in 2021, representing a year-on-year growth rate of 186 % that surpasses any other major markets. In general, the trend of China's green bond market development lies in the growing diversity of entities and products as well as the continual expansion of market coverage.

valuable solutions to the challenges associated with financing environmental initiatives. Nations can harness fintech innovations to achieve their environmental targets successfully.

We first discuss the uniqueness of green bonds and related literature in Section 2, and then analyse how fintech development affects green bond issuance and propose three hypotheses in Section 3. Next, we describe our variable construction and analysis results in Sections 4 and 5. Finally, Section 6 concludes the study and discusses its results and managerial implications.

2. The uniqueness of green bonds and related literature

In recent years, there has been growing interest in sustainable finance, and green bonds have emerged as a powerful tool for funding environmentally friendly projects (Flammer, 2020; Fatica and Panzica, 2021). Different from conventional bonds and other securities, green bonds are unique in the following aspects: the use of proceeds, the process for project evaluation and selection, management of proceeds, and reporting.

The fundamental aspect of a green bond is the utilisation of its proceeds for environmentally friendly projects. Hence, it seems puzzling why companies choose to issue green bonds instead of conventional bonds, despite the restricted application of proceeds. Contemporary research has proposed three potential explanations for this. First, green bonds can act as credible signals of a company's environmental dedication, as investors may otherwise lack information about a company's environmental commitment (Lyon and Maxwell, 2011; Lyon and Montgomery, 2015). Dutordoir et al. (2023) show that companies with greater reputational benefits from being perceived as environmentally friendly and those with a heightened emphasis on eco-innovation are more likely to issue green bonds. Flammer (2021) provides evidence that investors react favourably to green bond announcements. Sangiorgi and Schopohl (2023) further corroborate the signalling strength of green bonds. Second, the issuance of green bonds can be perceived as a form of greenwashing, a practice in which companies make unfounded or deceptive assertions about their environmental commitment. In this context, companies may issue green bonds to project an image of environmental responsibility without taking substantial action.

Third, another potential motivation for issuing green bonds is the green pricing premium (cost of capital argument), which suggests that if investors in green bonds are prepared to sacrifice financial returns for societal benefits, companies may issue green bonds to obtain cheaper financing. Karpf and Mandel's (2018) study on municipal green bond pricing indicates that these bonds are priced at a discount of approximately eight basis points. Based on different bond samples, Zerbib (2019), Baker et al. (2018), and Bachelet et al. (2019) report price premiums for green bonds. However, Larcker and Watts (2020) find no pricing difference between green bonds and their plain vanilla counterparts when a strict matching procedure is applied. This is supported by Flammer (2021) and Tang and Zhang (2020), who also find no significant green bonds. Fatica et al. (2021) demonstrate that the existence of a premium depends on the issuer type.

As for the process of project evaluation and selection, The Green Bond Principles (GBP) issued by The International Capital Market Association suggest issuers clearly communicate to investors about environmental sustainability objectives, the process by which the issuer determines how the projects fit within the eligible green project categories, and the related eligibility criteria. Currently, however, different countries, international organisations, and institutions have different certification standards for the specific identification of green bonds, although the connotations and extensions of green bonds are similar among different countries or regions. Differences in standards increase the transaction costs in terms of assessment and compliance. To ensure that green bond issuances and related documentation align with market expectations, some issuers seek third-party guidance. Issuers typically appoint external review providers to assess the alignment of their green bonds with the GBP (Flammer, 2021; Sangiorgi and Schopohl, 2023). Some regions or institutions, such as the Association of Southeast Asian Nations, European Union (EU),[4] and Climate Bonds Initiative (CBI),[5] have mandatory external review requirements, whereas others, such as China, adopt a voluntary and encouraging approach. As reported by Sangiorgi and Schopohl (2023), most issuers utilise external parties when issuing green bonds, with only a minority (16 %) stating that they manage the issuance process entirely internally. Flammer (2021) demonstrates that investors react more positively to issuance announcements when third parties certify green bonds.

Management of proceeds and reporting are also crucial for green bonds, particularly in light of the recent rise in greenwashing concerns. The EU recently enhanced regulations to address greenwashing, such as the Sustainable Finance Disclosure Regulation, which came into effect in March 2021. This regulation mandates financial market participants to disclose ESG-related information, thereby increasing the transparency of green investment products and preventing greenwashing. However, in other regions, the process management and reporting systems for green bonds are far from perfect, and greenwashing remains a major concern for investors. For example, according to a CBI report, a total of 5.6 billion yuan (USD$792 million) of Chinese green bonds issued in 2019 were with insufficient disclosure on how the funds raised were used.[6]

Despite the challenges associated with issuing green bonds and the green bond market, the overall impact of green bonds is positive. Flammer (2021) and Tang and Zhang (2020) demonstrate that corporate issuers' stock prices respond positively to the announcement of green bond issuance, suggesting that equity investors perceive this as value-enhancing. Baker et al. (2018), Flammer (2021), and Tang and Zhang (2020) show that following green bond issuance, corporate issuers experience an increase in stock institutional ownership, particularly by long-term and green investors as well as domestic institutional investors. This finding suggests that green

[4] For European Green Bonds. See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R2631.

[5] For certified bonds under the Climate Bonds Standard version 4.0 (Updated April 2023).

[6] Climate Bonds Initiative. (2020). China's green bond issuance and investment opportunity report 2020. Available online: https://www.climatebonds.net/files/reports/cbi_gfo_china_05b.pdf.

bonds attract new investors and diversify the issuer investor base. Furthermore, green bonds can significantly aid firms in environmental policies and performance (Flammer, 2021).

3. Hypothesis development

3.1. Fintech and green bond issuance

Given the uniqueness of green bonds discussed above, one of the major challenges in green bond issuance is the complexity and cost associated with verifying the environmental effect of projects and the uncertainty in bond quality and profitability. Furthermore, monitoring and regulating these emerging assets presents difficulties.

Fintech development offers solutions to these problems. For instance, a blockchain infrastructure with a decentralised immutable ledger and smart contracts can enhance transparency and traceability throughout the lifecycle of a green bond. These technologies enable recording project data, certifications, and effect metrics, allowing investors to assess the environmental performance of the underlying projects (Dorfleitner and Braun, 2019). This transparency helps build trust among investors, attracting an increased pool of capital to the green bond market. Moreover, the automation capabilities of fintech platforms can streamline the green bond issuance (Quddus, 2020). Traditionally, issuing a bond involves numerous intermediaries, extensive paperwork, and time-consuming manual processes. Especially for green bonds, with the special project evaluation and selection process, there are more paperwork and time-consuming manual processes. Fintech platforms can digitise and automate these processes, thereby reducing administrative burden and transaction costs. By simplifying issuance, fintech can allow for increased access to green bonds for a broader range of issuers, including smaller organisations and local governments, who may have been deterred by its high costs. Furthermore, fintech can enhance transparency, traceability, and automation, thus allowing for easier regulation and supervision, and creating a more reliable ecosystem of green finance (González Páramo, 2017). Collectively, these fintech functions can lead to a large supply of green bonds for issuers.

Market development relies on both the supply and demand sides. Fintech development can broaden the investor base for green bonds by enhancing environmental awareness (Dietz et al., 2016). Fintech platforms enable retail investors to participate in green bond investments and democratise access to sustainable financing. For example, Alipay, a predominant fintech platform in China, provides a variety of green bond products to retail investors (Fig. 1), encouraging further investment in green bonds by retail investors. By engaging a wider audience, fintech can mobilise additional capital for green projects and create an inclusive and resilient financial ecosystem. Fintech can also improve green bond liquidity by facilitating efficient matching between investors and sellers, thereby enhancing price discoveries and market efficiency.

To summarise, the integration of fintech into the green bond market has immense potential to accelerate the issuance of these financial instruments. On the supply side, fintech can enhance transparency, streamline processes, and improve intermediary institutions by leveraging technologies such as blockchain, automation, and digital platforms. On the demand side, these advancements can increase overall environmental awareness, broaden investor participation, and facilitate the transition to a greener and more sustainable economy. Therefore, we formulate Hypothesis 1 as follows:

H1: Fintech development has a significantly positive impact on the issuance of green bonds.

3.2. Fintech and green bonds supply

Hypothesis 1 formulates a general relationship between fintech development and green bond issuance. To find further empirical evidence of why fintech can accelerate green bond issuance from the supply and demand sides, we separately formulate hypotheses based on the two possible channels.

On the supply side, financial intermediaries are essential participants in the bonds market. Intermediary institutions such as banks, insurance companies, and investment firms play a crucial role in facilitating transactions, managing risks, and providing green bonds services to individuals and businesses (Buchak et al., 2018; Erel and Liebersohn, 2022). The development of Fintech has empowered intermediary institutions in the financial industry. Innovative Fintech applications provide efficient and seamless digital solutions, promoting transparency and trust facilitate effective matchmaking for environmentally friendly projects with investors who are specifically interested in supporting sustainable initiatives.

Shenzhen, China, is a pioneering city for fintech development. In 2016, Shenzhen proposed a comprehensive green financial service system that integrates green financial institutions, products, markets, and intermediary services. The city also established a Green Finance Professional Committee to assist in implementing the ‘Green Ticket’ Initiative, serving small- and medium-sized green businesses. The proposal became reality in 2019, when Shenzhen launched the world’s first financial service platform linking green bonds with the green real economy in collaboration with the United Nations Environment Program and as a member of FC4S.[7] This platform further solidifies Shenzhen’s role in accelerating intermediary development related to green bonds through fintech.

In this case, the Green Finance Professional Committee and the newly built financial service platform act as intermediaries linking green finance to the green real economy. They play a crucial role in connecting investors to green businesses and facilitating green

[7] Financial Centres for Sustainability (FC4S) is a global network of 40 financial centres, working together to achieve the objectives set by the 2030 Agenda and the Paris Agreement. See https://www.fc4s.org/about-us/.

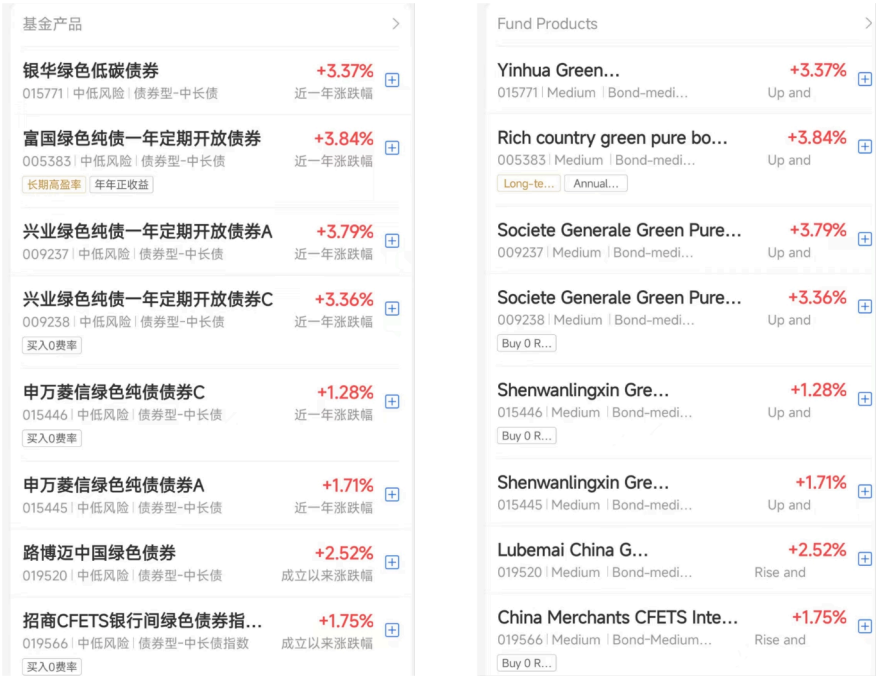


Fig. 1. Examples of Green Bond Products in Alipay. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

bond issuance and trading. Fintech empowers intermediaries in several ways. First, it provides the necessary tools and infrastructure to efficiently manage and process green bond transactions. This includes digital platforms that allow the transparent and streamlined issuance and trading of green bonds. Second, fintech enables intermediaries to reach wider audiences. Information about green bonds can be easily disseminated to potential investors through digital platforms, thereby increasing their accessibility.

As mentioned in the above example, one of the key effects of fintech-empowered financial intermediaries is the increased efficiency and speed of green bond issuance. Financial intermediaries can significantly reduce the steps involved in this process by introducing more efficient and streamlined digital solutions (Cai, 2018). Traditionally, issuing bonds involves numerous intermediaries, extensive paperwork, and manual processes that can be time-consuming, costly, and prone to errors. However, financial intermediaries adopting fintech allow for the feasibility and practicality of digitising bond issuance documentation and automating various processes, such as legal documentation, verification, and compliance checks (Malamas et al., 2020). This feasibility can reduce the time and effort required to prepare and process the necessary paperwork, leading to faster and more streamlined bond issuances (Li et al., 2022). In addition, financial intermediaries can leverage cloud-based document management systems to store and organise bond issuance files securely (Hill, 2018; Kumar, 2014). Cloud platforms provide easy access to authorised parties, facilitate collaboration among multiple stakeholders, and ensure document version control. These capabilities eliminate the need for physical document storage, and enhance document sharing and accessibility. Fintech is also poised to significantly reduce the potential for fraud, enhance trust, and improve intermediary environments through innovative technologies. For example, with the advent of blockchain and smart contracts, fintech solutions can ensure increased transparency, immutability, and traceability in financial transactions, thereby minimising the probability of fraud (Shin et al., 2020; Monrat et al., 2019; Cong et al., 2020). Additionally, digital identity verification systems offered by fintech platforms enable robust 'Know Your Customer' procedures, allowing for easier authentication of individual identities and mitigation of the risks associated with money laundering and terrorism financing (Soni and Duggal, 2014). This scenario fosters trust and encourages the supply of financial instruments such as green bonds by reducing the perception of risks associated with fraudulent or manipulative practices.

Fintech's data analytics capabilities can also facilitate investment matchmaking (He et al., 2023). Fintech-empowered financial intermediaries can leverage data analytics and artificial intelligence technologies to improve bond issuances (Davradakis and Santos, 2019). Data analytics can help identify market trends, investor preferences, and pricing insights, enabling investment banks to optimise bond offerings. Recognition of climate change as a pressing global issue has driven the need for sustainable and environmentally friendly solutions (Dwivedi et al., 2022). Governments encourage businesses and investors to adopt sustainable projects. Therefore, consumer demand for environmentally friendly products and services is growing. We expect that fintech-empowered financial intermediaries are well-positioned to stay informed about the growing green trend and meet the increasing demand for green bonds from their clients. Furthermore, fintech-empowered financial intermediaries can access a broader pool of investors through digital marketplaces, such as mobile apps, and expand the reach of potential investors, incentivising financial intermediaries to provide more products (Cumming et al., 2022). Considering this supply channel, we formulate Hypothesis 2 as follows:

H2: Fintech increases green bond issuance by empowering market intermediaries.

3.3. Fintech and green bonds demand

On the demand side, environmental awareness has significantly increased among investors and society as a whole. Fintech can promote environmental awareness in society, thereby increasing attention and expenditure on green projects. Individuals and institutions are increasingly prioritising sustainable investments to address pressing environmental challenges. Many fintech platforms now offer user-friendly interfaces, educational resources, and effect-measurement tools that allow investors to align their financial objectives with environmental goals. For example, Ant Forest was introduced in August 2016 by Ant Financial Services Group, a subsidiary of Alibaba, China's largest online shopping company, with the primary objective of motivating users of Alipay, Alibaba's mobile payment platform, to actively reduce their carbon footprint. Ant Forest combines the elements of the Internet, finance, and a low-carbon lifestyle, offering a gamified application that serves as a personal carbon account and facilitates participation in public activities. With the help of fintech development, channels for cultivating environmental awareness have further expanded to improve the environmental awareness of the whole society through the daily use of fintech applications. Increased environmental awareness results in higher environmental expenditures and demand for green projects (Eyraud et al., 2013; Liao, 2018), thereby acting as a mediator to increase the demand for green bonds. Following this mediation on the demand side, we formulate Hypothesis 3 as follows:

H3: Fintech magnifies green bond issuance by promoting social environment awareness.

Consequently, enhanced market mediation on the supply side, coupled with increasing environmental awareness on the demand side, lead to the acceleration of green bond issuance in the fintech sector. This positive trend not only promotes sustainable finance but also drives the transition to a more environmentally conscious and socially responsible economy.

4. Data and measures

The sample dataset begins in 2016, the year in which the first green bond in China was issued. The Chinese city-level fintech index is from the Institute of Digital Finance at Peking University and the Ant Group. Many studies have used the same index to measure fintech development (e.g. Ding et al., 2022; Luo et al., 2022). The aggregate fintech index is the weighted average of three sub-indices: breadth of coverage, depth of usage, and level of digitalisation. The breadth of coverage includes the number of Alipay accounts per 10,000 people, the average number of bank cards linked to each Alipay account, and the proportion of Alipay-linking bank card users. The depth of usage is measured by Alipay users' participation in payment, money funds, lending, insurance, investment, and credit-scoring businesses. The level of digitalisation is calculated by the number and amount of digital payments, the average lending interest rate, and credit use.[8]

Green bond data are derived from the China Stock Market & Accounting Research (CSMAR) database and consist of different types of green bonds, including corporate, government-related, asset-backed securities, and financial bonds. Green bond information also includes the city of issuance, and can be matched to other city-level variables. The city-level controls are obtained from the China Statistical Yearbook. We combine the datasets into a bond-city-year level panel. Table 1 presents the summary statistics of our final sample, with 2,153 bond-city-year observations for 337 cities. All continuous variables are winsorised at the 1 % and 99 % levels. Among all the cities where our sample firms are located, the average level of financial technology development is measured as 236.60 by the Peking University Digital Financial Inclusion Index of China (PKU-DFIIC). We include bond- and city-level control variables in our empirical setting. Bond-level control variables include the terms of the loan of bonds in years, bonds' credit levels, and the approved scale of issued green bonds (in RMB Yuan) by financial authorities. City-level control variables include the Gross Domestic Product per capita (in RMB Yuan) of cities, the population of cities, the total loan balance of financial institutions (in RMB Yuan) of cities, the administrative area (in square kilometres) of cities, and the number of words related to 'green development' in the annual reports of the government of cities. The definitions of all variables are shown in Appendix Table A1. Table 2 shows the correlations among all variables. The correlation between the fintech index and green bond issuance is significantly positive, suggesting a positive relationship between the fintech index and green bond issuance.

5. Methodology and empirical results

5.1. Baseline analysis

We first use an ordinary least squares (OLS) regression model to document the relationship between the fintech index and the issuance of green bonds as follows:

$$Log(Issue\_scale)_{i,c,t} = a_0 + \alpha_1 Fintech\_index_{c,t} + a_2 Bond\_Level\_Controls_{i,t} + a_3 City\_Level\_Controls_{c,t} + FE(Year, City) + \varepsilon_{i,c,t}. \quad (1)$$

[8] A more detailed introduction of the index indicators is given in Appendix A2. For more details of the index calculation, please refer to https://en.idf.pku.edu.cn/docs/20190610145822397835.pdf.

Table 1
Summary statistics.

VARIABLES	Obs.	Mean	Median	Std. Dev.	Min	Max	p25	p75
Log(Issue_scale)	2,153	5.97	0.00	9.21	0.00	24.12	0.00	18.42
Fintech_index	2,153	236.60	233.59	34.08	125.50	334.50	213.40	260.70
Bond_term	2,153	1.43	0.00	2.87	0.00	20.00	0.00	2.68
High_rating	2,153	0.24	0.00	0.43	0.00	1.00	0.00	0.00
Log(Approval_scale)	2,153	6.46	0.00	6.54	0.00	24.64	0.00	0.00
Log(GDP_percapita)	2,153	8.28	10.62	4.92	0.00	13.19	0.00	11.53
Log(Population)	2,153	11.73	15.06	6.52	0.00	17.35	13.35	15.75
Log(Total_loan_percapita)	2,153	8.64	10.57	4.91	0.00	13.87	9.59	12.08
Log(City_area)	2,153	7.15	9.06	4.03	0.00	12.92	7.56	9.71
Log(Green_words)	2,153	7.18	8.65	3.29	0.00	9.44	8.46	8.79
Log(Distance)	2,153	6.77	6.98	0.91	0.00	8.31	6.42	7.28
Refinance	2,153	0.04	0.00	0.20	0.00	1.00	0.00	0.00
NonSOI	2,153	0.76	1.00	0.43	0.00	1.00	1.00	1.00
Eastern	2,153	0.19	0.00	0.39	0.00	1.00	0.00	0.00
IntEnv	2,153	9.10	9.03	3.03	1.76	15.19	7.21	11.35
EnvAwa	2,153	8.69	8.70	0.19	7.02	9.43	8.60	8.79
HSR_connection	2,153	0.75	1.00	0.43	0.00	1.00	1.00	1.00

Notes: This table presents the summary statistics. The sample period is from 2016 to 2020. The dependent variable is *Log(Issue_scale)*, the natural logarithm of the scale of issued green bonds, and the independent variable is *Fintech_index*, which is the Peking University Digital Financial Inclusion Index of China (PKU-DFIIC). Control variables include *Bond_term*, *High_rating*, *Log(Approval_scale)*, *Log(GDP_percapita)*, *Log(Population)*, *Log(Total_loan_percapita)*, *Log(City_area)*, *Log(Green_words)*, and *Log(Distance)*. Variable definitions are shown in the Appendix Table A1.

Our sample comprises bond-city-year-level data, where *i* refers to bonds, *c* refers to cities, and *t* refers to years. In the model, *Log(Issue_scale)* is the natural logarithm of the green bonds issued in RMB yuan and *Fintech_index* is the PKU-DFIIC, where a high number indicates a high level of digital financial development. The control variables at the bond and city levels, as shown in Table 1, are included in the model. *FE* denotes the year and city fixed effects. Our coefficient of interest is α_1.

Table 3 shows the regression results are presented in Table 3. In Column (1), we find a positive coefficient and statistically significant effect of fintech development on the issuance scale of green bonds. To test whether the effect is attributable to city- and year-specific characteristics, given that the fintech index tends to cluster significantly within specific cities, we include different fixed effects. The results are presented in Columns (2)–(4). The positive and statistically significant coefficients remain, indicating that fintech growth facilitates the issuance of green bonds among Chinese cities. This effect is also economically significant: a one-standard-deviation increase in the fintech index leads to a 0.714 billion RMB (≈ 98.04 million USD) increase in the issue scale of green bonds.[9]

5.2. Endogeneity

Although city-level green bond issuances are unlikely to influence fintech development within the same year, potential endogeneity occurs in two other ways. First, fintech and green bonds may be simultaneously influenced by omitted factors, which can range widely from sociodemographic and individual consciousness, which are difficult to measure quantitatively. Second, the fintech index has potential measurement errors. To address the potential endogeneity issue, we follow the settings of Qin et al. (2022) and Ding et al. (2022), who use distance to Hangzhou as an instrumental variable. Hangzhou is the centre of fintech in China and has a significant effect on fintech development. The distance to this city is highly related to the fintech development level and is not likely to affect green bond issuance directly or indirectly through other channels, thus being exogenous in our study. We use the two-stage least squares method in Table 4, and the results are consistent with the baseline regression in Table 3 after instrumentation.

We also apply a Heckman two-stage regression to alleviate concerns about self-selection bias, which means that the issuance scale of green bonds is conditional only on cities that have issued such bonds. Table 4 shows the results, which indicate a strong and statistically significant association between fintech development and green bond issuance.

The instrumental variable (IV) and Heckman two-stage models aim to address concerns related to omitted variables and selection bias, respectively. Both the methodologies rely on the fintech index as a crucial factor. To complement these established methods, we also utilise the staggered adoption of city-level fintech development policies as exogenous shocks, impacting regional fintech development, and consequently influencing green bond issuance. Since 2018, several major cities across mainland China, including Beijing, Shanghai, Shenzhen, Guangzhou, Chongqing, Chengdu, and Hangzhou, have introduced policies supporting financial technology. These policies include various preferential measures such as investment attraction, financing, talent subsidies, financial support, research incentives, and special investment funds to attract high-quality financial technology enterprises, research institutions, and top

[9] When the fintech index increases by a standard deviation, which is 34.08, issue scale (in RMB) increases on average by [exp(0.03 × 34.08) − 1] × 0.42 billion (mean value of issue scale), which is 0.714 billion RMB (≈ 98.04 million USD). Considering that more than half the cities do not issue green bonds (issue scale is zero), which lowers the mean value of the issue scale, the magnitude of the effect of the fintech index is considerably reasonable.

Table 2
Variable Correlations.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) *Log(Issue_scale)*	1																
(2) *Fintech_index*	0.55***	1															
(3) *Bond_term*	0.78***	0.43***	1														
(4) *High_rating*	0.54***	0.13***	0.41***	1													
(5) *Log(Approval_scale)*	0.86***	0.46***	0.66***	0.50***	1												
(6) *Log(GDP_percapita)*	0.42***	0.13***	0.33***	0.22***	0.37***	1											
(7) *Log(Population)*	0.37***	0.03	0.29***	0.21***	0.32***	0.94***	1										
(8) *Log(Total_loan_percapita)*	0.45***	0.15***	0.35***	0.24***	0.39***	0.95***	0.97***	1									
(9) *Log(City_area)*	0.30***	−0.04*	0.24***	0.18***	0.27***	0.91***	0.98***	0.95***	1								
(10) *Log(Green_words)*	0.25***	0.29***	0.20***	0.15***	0.21***	0.49***	0.49***	0.50***	0.46***	1							
(11) *Log(Distance)*	−0.27***	−0.42***	−0.21***	−0.09***	−0.25***	−0.28***	−0.27***	−0.28***	−0.19***	−0.36***	1						
(12) *IntEnv*	0.30***	0.65***	0.21***	0.03	0.23***	0.07***	0.00	0.05**	−0.06***	0.35***	−0.47***	1					
(13) *EnvAwa*	0.25***	0.16***	0.16***	0.11***	0.20***	0.10***	0.07***	0.09***	0.04*	0.00	0.01	0.06***	1				
(14) *HSR_connection*	0.30***	0.38***	0.23***	0.15***	0.26***	0.08***	0.04**	0.08***	−0.02	0.11***	−0.24***	0.27***	0.09***	1			
(15) *Refinance*	0.34***	0.14***	0.36***	0.37***	0.51***	0.15***	0.14***	0.16***	0.12***	0.10***	−0.05**	−0.17***	0.07***	0.11***	1		
(16) *NonSOI*	−0.87***	−0.49***	−0.69***	−0.74***	−0.43***	−0.36***	−0.32***	−0.39***	−0.26***	−0.23***	0.20***	0.07*	−0.22***	−0.25***	−0.29***	1	
(17) *Eastern*	0.74***	0.50***	0.52***	0.61***	0.37***	0.35***	0.29***	0.36***	0.21***	0.23***	−0.29***	0.65***	0.23***	0.23***	0.24***	−0.58***	1

Notes: This table presents the Pearson correlation matrix. ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

Table 3
Fintech index and green bonds issuance.

	Log(Issue_scale)			
	(1)	(2)	(3)	(4)
Fintech_index	**0.040*****	**0.048*****	**0.033*****	**0.030****
	(0.004)	**(0.005)**	**(0.004)**	**(0.015)**
High_rating	10.451***	10.211***	8.826***	8.687***
	(0.447)	(0.451)	(0.509)	(0.507)
Bond_term	0.914***	0.890***	0.732***	0.713***
	(0.065)	(0.064)	(0.063)	(0.062)
Log(Approval_scale)	0.177***	0.203***	0.138***	0.158***
	(0.021)	(0.022)	(0.022)	(0.022)
Log(GDP_percapita)	−0.021	−0.053	0.020	0.014
	(0.036)	(0.037)	(0.049)	(0.051)
Log(Population)	0.057	0.015	0.100**	0.035
	(0.053)	(0.051)	(0.047)	(0.045)
Log(Total_loan_percapita)	0.605***	0.495***	0.564***	0.532***
	(0.103)	(0.107)	(0.163)	(0.162)
Log(City_area)	−0.521***	−0.398***	−0.609***	−0.563***
	(0.092)	(0.099)	(0.145)	(0.143)
Log(Green_words)	−0.105***	−0.068***	−0.004	0.001
	(0.021)	(0.022)	(0.099)	(0.098)
Year Fixed Effect	No	Yes	No	Yes
City Fixed Effect	No	No	Yes	Yes
Observations	2,153	2,153	2,153	2,153
Adj. R-squared	0.862	0.865	0.908	0.910

Notes: This table presents the OLS estimation results based on the baseline model, in which the dependent variable is *Log*(*Issue_scale*), the natural logarithm of the scale of issued green bonds, and the independent variable is *Fintech_index*, which is the Peking University Digital Financial Inclusion Index of China (PKU-DFIIC). Control variables include *Bond_term, High_rating*, *Log(Approval_scale)*, *Log(GDP_percapita)*, *Log(Population)*, *Log(Total_loan_percapita)*, *Log(City_area)*, *Log(Green_words)*, *and Log(Distance)*. City and year fixed effects are included. Variable definitions are shown in the Appendix Table A1. Robust standard errors are reported in parentheses. ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

Table 4
Instrument variable approach and Heckman test.

	IV(2SLS)		Heckman	
	(1) 1st Stage *Fintech_index*	(2) 2nd Stage *Log(Issue_scale)*	(3) 1st Stage *Green_bond*	(4) 2nd Stage *Log(Issue_scale)*
Log(Distance)	−76.510***			
	(−30.79)			
Fintech_index			**0.019*****	**0.011*****
			(0.007)	**(0.003)**
$\widehat{\textbf{\textit{Fintech\_index}}}$		**0.040*****		
		(12.43)		
Inverse_Mills				−0.081
				−0.368
Controls	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	No	No
City Fixed Effect	Yes	Yes	No	No
Observations	2,153	2,153	2,153	2,153
Adj. R-squared		0.864		

Notes: This table presents the estimation results of two-stage least squares model and Heckman two-stage model. The dependent variable is *Log*(*Issue_scale*), the natural logarithm of the scale of issued green bonds, and the independent variable is *Fintech_index*, which is the Peking University Digital Financial Inclusion Index of China (PKU-DFIIC). *Log(Distance)* is the instrument variable, measured as the natural logarithm of the spherical distance between a specific city and Hangzhou. *Green_bond* is a dummy variable that equals 1 if the city has issued green bonds in a year, and otherwise 0. Control variables are the same as those used in Table 2. Variable definitions are shown in the Appendix Table A1. City and year fixed effects are included. Robust standard errors are reported in parentheses. ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

talent, promoting, encouraging, and supporting the development of financial technology.[10] The results are presented in Table 5 Column (1). The primary independent variable, *Treat_Post*, takes the value of one if the city has implemented a fintech policy in the respective year and thereafter, and zero otherwise. Notably, the coefficient of *Treat_Post* is positive and statistically significant at the 5 % level, supporting our notion that fintech development drives green bond issuance. Recognising the current discussion on heterogeneity in treatment effects within staggered DiD models, following Zhou et al. (2023) and Butts and Gardner (2021), we incorporated a two-stage DiD model to verify the robustness of our findings and assess the validity of the parallel trend assumption. The detailed results are presented in Table 5 Columns (2) and (3), and the accompanying Fig. 2 illustrates the absence of a pre-trend before the implementation of the policies.

5.3. Mediating factors

The previous section tested the causal relationship between fintech development and green bond issuance. Now, we illustrate why fintech can accelerate green bond issuance, as in our hypotheses. An enhanced intermediary environment and increased social environmental awareness can serve as two possible channels through which green bond issuance increases with fintech development. Accordingly, we examine the mediating effects of an enhanced intermediary environment and increased social environmental awareness using the Sobel test (Sobel, 1982a, 1982b, 1987). The regression models for the mediation tests are as follows:

$$\begin{cases} IntEnv_{c,t}\left(EnvAwa_{c,t}\right) = \beta_0 + \beta_1 Fintech\_index_{c,t} + \beta_2 Bond\_Controls_{i,t} + \beta_3 City\_Controls_{c,t} + \varepsilon_{i,c,t} \\ Log(Issue\_scale)_{i,c,t} = \gamma_0 + \gamma_1 Fintech\_index_{c,t} + \gamma_2 IntEnv_{c,t}\left(EnvAwa_{c,t}\right) + \gamma_3 Bond\_Controls_{i,t} \\ \qquad\qquad + \gamma_4 City\_Controls_{c,t} + \varepsilon_{i,c,t} \end{cases} \tag{2}$$

where *Intermediary Environment* (*IntEnv*) and *Environmental Awareness* (*EnvAwa*) are the two mediating variables; γ_1 is the direct effect coefficient of fintech development on green bond issuance, controlling for the mediator variables; and $\beta_1 \times \gamma_2$ is the mediating effect of the two mediators between fintech development and green bond issuance. We use the 'Development of Intermediary Environment' sub-index extracted from the 'Marketization Index for China's Provinces' (Fan et al., 2001) to carry out a mediation analysis on the channel of enhanced market intermediaries. This index provides province-year measurements spanning 2016 to 2020, where a high value signifies advanced development of market intermediaries. Table 6 Panel A presents the results, which reveal a significantly positive mediation effect, with the Sobel test's Z statistics being significant at the 5 % level. Thus, fintech progress contributes to the enhancement of market intermediaries, which subsequently facilitates green bond issuance. These results support a supply-side mechanism that illustrates how fintech advancements expedite green bond adoption.

Additionally, in our conceptual analysis, environmental awareness serves as another possible channel through which fintech promotes green bond issuance. We count the total number of environment-related words appearing in city government work reports as a proxy for a city's environmental awareness. A high number of such words indicates high citizens' concerns about the environment, which reflects environmental awareness in the city. Table 6 Panel B presents the results. In line with our prediction, the coefficient $\beta_1 \times \gamma_2$, which indicates the total mediation effect of environmental awareness is positive and the Z statistics of Sobel test is significant at 5 % level. The mediation results show that fintech development can contribute to environmental awareness and positively affect green bond issuance. The results support the demand-side channel, in which environmental awareness mediates the relationship between fintech development and green bond issuance.

5.4. Heterogeneous effects

Our tests show that fintech development enhances green bond issuance. A related question is how this effect varies in different situations. In this section, we answer this question by conducting a heterogeneous test. First, regarding green bond issuance, we argue that the enhancement effect is more pronounced for bonds with low rather than high ratings. In China, bond-rating agencies have been criticised for their inability to provide high-quality ratings (Livingston et al., 2018). Investors face difficulties in obtaining sufficient information about bonds from rating agencies, especially for those without high ratings. Fintech can improve the development of market intermediary institutions, through which the public can obtain more information about bonds. Given that investors can already receive adequate information on high-rated bonds, we argue that this incremental effect is greater for bonds without high ratings. Fintech can also provide more information about bonds on different platforms using varying technologies (Buchak et al., 2018; Erel and Liebersohn, 2022). Bonds without high ratings are difficult to advertise or draw investors' attention through traditional channels, and thus fintech can be used to provide more information to investors. Therefore, we conjecture that the effect of fintech on green bond issuance is highly pronounced in bonds without high ratings. Table 7 Column (1) shows the results. We define high-rated bonds as those with AA ratings of or above. The interaction term is negative and statistically significant, supporting our conjecture.

Next, from the fintech perspective, we argue that collaborations and communications between the IT sector, financial sector, and other organisations are very important for fintech development, given the introduction of new technologies into the financial sector. At the city level, travel costs are important components of collaboration and communication (Catalini et al., 2020). Following Yao and Li (2022), we use Chinese High-Speed Railways (HSR) construction as a quasi-natural experiment to see whether the enhancement effect of fintech on green bond issuance is more pronounced in cities connected to the HSR network than in other areas. In China, HSR is a

[10] Source: Chinese Fintech Ecosystem White Paper (2020) https://www.caict.ac.cn/kxyj/qwfb/bps/202211/t20221117_411575.htm.

Table 5
Staggered Difference-in-Difference (DiD) and DiD Two-Stage Test.

	Staggered DiD *Log(Issue_scale)*	DiD Two-Stage *Log(Issue_scale)*	
	(1)	(2)	(3)
Treat_Post	**2.093****	**3.423*****	
	(0.883)	**(−4.91)**	
Event_-3			−3.272***
			(−3.12)
Event_-2			−1.198*
			(−1.69)
Event_-1			0.305
			(−0.70)
Event_0			1.347**
			(−2.39)
Event_1			2.717**
			(−2.21)
Event_2			5.350***
			(−8.94)
Controls	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes
City Fixed Effect	Yes	Yes	Yes
Observations	2,153	2,153	2,153
R-squared	0.911		

Notes: This table presents the results of the staggered Difference-in-Difference (DiD) regression and DiD two-stage regression. Our identification strategy employs a series of regional policies that aims to facilitate financial technology development as an exogenous shock. The dependent variable is Log(Issue_scale), the natural logarithm of the scale of issued green bonds. Treat_Post equals 1 if a city i implements the policy in and after year t, otherwise 0. In the DiD two-stage model, Event_-3, Event_-2, and Event_-1 refer to the time three, two, and one years before the real timer of policy implementation, respectively. Event_0, Event_1, and Event_2 refer to the time in and one and two years after the real timer of policy implementation, respectively. Controls, city and year fixed effects are included. Variable definitions are shown in the Appendix Table A1. Robust standard errors are reported in parentheses. ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

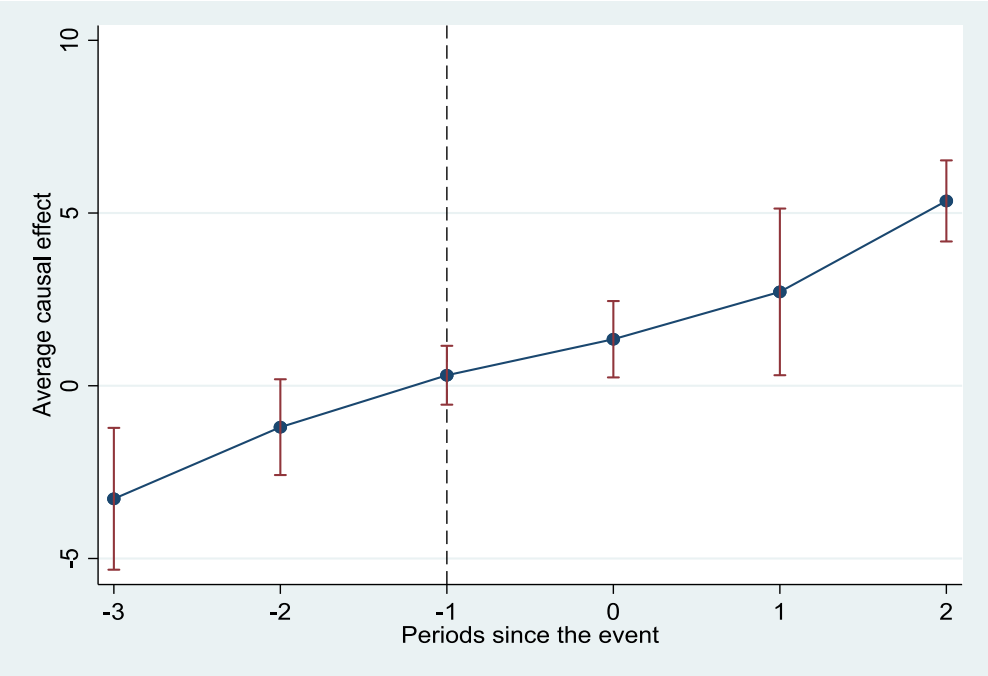
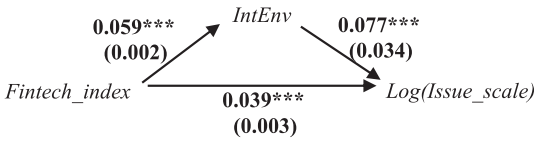


Fig. 2. Event Plot of the Effect of Fintech-Facilitating Policy on Green Bond Issuance. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

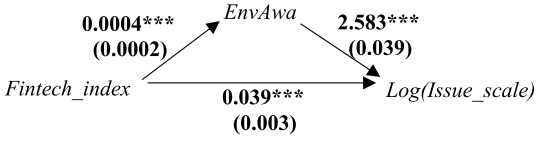
Table 6
Effects of Mediating Tests.

Panel A: Mediating Effect of Intermediary Environment



	Coef(β_1*γ_2)	Z
Sobel	0.005	2.255**
Goodman-1 (Aroian)	0.005	2.253**
Goodman-2	0.005	2.256**

Panel B: Mediating Effect of Environmental Awareness



	Coef(β_1*γ_2)	Z
Sobel	0.001	2.323**
Goodman-1 (Aroian)	0.001	2.323**
Goodman-2	0.001	2.348**

Notes: This table presents the estimation results of mediation tests. The dependent variable is *Log(Issue_scale)*, the natural logarithm of the scale of issued green bonds, and the independent variable is *Fintech_index*, which is the Peking University Digital Financial Inclusion Index of China (PKU-DFIIC). In Panel A, *IntEnv* is the Development of Intermediary Environment, a sub-index of the Marketization Index for China's Provinces. In Panel B, *EnvAwa* is the environmental protection focus, measured by the natural logarithm of the total number of environment-related words appearing in city government work reports. Controls, city and year fixed effects are included. Variable definitions are shown in the Appendix Table A1. ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

cost-effective transport mode with high travel speed and relatively low cost. We argue that, in cities connected to the HSR network, fintech developers can gain more opportunities to collaborate and communicate with other organisations because the high travel speed across cities brought about by the HSR network creates a larger market for developers to match partners for fintech projects. In addition, HSR networks allow team members in inter-organisational collaborative fintech projects to easily interact face-to-face, which can facilitate more efficient contact and interaction to build rapport, share tacit knowledge, and resolve differences. Thus, an HSR connection is helpful for fintech development and function. Based on the above arguments, we conjecture that the effect of fintech on green bond issuance is more pronounced in cities connected to HSR networks than in other areas. We define a city as one with at least one HSR station as connected to the HSR network. The opening dates of the HSR station are collected from the official website 12306.cn, maintained by the National Railway Administration of China. Table 7 Column (2) shows that the interaction term is positive and statistically significant, supporting our conjecture.

To delve deeper into the underlying motives behind bond issuances, we create a new dummy variable, *Refinance*, based on the use of proceeds from green bonds. This variable differentiates between funds earmarked for new projects and those intended to refine existing projects. A value of 1 is assigned to *Refinance* if the primary purpose of the issuance is to refine an ongoing green project, and 0 otherwise. We argue that the impact of fintech on green bond issuance is less prominent in refinancing projects. This conjecture arises from the notion that new projects are inherently less transparent than existing ones. Moreover, refinancing bonds can be viewed as a renewal, conveying positive signals regarding the borrower's outlook (Karavitis et al., 2021). In the green bond market, green bond renewals indicate a borrower's ability to meet their obligations and succeed in green endeavours. This positive outlook may contribute to improved credibility and trustworthiness, fostering a more favourable environment for future bond issuance opportunities. In this scenario, the impact of fintech may be minimal because of the already enhanced creditworthiness of refinancing projects. However, new projects are inherently characterised by uncertainty (Loch et al., 2008). Investors often harbour reservations regarding newly issued green bonds, and it is uncertain whether the invested funds genuinely contribute to a green project. In this context, fintech is expected to play a more pronounced and effective role in providing transparency and mitigating information asymmetry, particularly in the financing of new projects. In line with our conjecture, as shown in Table 7 Column (3), the interaction term between refinance and fintech is negative and statistically significant, indicating that fintech development has a more pronounced impact on new green bond issuance.

Given China's unique institutional background, in which the state plays an important role in the economy, we create a dummy variable, *NonSOI*, to differentiate state-owned issuers (SOIs) and non-state-owned issuers (NonSOIs). *NonSOI* is assigned the value of 1 if the issuer is not state-owned and 0 otherwise. We argue that the effect of fintech on green bond issuance is more pronounced for NonSOIs because, in Chinese financial markets, NonSOIs encounter more severe information asymmetry than SOIs (Tang and Fang,

Table 7
Heterogeneity Test: Credit Ratings, High-Speed Railway, Refinance, *NonSOI*, and Region.

	Log(Issue_scale)				
	(1)	(2)	(3)	(4)	(5)
Fintech_index	0.064***	0.006	0.030**	−0.001	0.006
	(0.018)	(0.014)	(0.015)	(0.014)	(0.012)
Fintech_index*High_rating	**−0.066*** **				
	(0.011)				
High_rating	26.041***				
	(2.966)				
Fintech_index*HSR_connection		**0.022*** **			
		(0.006)			
HSR_connection		−5.189***			
		(1.213)			
Fintech_index*Refinance			**−0.058*** **		
			(0.018)		
Refinance			13.070***		
			(4.756)		
Fintech_index*NonSOI				**0.044*** **	
				(0.010)	
NonSOI				−18.253***	
				(2.739)	
Fintech_index*Eastern					**0.030*** **
					(0.010)
Eastern					1.628
					(2.701)
Controls	Yes	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes	Yes
City Fixed Effect	Yes	Yes	Yes	Yes	Yes
Observations	2,153	2,153	2,153	2,153	2,153
Adj. R-squared	0.913	0.912	0.913	0.936	0.930

Notes: This table presents the estimation results of the heterogeneity tests. The dependent variable is *Log*(*Issue_scale*), the natural logarithm of the scale of issued green bonds, and the independent variable is *Fintech_index*, which is the Peking University Digital Financial Inclusion Index of China (PKU-DFIIC). *High_rating* is a dummy variable that equals 1 if a bond is rated AA or above, and otherwise 0. *HSR_connection* is a dummy variable that equals 1 if a city has an HSR station, otherwise 0. *Refinance* is a dummy variable that equals 1 if the proceeds of green bonds are partly used for refinancing, otherwise 0. *NonSOI* is a dummy variable that equals 1 if the issuer is not state-owned, otherwise 0. *Eastern* is a dummy variable that equals 1 if the green bond is issued in a city located in the eastern region of China otherwise 0. Controls, city and year fixed effects are included. Variable definitions are shown in the Appendix Table A1. Robust standard errors are reported in parentheses. ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

2022), and fintech can be effective in mitigating information asymmetry. China's SOIs often have implicit government guarantees. SOIs are entities owned and operated by the government, and therefore, there is a widespread expectation that the government will support them in times of financial distress. This ownership structure creates an implicit understanding that governments prevent SOIs from failing. Information asymmetry can be minimised with the help of fintech development. Although SOIs are inherently less susceptible to information asymmetry concerns, the advantage of these circumstances leans towards NonSOIs. Therefore, we should observe that NonSOIs tend to issue more green bonds with fintech development. In line with our prediction, as presented in Table 7 Column (4), the interaction between fintech and NonSOIs is positive and significant, suggesting that fintech development has a more pronounced impact on green bond issuance for NonSOIs.[11]

To explore regional heterogeneity, we introduce a dummy variable, *Eastern*. Following Huang et al. (2023), we assign *Eastern* value of 1 if the green bond issuer is located in Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, or Shandong, and 0 otherwise. Fintech has achieved greater advancement in the eastern region of China, notably in major fintech hubs such as Hangzhou and Shenzhen, which are home to industry giants such as Alibaba and Tencent. We hypothesise that, owing to the well-established fintech culture in the eastern area, issuers located in this region will experience more positive effects with the continued development of fintech innovation. Innovation diffusion is influenced not only by the features of the technology itself but also by user characteristics (Ryu, 2018). Given that users embrace and engage with new services or technologies at various time

[11] To answer the question whether the results regarding the Chinese market are generalisable to other regions, we also conduct a subsample test by retaining only those bonds issued by NonSOIs, as they operate independently of government control. The result reveals that the coefficient of fintech remains positive and statistically significant. This additional analysis reinforces the notion that fintech can drive green bond issuance even in the absence of strong state influence, supporting the argument that such activities are reflective of free-market dynamics rather than being driven solely by government initiatives, enhancing the generalisability of our findings.

periods and to varying extents, fintech users can be categorised into early adopters and late adopters, determined by the time they are exposed to the new technology (Kim et al., 2010). Early adopters play a crucial role as opinion leaders, inspiring others to embrace and utilise new technologies by providing evaluative information (Rogers, 1995). By contrast, late adopters exhibit resistance to change and harbour scepticism towards it (Escobar-Rodríguez and Romero-Alonso, 2014). Early adopters anticipate that the benefits of fintech usage outweigh the risks, whereas late adopters perceive the risks associated with fintech usage to be greater than the benefits. In the green bond market, we posit that users in the eastern region of China are early adopters of fintech given its longstanding fintech environment. Consequently, we anticipate that, as fintech develops, early adopters, represented by users in the eastern region, are inclined to issue more green bonds. Consistent with our prediction, as shown in Table 7 Column (5), the interaction between fintech and *Eastern* is positive and significant, suggesting that fintech development has a more pronounced impact on green bond issuance in the eastern region of China.

5.5. Additional tests

One may be concerned about possible multicollinearity in our dataset because some of the city-level control variables are highly intercorrelated, as presented in the correlation table. To mitigate the multicollinearity issue, following Tibshirani (1996) and Shi et al. (2020), we apply the Least Absolute Shrinkage and Selection Operator (LASSO) regression model to our baseline analysis. LASSO addresses multicollinearity and overfitting issues by adding a regularisation term, which is a penalty based on the absolute values of the coefficients, to the OLS objective function. The regularisation term imposes constraints on the sum of the absolute values of the coefficients, causing many of them to be exactly 0, thus offering models with a higher prediction accuracy. We present the LASSO regression result in Table 8 Column (1). Fintech has a significantly positive impact on green bond issuance, indicating the robustness of our results despite the high correlations between some of our city-level control variables.

Another concern is there may exist underlying market factors related to green bond issuances, such as macroeconomic development, secondary market volatility, and capital and monetary market liquidity. Following Ağca et al. (2023), we consider these factors by employing an alternative regression model:

$$Log(Issue\_scale)_{i,c,t} = a_0 + \alpha_1 Inf_t + a_2 SSE_t + a_3 Bondrate_t + a_4 Dep_t + a_5 Loan_t + \varepsilon_{i,c,t} \quad (3)$$

where Inf_t is the monthly inflation rate, SSE_t represents the yearly return of the CSI300 Index; $Bondrate_t$ is the monthly rate of China's 10-year treasury bond yield; Dep_t is the one-year deposit rate; $Loan_t$ represents the one-year loan rate. All variables are between 2016 and 2020. The residuals from Equation (3) are used as adjusted green bond issuance $Adj\_Log(Issue\_scale)_{i,c,t}$. The results are in Table 8 Columns (2) and (3). These outcomes are consistent with the baseline regression results. Hence, our results remain robust even after considering other market-driven factors.

6. Discussion and conclusions

Using bond-city-year data from China, this study empirically documents a significantly positive relationship between fintech development and the promotion of green bond issuance. Using a two-stage least squares estimation with distance to Hangzhou as an instrumental variable, the Heckman two-stage regression to address the self-selection bias, and a staggered DiD model that identifies a series of fintech initiatives in Chinese cities as an exogenous shock, we validate our findings' robustness.

By delving deeper into the underlying mechanisms driving this association, this investigation reveals two plausible channels through which fintech accelerates the development of green bonds. First, the increased supply of green bonds can be attributed to the

Table 8
Additional Tests.

	Lasso Regression *Log(Issue_scale)*	Residual Test *Adj_Log(Issue_scale)*	
	(1)	(2)	(3)
Fintech_index	**0.039*****	**0.047*****	**0.030****
	(0.003)	**(0.005)**	**(0.015)**
Controls	Yes	Yes	Yes
Year Fixed Effect	Yes	No	Yes
City Fixed Effect	Yes	Yes	Yes
Observations	2,153	2,153	2,153
R-squared		0.860	0.906

Notes: This table presents the LASSO regression and residual regression results. The dependent variable in LASSO regression is *Log (Issue_scale)*, the natural logarithm of the scale of issued green bonds, and the dependent variable in residual test is *Adj_Log (Issue_scale)*, the adjusted green bond issuance proxied by the residuals from Equation (3). The independent variable is *Fintech_index*, which is the Peking University Digital Financial Inclusion Index of China (PKU-DFIIC). Controls, city and year fixed effects are included. Variable definitions are shown in the Appendix Table A1. Robust standard errors are reported in parentheses. ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

enhanced intermediary market facilitated by fintech advancement. Second, the growing demand for green bonds is stimulated by improved environmental awareness catalysed by fintech innovations.

Furthermore, our analysis revealed several heterogeneous patterns. First, we find that the abovementioned positive effect is particularly intensive for bonds without high ratings and whose proceeds are not used for refinancing. Additionally, we find that the positive effect of fintech development on green bond issuance is notably more pronounced for NonSOIs, cities with better travel connectivity, as proxied by the development of the Chinese HSR network, and those located in the eastern region of China.

Our empirical findings necessitate increased focus from policymakers, investors, and financial intermediaries on the potential of regional fintech development in green finance products. These findings are relevant for policymakers and regulators. It is essential for regulators to understand the unique roles of fintech infrastructure and the environment in promoting green bond issuance, especially in relation to intermediary development. They should actively refine legislation and supervisory frameworks to adapt to developing intermediaries that embrace fintech, while protecting investors. Regulators should guide innovative entities to enhance environmental awareness. It is vital for investors to utilise the transparency and accessibility provided by fintech to assess and invest in green bonds. Financial intermediaries should also acknowledge the usefulness of fintech as a valuable tool for investment matchmaking, bridging the gap between bond financing and investors.

CRediT authorship contribution statement

Jin Huang: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Ruiqi Liu:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Wenting Wang:** Visualization, Software, Data curation. **Zi'ang Wang:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Congwei Wang:** Writing – review & editing, Writing – original draft, Resources, Conceptualization. **Yong (Jimmy) Jin:** Resources, Project administration, Investigation.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.intfin.2024.102009.

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