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Research article

How do green bonds affect green technology innovation? Firm evidence from China

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Abstract: As an emerging financial tool, green bonds can broaden the financing channels of enterprises and stimulate the green innovation of enterprises. Based on the A-share data of Chinese listed companies from 2012 to 2020, this paper analyzes the impact of green bonds on green technology innovation by using a method of Difference in Difference with Propensity Score Matching (PSM-DID). We found that green bonds can significantly improve enterprise green technology innovation. Its positive impact is attributed to increases in media attention and R&D capital investment and a reduction in financing constraints. Green bonds play a greater role in the green innovation of strong financial constraints enterprises, non-SOEs and large-scale enterprises. Our findings have important reference significance for the improvement of the resource allocation role of green bonds and achievement of sustainable growth.

Keywords: green bonds; green innovation; financing constraint; technology investment; China

JEL: G38, G12

1. Introduction

The current global climate change situation is grim (Hao et al., 2021). The earth's temperature on the ground has warmed by an average of nearly 0.9°C since the Industrial Revolution. If governments around the world do not take effective measures as soon as possible, the global temperature will climb

by more than 4°C near the end of the century, triggering many disasters such as rising seas, glacier melting, reduced food production, species extinction and other serious threats that seriously threaten mankind's normal production and livelihood (Ren et al., 2021). Over the past decades, in response to environmental pollution, the world's major economies have continued to negotiate to solve climate and environmental problems by employing carbon emission reduction, carbon pricing, carbon trading, carbon tariffs, etc. (Zhou et al., 2022). In the case of China, the coal-based energy structure and the crude energy development approach have brought about serious problems such as huge carbon emissions, air pollution and the waste of resources (Wu et al., 2021a; Yang et al., 2021). China has clearly stated that the share of non-fossil energy in its primary energy consumption will reach 20% by 2030, implying that promoting the iterative upgrade of energy production methods is a necessary path to achieve green economic growth. In March 2021, China clearly pointed out carbon neutrality goals and further optimized the industrial structure and energy structure.

Climate change caused by fossil fuel burning and greenhouse gas emissions has become a global problem facing mankind (Yao et al., 2021; Yang et al., 2022). Countries around the world are actively focusing on climate change and exploring a green growth model. Green innovation, as a new technological paradigm, can improve resource utilization and realize the efficient use of resources (Dangelico and Pujari, 2010; Barbieri et al., 2020). Different from direct participation in environmental protection investment, green innovation can effectively reduce pollution emissions and energy consumption (Yii and Geetha, 2017; Mughal et al., 2022; Miao et al., 2020). Moreover, it can stimulate new market demand, satisfy the concept of green consumption and improve its competitiveness by producing green products (Xie et al., 2019; Yin et al., 2020). Green innovation reduces the environmental cost of firms and provides lasting resources for the long-term development of firms (Li et al., 2021; Singh et al., 2016; Mbanyele et al., 2022). Ghisetti and Quatraro (2017) found that green innovation significantly promotes the development of a green economy. Besides, green innovation has dual externalities of the “spillover effect” and “external environmental cost” (Ren et al., 2022a; Wu et al., 2021b; Liu et al., 2022). However, the impact of green bonds on green technology innovation (GT) lacks sufficient discussion.

In the process of achieving the carbon peak goal, green innovation is essential to coordinate economic growth and environmental protection (Hao et al., 2022; Zhang and Li 2020; Du et al., 2021; Lv et al., 2021). It is not only the common pursuit of the country and society, as it is also the practical action to enhance the green competitiveness of enterprises (Li et al., 2020; Keohane and Olmstead, 2016). In terms of the theoretical research and policy formulation to stimulate green innovation, there have been two different views and ideas, where one is referred to as resource compensation, which is to promote green innovation through government subsidies (Lin and Luan, 2020). Moderate government subsidies are conducive to enterprise innovation, but government subsidies for environmental protection show excessive resource compensation (Liu et al., 2020; Wang et al., 2021b). Due to the lack of necessary supervision, green technological innovation also has an obvious crowding-out effect. The second is the Porter hypothesis, which is where enterprises are forced to develop GT under stricter regulations (Zhao et al., 2022; Managi et al., 2005). Some studies have analyzed the “reverse effect” of environmental regulation intensity on firm green innovation in different scenarios. Strict environmental regulation systems, such as environmental supervision costs, pollution charges and environmental taxes, all play a role in pushing enterprises to carry out GT (Jiang et al., 2021; Huang et al., 2019). In addition, GT can help enterprises reduce the cost of pollution control, obtain the public trust and then increase their competitive advantage (Borsatto and Bazani, 2021; Ren et al., 2022b).

The sustainable development goals are not only attributed to the optimization of the energy structure, but they also require efficient support from financial policies (Rahman et al., 2022; Wang et al., 2021a). Facing global climate risks, green finance is vital in promoting sustainable growth (Zheng et al., 2022). There is widespread global awareness that financial development needs to meet the goals of global net-zero carbon emissions commitments (Zhang et al., 2019). According to the forecast of the United Nations Environment Programme, to achieve the goal of temperature control, the annual investment in low-carbon infrastructure by 2050 should be at least 1 trillion US dollars. Green bonds are considered as a potential emission reduction measure to help achieve sustainable development goals in China. To date, China has successively introduced relevant financial support policies to promote the development of a green economy. In March 2021, the Chinese government clearly pointed out its carbon neutrality goals. It particularly emphasizes the implementation of special policies of financial support for green and low-carbon development, as well as the establishment of low-carbon emission reduction support tools to promote resource conservation and efficient use. Besides, in 2021, China had issued 327 billion yuan of green bonds worldwide. From the perspective of enterprises, issuing green bonds may limit the company investment decisions and increase the difficulty of management and issuance. Hence, compared with general bonds, it is not wise for companies to issue green bonds. Some scholars, however, believe that green bonds can reduce the cost of corporate financing. Due to the existence of innovation risks, the effect of green bond issuance is very uncertain. In the existing literature, some studies involve the relationships between green credit policy and environmental performance, enterprise financing, bank investment efficiency, etc.; whether green bonds can promote green innovation requires further analysis. To make up for the shortage of existing literature, we have integrated green bonds and GT into a research system. The empirical results show green bonds to significantly promote GT. Increasing media attention and R&D investment and reducing financing constraints are important influence channels. Additionally, green bonds have more significant green innovation effects in strong financial constraints enterprises, non-SOEs and large-scale enterprises.

The research contribution of this paper mainly includes three aspects. (1) Different green financing policies, such as green credit, green bonds, green development funds, green insurance and carbon finance, may have different effects and mechanisms on enterprise GT behavior. The existing research mainly adopts the “Green Credit Guidelines” proposed in 2012 for policy testing, but few scholars have discussed the relationship between green bond issuance and GT. Therefore, based on the A-share data of Chinese listed companies from 2012 to 2020, we have studied the green innovation effect of green bonds. It broadens the research perspective of green innovation and provides a new scientific basis for the government to evaluate and improve green bond policies. (2) Our research clarifies the external conditions and internal mechanisms by which green bonds promote green innovation. Its positive effect is attributed to increases in media attention, financing channels and R&D investment. (3) We discussed the heterogeneity influence of green bonds on GT in the empirical analysis. It guides policy-makers to formulate differentiated green bond policies to give play to the sustainable role of green bonds in the post-epidemic era. Overall, our research confirms the feasibility and effectiveness of China's green bonds for application to climate change, and it introduces the experience to some developing countries facing serious pollution problems.

2. Literature review and hypothesis development

2.1. Literature review

The literature on green bonds is mainly reflected in two perspectives. First, for the pricing of green bond issuance, scholars hold different views on the pricing differences between green bonds and ordinary bonds. Green bonds have a discount compared to ordinary bonds (Zerbib, 2019; Hyun et al., 2020; Wang et al., 2020). Hachenberg and Schiereck (2018) studied the issue of green bond discounts in the secondary market. They found a 1 basis point discount for green bonds compared to ordinary bonds. Moreover, this difference is mainly related to the rating of corporate ESG, the nature of the company and the rating of green bonds. On the other hand, scholars found that the rate of return of green bonds is not significantly different from that of traditional bonds. Larcker and Watts (2020) found no significant differences between green bonds and non-green bonds in terms of credit spreads, underwriter discounts and secondary market activity. Second, for the economic impact of green bonds, most scholars used the event study method to explore the stock market response to corporate green bond issuance. Baulkaran (2019) confirmed the positive reaction of the stock market to green bond issuance. Furthermore, Flammer (2021) found that companies can gain higher cumulative excess returns when the issued green bond is certified by a third party. Conversely, the negative reaction of green bonds to the stock market has been indicated in some literature (Zhang, 2020). Its negative reaction is mainly attributed to investors' emphasis on short-term benefits, which is contrary to the long-term and uncertain characteristics of green project benefits. In general, due to differences in the securities market, research scope, sample matching method and investor structure, there is no consensus on the research results of the economic consequences of green bonds.

2.2. Hypothesis development

As a typical capital-intensive industry, there exist a large financing demand and financial leverage dependence in the process of green technology R&D. Therefore, under the increasingly strict regulatory environment, financing pressure is an inevitable obstacle to the green innovation of enterprises (Huang et al., 2022; Flammer, 2021). Green bonds are non-current liabilities and have the characteristics of a long issuance period and lower issuance interest rate compared with ordinary bonds (Reboredo, 2018). They not only increase the proportion of non-current liabilities of enterprises and effectively solve the capital mismatch problem faced by green R&D projects, but they also increase the debt ratio of enterprises, reduce financing costs and ease financing pressure (Zerbib, 2019). Green bonds can be used to support the low-carbon technology R&D and the efficient use of clean energy in various industries (Broadstock and Cheng, 2019). They promote the optimization of the energy structure and technological upgrading process of enterprises, thus enhancing the effect of green technology in society and reducing the total amount of carbon emissions. Green bonds can adjust enterprise innovation awareness, innovation risk and income structure, guide enterprises to increase R&D investment and realize the sustainable production of enterprises (Sartzetakis, 2021). In addition, green bonds can generate incentives for investment behavior through financial means, which reduces the proportion of investment in energy-intensive industries and promotes economic transformation (Yeow and Ng 2021).

Hypothesis 1: Green bonds can promote corporate GT.

By issuing green bonds, enterprises can significantly enhance their social reputation and increase investor attention. Green bonds involve green projects such as energy conservation, emission reduction and pollution prevention. The issuance of green bonds conveys to customers, shareholders and the public that the company attaches importance to green development and actively undertakes the image of social responsibility. It is conducive to improving the company social reputation. From the perspective of information disclosure, green bonds require the disclosure of the company's necessary financial information, capital investment flows, green project planning and environmental benefits. This disclosed information alleviates the asymmetry of investment information and improves the transparency and reliability of information. From the perspective of information transmission, Flammer et al. (2021) concluded that green bonds deliver the credible "green" signal. With the deepening of the concept of sustainable development, investors tend to pay more attention to corporate green investment, green information disclosure and the environmental risks. The issuance of green bonds is a manifestation of actively undertaking social responsibilities, which helps enterprises establish a green image of energy conservation and gain the support of green investors. When companies are labeled as part of the green industry, it increases media exposure and attracts investor attention. Therefore, the popularity of the issuing company may increase, which in turn contributes to the green innovation.

Hypothesis 2: Green credit can improve corporate technological innovation by increasing media attention and reduce investor information asymmetry.

Innovation activities have the characteristics of long R&D and considerable capital investment. Once internal financing becomes the only financing channel for enterprises, it will increase the risk and instability of innovation activities. Due to information asymmetry and a lack of high-quality collateral, innovative enterprises, especially SMEs, face severe loan discrimination (Brown et al., 2009). Green bonds alleviate the above difficulties in the following ways. First, from the perspective of financing methods, the debt repayment period of bond financing can perfectly match the long cycle of innovation activities. Green bonds broaden financing channels and raise funds for green innovation. The issuance of green bonds can alleviate the information asymmetry and generate spillover effects of bank loans (Flammer, 2021). Second, from the perspective of financing costs, most empirical evidence supports that green bonds do not have a clear "green" premium (Zerbib, 2019; Flammer, 2021). Wang et al. (2020) found that local support and investors' "green" preference can reduce the cost of green bond financing. Therefore, through green bond financing, enterprises can reduce financing costs and reduce debt pressure, thus promoting green innovation. Third, green bonds have a financing punishment effect and an investment inhibitory effect. If companies issue green bonds for the purpose of "green washing", it may bring loss of social trust and higher financing costs to enterprises. Therefore, green bonds ensure the priority use of funds for green projects, thereby improving the green innovation of firms.

Hypothesis 3: Green bonds can improve the green innovation by reducing financing costs.

The innovation level of enterprises cannot be separated from the support of R&D investment. Hu and Jefferson (2009) suggested that patent applications are related to the R&D investment of enterprises. Therefore, green bonds increase innovation output by influencing R&D investment. Before the issuance of green bonds, higher R&D costs and lower environmental governance pressures resulted in insufficient funds flowing to green innovation. Green bond issuance promotes R&D investment through financing cost channels and social supervision channels. On the one hand, the green premium of green bonds reduces the R&D cost of enterprises and increases their willingness to spend on R&D. On the other hand, the strict environmental information disclosure system enables

investors to make more accurate valuation decisions based on the environmental performance of enterprises (El Ghoul et al., 2018). Therefore, companies are motivated to enhance their environmental competitiveness by increasing their R&D investment.

Hypothesis 4: Green bonds can improve corporate green innovation by increasing corporate R&D investment.

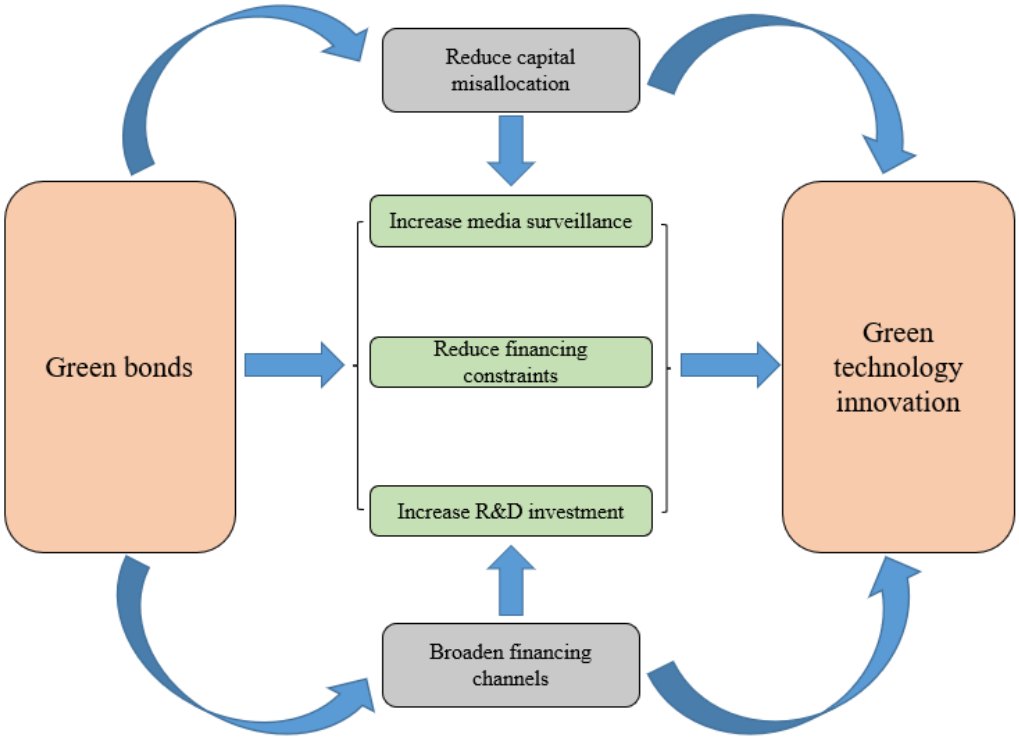

Figure 1. Influence mechanism.

3. Data and sample

3.1. Data

A-shares of Chinese listed companies from 2012 to 2020 were used in our study. The enterprise green patents came from the Chinese Research Data Services and the Green Patent Research Database. The company-level control variable data came from the Wind database and China Stock Market and Accounting Research Database. We processed the original data as follows: (1) Exclude listed companies in the financial and real estate industries. (2) Exclude ST- and PT-listed companies. (3) Exclude listed companies that have been delisted. (4) Exclude listed companies with missing financial data. Green bonds were measured by whether a company has issued green bonds; the data were taken from the Cathay Pacific database.

3.2. Basic model

To address the effect of green bonds and enterprise GT, we constructed the following panel model:

$$GT_{it} = \alpha + \beta_1 GB_i \times Post_t + \eta X_{it} + \gamma_i + \gamma_t + \varepsilon_{it}$$

where the dependent variable GT_{ijt} is the green innovation of firms, and it is measured by the natural logarithm of the adoption of a company's green patents. $GB_i \times Post_t$ represents the green bond. It is the main explanatory variable, representing the policy processing variable in the DID model (double difference sub item). Among them, GB_i is a dummy variable of the processing group and the control group. If the enterprise issues green bonds publicly, the enterprise *i* is assigned a value of 1; otherwise, it is 0. $Post_t$ is a dummy variable of time. For the processing group enterprises, if the time when the enterprise *i* issues bonds after the time when green bonds are issued, the value of $Post_t$ is 1; otherwise, it is 0. This work mainly focuses on β_1. If the company's issuance of green bonds significantly improves the GT, the coefficient β_1 is significantly positive. X_{it} represents a set of firm-level control variables, including the size (*the natural logarithm of the total assets of the business divided by 10,000*), the age (*the natural logarithm of the number of years established)*, the stock concentration (*shareholding ratio of the top 10 largest shareholders*), the asset-liability ratio (*the ratio of total liabilities to total assets*), the return on assets (*the ratio of net profit to total assets*), the business growth (*year-on-year growth rate of total operating income*), fixed assets (*the ratio of net fixed assets to total assets*), position overlap (*if the chairman and general manager of the company are the same person, the value is 1; otherwise, it is* 0) and independent directors (*proportion of independent directors*); μ_t is the time fixed effect, δ_j represents the individual fixed effect, ε_{ijt} is the residual term. Table 1 reports the descriptive statistics of the variables. The development trend of green bonds is reflected in Figure 2.

Table 1. Descriptive statistics.

Variable	Definition	Obs	Mean	SD	Median	Min	Max
GT	Green technology innovation	22778	0.30	0.70	0.000	0.000	6.753
SIZE	Enterprise size	22778	12.89	1.31	12.711	6.519	19.426
AGE	Enterprise age	22778	2.82	0.37	2.890	0.000	4.174
TOP	Capital concentration	22778	0.59	0.15	0.607	0.013	1.012
LEV	Asset liability ratio	22778	0.41	0.25	0.396	−0.195	11.510
ROA	Assets return ratio	22778	0.04	0.70	0.039	−6.776	108.366
GRO	Business growth	22778	0.16	0.44	0.093	−1.309	2.896
FIX	Fixed assets	22778	0.22	0.16	0.185	0.000	0.954
DUAL	Position overlap	22778	0.30	0.46	0.000	0.000	1.000
IND	Independent director	22778	0.38	0.07	0.368	0.188	0.800

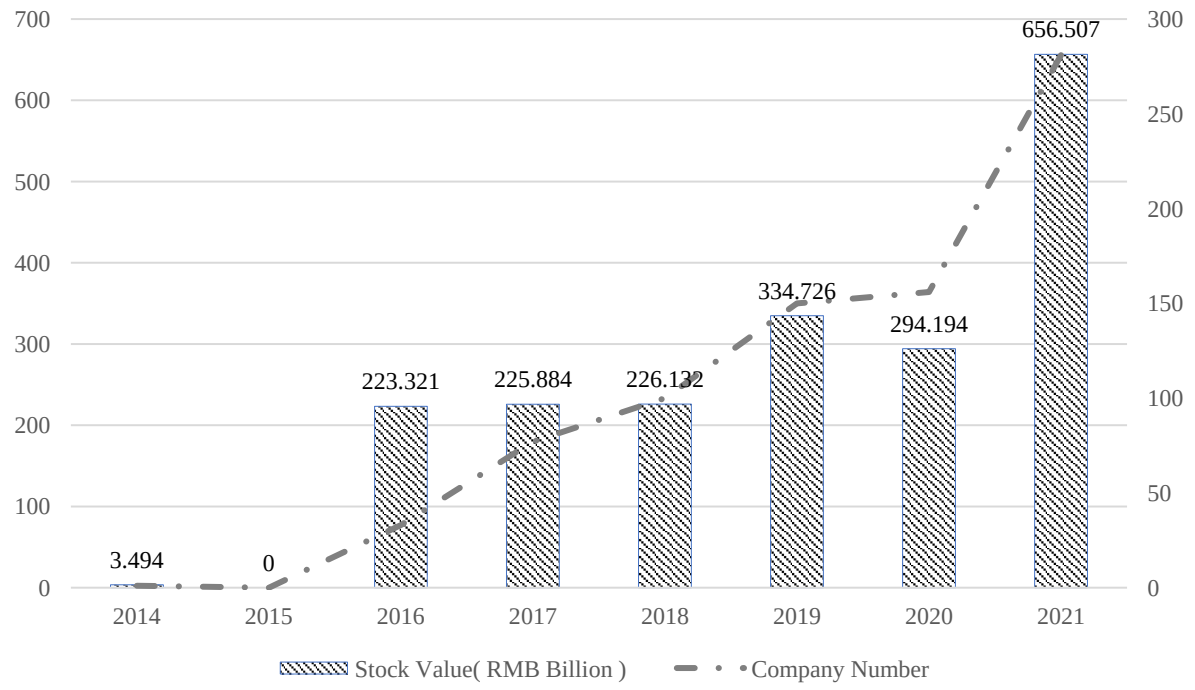

Figure 2. Development trend of green bonds.

4. Empirical results

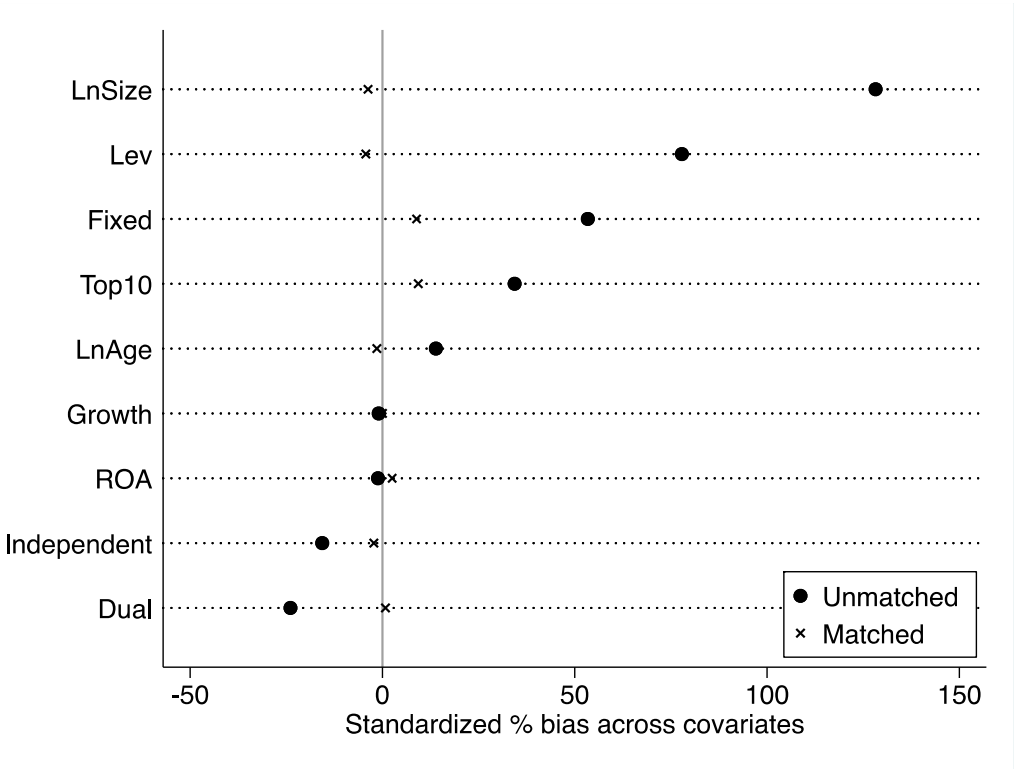

Figure 3. Variation of standardization deviation.

Considering that only some companies issue green bonds, it may lead to serious endogeneity bias if the model is estimated directly. Therefore, we adopted the PSM-DID method to address this problem. Figure 3 reports the effect of matching. It shows that, before matching, there are significant differences in each indicator between the overall sample firms and firms issuing green bonds. After the samples are matched, the variable distribution of the overall sample is basically around the green bond issuers, indicating that our sample matching was effective.

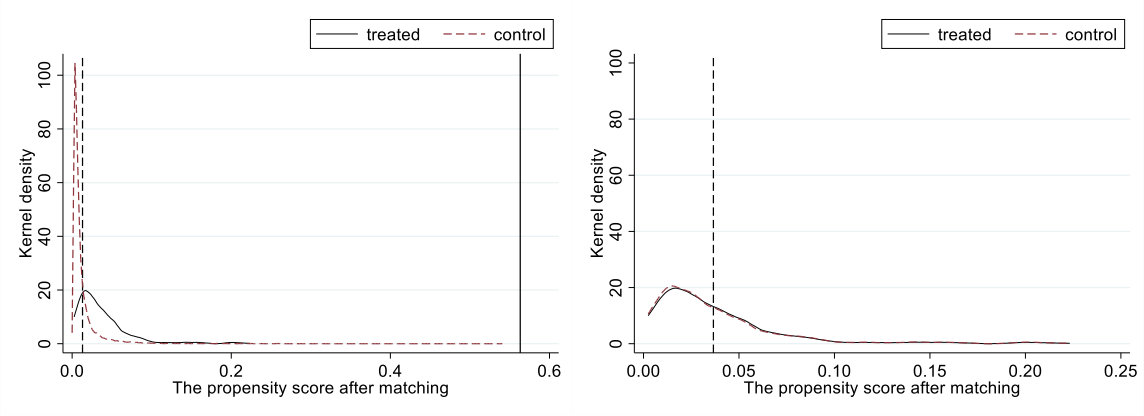

Figure 4. Sample matching results.

Then, we further tested whether there is a difference between the two groups of propensity score values before and after matching and used the kernel density curve to reflect it intuitively. If the deviation of the kernel density curve between the two groups is obvious, the kernel density curve is close after matching, indicating that the matching result is available. Figure 4 shows that the matching effect of this methodology is reliable.

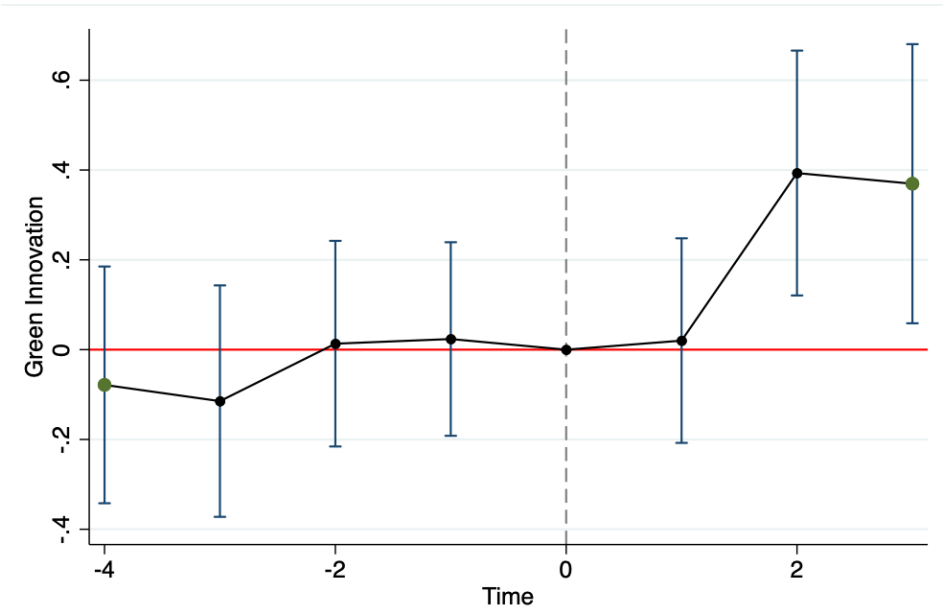

Figure 5. Parallel trend test.

Satisfying the parallel trend test is a prerequisite for empirical analysis using the PSM-DID method. If there is a time trend difference between the control group and the treatment group before the green bond issuance, the changes in green innovation may not be caused by the green bond issuance, but rather caused by the different time trend. Therefore, to verify the appropriateness of the PSM-DID method, we need to verify whether there is a parallel trend of green innovation before the issuance of green bonds. Figure 5 shows that, before the issuance of green bonds, the policy influence coefficients fluctuated around 0, indicating that there is no significant difference between the treatment group and the control group. After the issuance of green bonds, the influence coefficients deviates significantly from 0. It shows that this method has passed the parallel trend hypothesis test.

4.1. Baseline results

Table 2. Benchmark regression results.

Variable	(1) OLS	(2) FE	(3) Weight	(4) On_Support	(5) Weight_Reg
GB×Post	0.328***	0.224***	0.312***	0.237***	0.313***
	(4.180)	(3.223)	(3.539)	(3.471)	(3.573)
SIZE	0.252***	0.275***	0.469***	0.286***	0.468***
	(19.486)	(20.842)	(13.447)	(19.391)	(13.475)
AGE	−0.106***	−0.057***	−0.200	−0.058**	−0.173
	(−4.288)	(−2.662)	(−1.598)	(−2.535)	(−1.382)
TOP	−0.261***	−0.139***	−0.201	−0.179***	−0.184
	(−5.406)	(−3.544)	(−1.048)	(−4.598)	(−0.950)
LEV	−0.003	0.000	−0.155	0.006	−0.183
	(−0.128)	(0.006)	(−0.836)	(0.218)	(−0.986)
ROA	0.008***	0.007***	−0.711	0.007***	−0.775
	(4.286)	(4.872)	(−1.199)	(4.636)	(−1.315)
GRO	−0.000	0.000	0.012	−0.005***	0.013
	(−1.348)	(0.981)	(1.295)	(−3.757)	(1.279)
FIX	−0.508***	−0.223***	−0.102	−0.202***	−0.057
	(−8.770)	(−5.380)	(−0.592)	(−5.081)	(−0.324)
DUAL	0.047***	0.023*	−0.037	0.024*	−0.037
	(3.635)	(1.953)	(−0.414)	(1.861)	(−0.410)
IND	0.292***	0.169**	0.500	0.144**	0.546
	(4.025)	(2.502)	(1.022)	(2.001)	(1.134)
R^2	0.191	0.288	0.493	0.283	0.497
N	22778	22778	881	20827	909

Note: *t* statistics in parentheses, * $p < 0.1$, ** $p < 0.05$ and *** $p < 0.01$. GB represents the green bonds. This note is adapted to the table below.

Column (1) in Table 2 is the regression results of OLS, the coefficient of green bonds to corporate green innovation was 0.3282, which is highly significant. Column 2 reports the results of the fixed-effects regression, where the regression coefficients have decreased. Column (3) was obtained by using a sample whose weight is not empty, and the result is still significantly positive. Column (4) reports on the use of a sample that satisfies the common support hypothesis; the regression coefficient was 0.237 at the 1% level. Column 5 further shows the results of using frequency-weighted regression, and it indicates that green bonds can significantly promote GT. The issuance of green bonds broadens the financing channels of enterprises. It provides sufficient funds for enterprises' green innovation and reduces the instability of innovation activities. Since there is no obvious green premium for green bonds (Zerbib, 2019; Flammer, 2021), investors' green preference can reduce the financing cost of

green bonds (Wang et al., 2020). Green financing has a significant financing punishment effect and investment inhibitory effect. Once enterprises issue green bonds for the purpose of "green washing", enterprises will lose social trust and bear higher financing costs. Therefore, green bonds ensure the preferential use of funds for green projects and encourage enterprises to improve their green innovation level.

4.2. Heterogeneity analysis

Table 3. Heterogeneity results.

Variable	(1) Credit constraints	(2) Others	(3) SOE	(4) Others	(5) Large scale	(6) Small scale
GB×Post	0.793***	−0.089	−0.053	0.764***	0.312***	−0.006
	(4.847)	(−1.075)	(−0.528)	(4.185)	(3.566)	(−0.022)
SIZE	0.522***	0.377***	0.454***	0.466***	0.513***	−0.061
	(9.964)	(9.563)	(8.540)	(7.576)	(12.584)	(−0.338)
AGE	−0.257	−0.320*	−0.258	−0.003	−0.171	0.129
	(−1.422)	(−1.779)	(−1.293)	(−0.013)	(−1.233)	(0.416)
TOP	−0.077	−0.337	−0.565*	0.237	−0.253	−0.228
	(−0.271)	(−1.159)	(−1.811)	(0.728)	(−1.214)	(−0.502)
LEV	0.093	−0.662**	−0.624**	−0.266	−0.249	0.203
	(0.365)	(−2.122)	(−1.984)	(−1.096)	(−1.059)	(0.411)
ROA	−0.210	−1.966	−1.359	−0.976	−0.792	1.721
	(−0.264)	(−1.540)	(−1.640)	(−1.299)	(−1.094)	(0.891)
GRO	0.014	0.013	0.031	−0.004	0.013	0.085
	(0.783)	(1.133)	(1.387)	(−0.192)	(1.386)	(0.551)
FIX	0.368	−0.407*	−0.114	0.257	0.021	−0.536
	(1.368)	(−1.736)	(−0.526)	(0.616)	(0.104)	(−1.449)
DUAL	0.009	−0.338***	−0.185*	0.041	−0.036	0.014
	(0.076)	(−3.307)	(−1.763)	(0.300)	(−0.373)	(0.079)
IND	0.234	0.372	0.400	0.498	0.666	0.887
	(0.346)	(0.742)	(0.763)	(0.541)	(1.360)	(1.007)
_CONS	−6.280***	−3.307***	−4.614***	−6.267***	−6.272***	0.298
	(−7.030)	(−4.089)	(−4.941)	(−5.581)	(−8.245)	(0.107)
R^2	0.570	0.376	0.451	0.574	0.508	−0.300
N	480	429	472	304	834	63

Furthermore, a series of heterogeneity analyses are presented in Table 3. First, we consider the impact of credit constraint differences on green innovation. A series of green credit policies have been promulgated to limit the development of high-polluting industries in China since 2008. These policies also indirectly affect the firm innovation activities. Therefore, we regrouped the sample according to the industry directory of credit restrictions. The results show that green bonds promote the green innovation of firms in credit-constrained industries, but not significantly for other industries. Second, since state-owned enterprises play a leading role in economic development, China's state-owned enterprises have an absolute advantage in the credit market. Therefore, we divided the sample into SOE and the others. The regression results showed that the regression coefficient (GB) in the non-SOE group has a significantly positive correlation, while the regression coefficient in the SOE group is not significant. One possible reason is the fact that SOEs lack incentives to issue green bonds due to easier access to bank credit funds, leading to a greater positive impact of green bonds on the GT of non-SOEs. Finally, there are differences in access to credit and creditworthiness among public companies of different sizes. Large-scale enterprises have more reliable credit guarantees, abundant R&D funds and

talents and social recognition. This leads to the greater role of green bonds in promoting the GT of large-scale enterprises.

4.3. Influence mechanism analysis

The above research results show that green bonds promote GT, but what is the impact mechanism of green bonds on green innovation? The influence mechanism between them is considered from the perspectives of media attention, management efficiency and R&D investment (Table 4). Column (1) reports the impact of issuing green bonds on the probability of companies appearing in news headlines, and the regression coefficient is positive. Column (2) reports the impact of issuing green bonds on firms appearing in news reports, with a regression coefficient of 209.274. Therefore, issuing green bonds can garner more media attention, which motivates companies to green innovation. Column (3) reports the corresponding results of corporate financing constraints, and the regression coefficient is significantly negative. This shows that green bonds can improve technological innovation by alleviating the financial pressure of green long-term projects of enterprises. According to the credit rationing theory, information asymmetry and agency problems are the main reasons for the low efficiency of credit allocation. The issuance of green bonds releases a reliable signal about the environmental risks of enterprises. Therefore, the issuance of green bonds improves corporate reputation, reduces the level of information asymmetry between borrowers and lenders and helps enterprises to obtain more favorable credit support. Column (4) reports the impact of issuing green bonds on corporate R&D investment. We found that R&D and innovation investment increased by 0.4% after companies issued green bonds. Therefore, issuing green bonds allows firms to allocate more funds to R&D activities and promote GT. Green innovation requires continuous investment in R&D. The issuance of green bonds promotes R&D investment through financing cost channels and social supervision channels. On the one hand, the green premium generated by green bonds reduces R&D costs and enhances the R&D investment willingness of enterprises. On the other hand, green bonds require enterprises to disclose environmental information in a timely manner, which enables investors to make more accurate valuation decisions based on the environmental performance of enterprises (EI Ghoul et al., 2018).

Table 4. Impact mechanism results.

Variable	(1) News title	(2) News content	(3) Financial constraints	(4) R&D investment
GB×Post	32.005***	209.274***	−1.248*	0.004***
	(2.737)	(2.598)	(−1.740)	(2.757)
SIZE	10.452***	114.056***	0.369	−0.001
	(4.838)	(5.196)	(1.294)	(−1.355)
AGE	5.059	−5.584	−0.763	−0.009***
	(0.627)	(−0.093)	(−0.706)	(−2.679)
TOP	28.654*	215.002	−2.041	−0.007
	(1.664)	(1.497)	(−1.098)	(−0.894)
LEV	−5.545	−56.089	−0.773	−0.021***
	(−0.497)	(−0.618)	(−0.599)	(−2.718)
ROA	−26.441	−269.438	−3.086	−0.017
	(−0.684)	(−0.884)	(−0.697)	(−0.579)
GRO	−0.677	0.089	0.004	−0.000
	(−0.971)	(0.021)	(0.036)	(−0.319)
FIX	17.758	118.165	4.490	−0.009*
	(1.459)	(1.355)	(1.038)	(−1.778)
DUAL	22.785**	122.131**	0.302	0.002
	(2.585)	(2.138)	(0.377)	(0.776)
IND	170.916***	1137.461**	9.874	−0.016
	(2.602)	(2.451)	(1.339)	(−1.089)
_CONS	−245.623***	−2112.642***	−4.743	0.096***
	(−3.233)	(−3.812)	(−0.917)	(5.852)
R^2	0.318	0.354	0.034	0.420
N	897	897	546	782

4.4. Robustness test

(1) The number of green invention patent applications reflects the firm's efforts and enthusiasm toward green innovation. Therefore, this indicator is used to measure firm green innovation investment for robustness testing. Column (1) of Table 5 shows that the issuance of green bonds has a significant role in promoting GT.

(2) Further, we used the independent green patent data of enterprises to measure the GT of enterprises. Independent innovation and cooperative innovation are common forms of green innovation in enterprises. Compared with cooperative innovation, independent innovation is more difficult, and cooperative innovation is more difficult to divide the efforts made by the company. Therefore, independent innovation can better reflect the firm GT. The results are shown in Column (2) of Table 5. It shows that the company's issuance of green bonds to enhance the company's green innovation capability is relatively stable.

(3) Regarding replacing the regression model, considering that there are many vacancies in the green patent data of listed companies, we constructed a dummy variable according to whether the company has green patents to measure the GT. The logit regression method was used to re-run the regression test. After using different regression models, the results of green bonds in terms of improving the GT of enterprises are still relatively robust.

(4) Regarding the green bond amount, the expansion of the green securities of listed companies may promote the green innovation of companies. We used the value of green bonds to replace the GB

variable. As can be seen in Column (4) of Table 5, after testing different regression models, the scale of green bonds still had a positive effect in terms of improving the GT of enterprises.

(5) The placebo test can be used to verify whether other unobservable factors interfere with the results, and the results of the placebo test are shown in Figure 6. By randomly generating the listed companies issuing green bonds, double differential regression was performed on Equation (1) and repeated 400 times for placebo testing to verify the robustness of the regression results. Figure 5 shows the results of the placebo test of the impact of green bonds on GT. The regression coefficient for green bonds was concentrated around the 0 value, which is in line with the normal distribution, indicating that the interference of other factors can be excluded, and that the regression result is more robust.

Table 5. Robustness test results.

Variable	(1)	(2)	(3)	(4)
GB×Post	11.605**	8.910***		
	(2.534)	(3.316)		
GB_Dummy			0.101**	
			(2.253)	
GB_Value				0.446***
				(13.021)
SIZE	14.623***	3.499***	0.190***	−0.201
	(6.026)	(5.747)	(16.038)	(−1.629)
AGE	−3.335	0.064	−0.005	−0.191
	(−0.620)	(0.042)	(−0.079)	(−0.979)
TOP	7.949	1.981	−0.131	−0.117
	(0.851)	(0.651)	(−1.272)	(−0.622)
LEV	4.273	−1.471	−0.073	−0.500
	(0.570)	(−0.641)	(−0.727)	(−0.845)
ROA	−4.678	−12.765	−0.155	0.012
	(−0.217)	(−1.588)	(−0.497)	(1.165)
GRO	0.141	0.131	0.007	−0.063
	(0.386)	(0.746)	(0.983)	(−0.353)
FIX	3.861	2.850	−0.083	−0.030
	(0.633)	(1.194)	(−0.849)	(−0.331)
DUAL	2.813	1.489	−0.098**	0.428
	(0.756)	(0.724)	(−2.430)	(0.922)
IND	7.472	23.620*	0.091	0.012***
	(0.315)	(1.704)	(0.434)	(3.097)
_CONS	11.605**	8.910***	0.101**	−5.132***
	(2.534)	(3.316)	(2.253)	(−8.195)
R^2	0.265	0.263	0.347	0.497
N	909	909	909	909

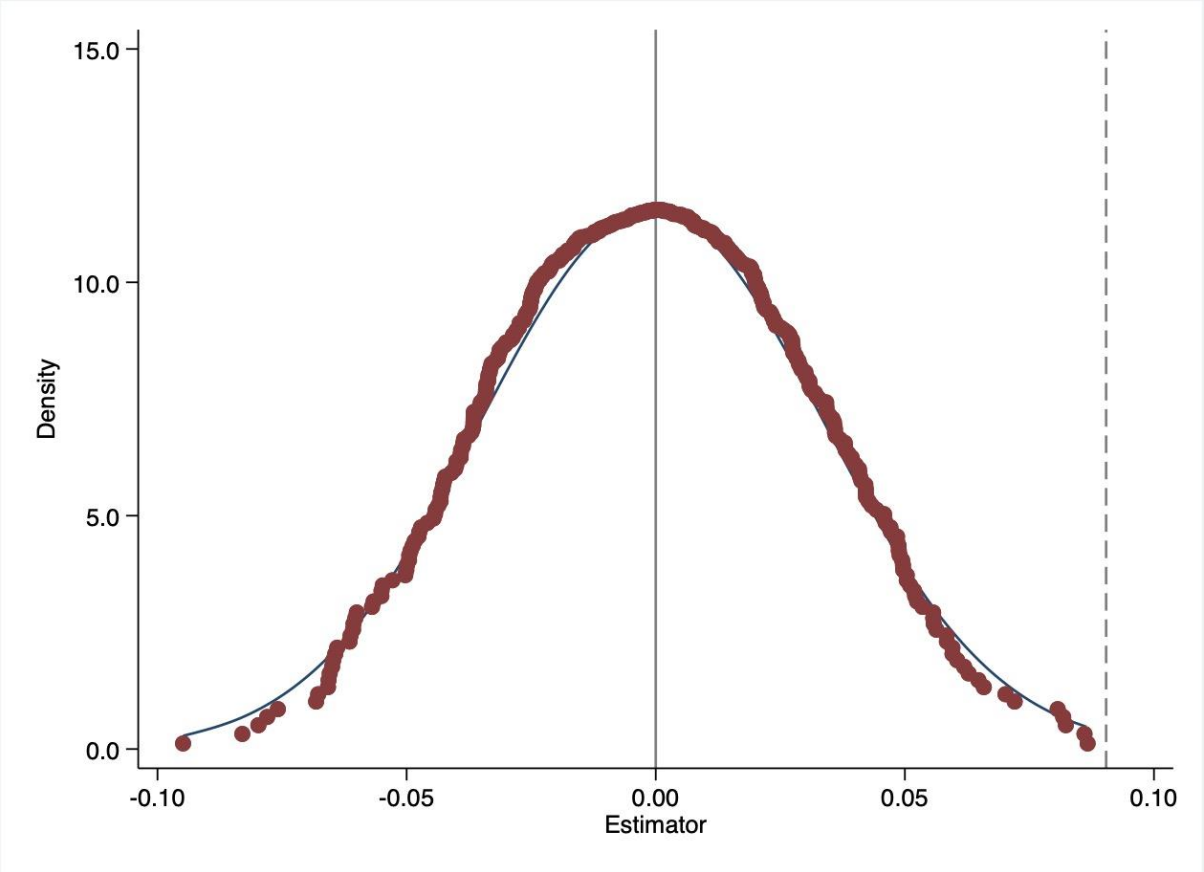

Figure 6. Placebo test results.

5. Conclusions and policy recommendations

This paper discusses the impact of green credit on firm GT. The results show that green bonds can improve GT. This promotion effect is mainly attributable to reduced financing constraints, increased R&D investment and increased media attention. The impact of green bonds on green technology is notoriously heterogeneous. Its positive role is greater in strong credit constraints enterprises, non-SOEs and large-scale enterprises. We propose some recommendations to accelerate green bond development.

First, our research shows that green bonds enhance the GT of enterprises. Therefore, the government should accelerate the cultivation and construction of the green bond market. For bond issuance, it is necessary to simplify the approval procedures for green bond issuance, increase financial support for green bond issuance and promote the implementation of incentives for green bond issuers. Besides, the government should strengthen the innovation of green bond products, improve the diversified green bond product system and optimize the investor structure and risk compensation mechanism. Reducing the risk weight and increasing the pledge rate of green bonds held by commercial banks can improve the attractiveness of green bonds. The government needs to improve the information disclosure mechanism of the green bond market, increase the transparency of the green bond market and realize the effective pricing function of the market. In addition, the Chinese government should continue to promote the international recognition of green bond standards and

continuously bridge the gap between Chinese and international green standards. It is necessary to standardize the governance structure of the bond market and gradually unify the risk-sharing mechanism of green bonds, which is conducive to giving full play to the market-oriented restraint mechanism and encouraging more companies to issue green bonds.

Second, our research shows that green bonds can improve GT by reducing financing constraints and increasing R&D investment. Therefore, enterprises should actively reduce the information asymmetry and establish a trust relationship between investors and enterprises. The green bond information disclosure system needs to be further improved to enable enterprises to timely disclose the status of enterprises and the flow of project funds. To reduce financing constraints, the government should actively improve the relevant laws and regulations of the capital market and credit market and setup special funds for green innovation. Moreover, under the condition of controllable risks, it is necessary to lower the financing threshold for the green innovation activities of enterprises, as well as to increase the channels for raising funds for enterprises with strong independent innovation and green and sustainable development. To enhance the information transparency of domestic green bond issuers and enhance the credibility of corporate green bond information disclosure, financial institutions should establish a complete and transparent green bond information disclosure framework to promote the standardization and digitization of green bond environmental benefit information disclosure. The central government should build a unified green bond environmental benefit information disclosure standard and green bond database. It is beneficial to standardize and strengthen the transparency of green bond information disclosure and clarify the support scope of green bonds.

Third, the heterogeneity results show that the role of green bonds on GT is greater for large-scale enterprises, non-SOEs and strong financial constraints enterprises. Therefore, the government and financial institutions should formulate evaluation and certification policies for different types of enterprises. Generally, private enterprises and smaller enterprises have difficulty obtaining funds in the financial market, frequently facing funding shortages and financing obstacles. Therefore, financial institutions need to reduce the transaction cost of green bond issuance, improve the convenience of issuing subjects and encourage enterprises with difficulty in financing to issue green bonds. At the same time, it is necessary to expand diversified green financing channels and attach importance to the synergy between green bonds and other green financing tools. It injects long-term stable funds for green projects, alleviates the pressure on project funds and promotes the financing and sharing of the green industry chain. In addition, the government should reduce credit restrictions on private enterprises and provide a good external environment for green finance to support enterprise innovation. It is necessary to rationally allocate green financial resources and dynamically adjust the intensity of pollution penalties and incentive policies.

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