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Can Green Bonds Stimulate Green Innovation in Enterprises? Evidence from China

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Abstract: Green innovation is the main driving force to improve green productivity and achieve green circular economy development. The existing literature has demonstrated extensively that government policies can promote green innovation in enterprises. However, there is much less literature exploring whether green finance policies can promote green innovation in enterprises. In this paper, we investigate the impact of corporate green bond issuance on green innovation in China's listed companies. The findings indicate that the issue of green bonds by enterprises has had a positive and significant effect on the output of green patents. The effect is stronger for state-owned, large, and low-pollution enterprises. Furthermore, this positive effect is achieved by easing the financing constraints of the enterprise and has a dynamic and continuous impact. These results suggest green bonds stimulate green innovation by easing financing constraints, thereby promoting green transformation in a rapidly industrializing economy.

Keywords: green bond; green innovation; financial constraints; China

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1. Introduction

China's reform and opening-up have brought remarkable economic growth but resulted in a severe increase in environmental pollution. In order to solve environmental problems, the mode of human production must be changed. Leading enterprises toward a green transition while preserving economic rewards has become a critical problem [1]. Green innovation not only improves the competitive advantage of enterprises [2,3] but is also the main force for achieving a green transformation of the economy [4,5]. Hence, this study analyzes whether the issuance of green bonds can encourage green innovation by enterprises and, if so, through which mechanism.

With the policy of carbon peaking and carbon neutrality, the size of China's green bond market reached 1.24 trillion RMB in 2020 and 1.73 trillion RMB by the end of 2021. Thus, its effects on enterprises have received great academic attention [6,7]. Recent research on green bonds has focused on asset pricing [8], financing costs [9–12], the interaction with the financial market [13], and the economic effects [10,14–17]. However, it is unknown whether the issuance of green bonds has a lasting impact on the green innovation of enterprises, which is the main driving force for attaining environmental protection and green economic growth [18,19]. Empirical research has shown that green finance policy may stimulate green innovation in enterprises through incentive or constraint mechanisms [20–22], achieving a low-carbon green economy [23]. Green bonds are an essential product of green finance, and their capacity to stimulate green innovation in enterprises is crucial, as it determines the effectiveness of green bonds in green economic growth. The factors that affect the green innovation of enterprises are focus on government environmental regulations [21,24], government support and subsidies [25–27], and R&D investment [28,29]. Nevertheless, few studies have provided direct evidence showing that green bonds affect green innovation in micro-enterprises.

Based on this, our study empirically investigated the impact of green bonds on corporate green innovation using a multi-temporal difference-in-difference model and conducted a series of robustness tests and endogeneity tests. At the same time, we used the mediation test to explore the plausible channels through which green bonds influence corporate green innovation. Finally, the heterogeneity test of the green bonds issued by enterprises in different scales, different property rights, and different industries on green innovation empowerment effects was analyzed. After empirical tests, this paper concludes that green bonds significantly and positively impact corporate green innovation. In terms of the mechanism of action, the green bond can enhance green innovation by easing the financial constraints of enterprises. Furthermore, the enhancement in green innovation due to green bonds is found to be stronger in enterprises with a large scale, low pollution, and state ownership. Our findings provide strong evidence that the issuance of green bonds indeed has a positive impact on enterprises' green innovation and offers more reason to encourage governments to develop the green bonds market, which assists in achieving carbon-neutral goals of slowing climate deterioration and reducing environmental pollution. In addition, our study reveals that high-pollution enterprises have weaker incentives to issue green bonds for green innovation. However, green innovation by high-pollution enterprises is the top priority for achieving green development. Therefore, green bond issuance policies should be more favorable to high-pollution enterprises.

This study contributes to the literature in the following ways. First, the literature on green bonds is mainly concerned with asset pricing [8], the cost of capital [9,10], and the economic effects [10,14–16], leading to limited knowledge about the long-term effects of green bonds on corporate green innovation. This study fills the research gap by suggesting that green bonds can encourage corporations to engage in green innovation. Second, many studies have shown that external financing is a crucial funding source for corporations that engage in innovation [30–32]. As a novel financing instrument, the impact of green bonds on corporate green innovation has not been examined in the literature. This paper discusses the impact of green innovation from the perspective of green bonds and enriches the literature on the relationship between external financing and corporate innovation. Third, we analyze whether the effect of green bond issuance on enterprises' green innovation is heterogeneous. Enterprises were first categorized using measures including the nature of property rights, firm scale, and pollution level, and then were independently regressed to assess the heterogeneous impact of green bonds on their green innovation. This outcome offers new evidence to revise future green bond issuing policies.

This paper is organized as follows. Section 2 introduces the background and literature review. Section 3 develops our testable hypotheses. Section 4 discusses the data sources and our regression model. Section 5 presents the analysis of the main empirical results, including robustness tests and plausibility tests. Section 6 examines the moderating effects in different backgrounds of the firm. Finally, Section 7 concludes this paper and provides detailed discussions.

2. Background and Literature Review

2.1. Green Bond in China

Green bonds are a new financial instrument to raise funds for climate change mitigation efforts. Unlike traditional fixed-income securities, green bonds are issued by enterprises to fund green, circular, and low-carbon initiatives. The first green bond in the world was the "climate awareness bond" issued by the European Investment Bank (EIB) in 2007. Since then, green bonds, which enable green economic development, have gained attention from countries worldwide. According to Thomson Reuters, the annual issuance of green bonds reached $155.5 billion in 2017 and is gaining momentum to reach the $1 trillion goal by 2020 (https://www.reuters.com/article/greenbonds-issuance/global-green-bond-issuance-hit-record-155-5-billion-in-2017-dataidUSL8N1P5335 (accessed on 25 May 2022)).

Compared to the international market, China's green bond market started late. In 2015, the Green Bond Support Catalogue published by the China Green Finance Committee first provided clear guidance criteria for green bonds. The China Development and Reform Commission (CDRC) announced Guidelines on Green Bond Issuance in late 2015, followed by the China Securities Regulatory Commission (CSRC), which issued Guiding Opinions on Supporting the Development of Green Bonds in early 2016. Since then, China's green bond issuance has grown rapidly in size and number. China's green bonds increased steadily in 2017 and 2018, with issuance totaling 73.8 billion yuan in 2017 and 97.4 billion yuan in 2018. In 2019, China's green bond market began to overgrow, with the issuance as large as 542.3 billion yuan. In 2020, under the guidance of the carbon peak policy and the stimulation of carbon-neutral goals, the market reached 1.24 trillion yuan. In 2021, the size of green bond issuance decreased, but the number of issuances rose (see Figure 1). By the end of 2021, the total number of green bonds issued in China was 1647, for a total market capitalization of 1.73 trillion yuan. Despite its late start, China is now the largest issuer of green bonds worldwide [10].

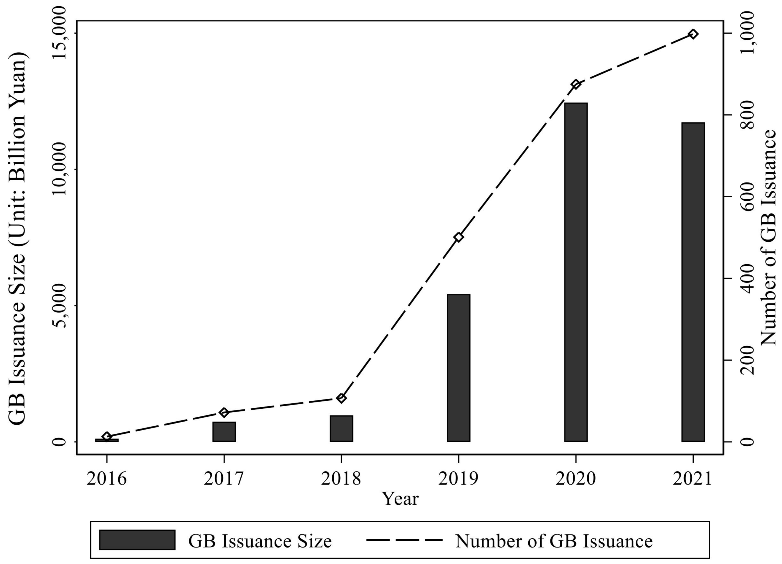

Figure 1. Current status of green bond issuance in China.

2.2. Literature Review

The literature review discusses both green bonds and green innovation. Recent research on green bonds has focused on asset pricing, financing costs, the interaction with the financial market, and the economic effects. Xu et al. found that greenwashing exists in the Chinese green bond market with higher credit spreads than general bonds [8]. Zerbib, Flammer, and Su et al. argue that green bonds have lower financing costs, which may be due to investors' environmental preferences [9,10,12] and certification by third-party institutions [11]. In addition, the interactions between green bonds and other financial markets were studied. Reboredo and Ugolini found that the green bond market is closely linked to the fixed-income and currency markets but weakly linked to the stock, energy, and high-yield corporate bond markets [13]. Research about the impact of issuing green bonds on the economic effects has focused on both the enterprises' value and environmental performance. Some studies have found that the stock market responds positively to the issuance of green bonds [14,15,17]. Other studies have found that issuing green bonds can improve environmental, social, and governance (ESG) performance [10,16].

Green innovation, mainly referring to inventing or enhancing manufacturing processes to accomplish energy savings, emission reduction, and environmental pollution mitigation, is regarded as a main driving force for increasing green productivity [4,5]. The factors influencing enterprise green innovation have recently been a popular research topic. For the government, environmental regulations [21,24] and government support and subsidies [25–27] can stimulate the intention of enterprises to green innovation. For firms, R&D investment [28,29] and green human resource management [33,34] have a significant impact. In addition, green finance policies have been shown to stimulate green innovation in enterprises through incentive or constraint mechanisms [20,22,35]. The literature on green finance mainly explores the impact of green credit on green innovation. However, little literature has explored the impact of green bonds, an important tool of green finance, on green innovation.

Based on the above analysis, this study empirically investigated the impact of green bonds on corporate green innovation. Compared with the existing studies, the main contributions of this paper are as follows. First, it contributes to the literature on the green bond market [8–11,13–16]. This literature focuses primarily on the cost of capital, the stock market's response, and ESG performance. Our study complements this body of research by empirically investigating how green innovation outcomes evolve following the issuance of green bonds. Second, external financing is an important source of funding to carry out innovation [30–32]. The impact of green bonds, as a new external financing instrument, on corporate green innovation has not been studied in the literature. Therefore, this paper enriches the literature on the relationship between external financing and corporate innovation.

3. Hypotheses

In recent years, the environmental challenges associated with the deterioration of the global climate have become increasingly severe, compelling governments to focus on environmental protection issues and consistently enhance environmental management. Realizing low-carbon development in business is the key to resolving the problem of global climate deterioration [36]. Green innovation is the main driving force in firms' efforts to increase green productivity and can contribute to low-carbon development [4,37,38]. Corporate managers deeply influence corporate innovation [39], but corporate innovation depends on funding, and external financing is the primary funding source [30–32]. However, the development of green finance in China is relatively slow at this stage. Some financial resources tilt toward brown enterprises, with high pollution and energy consumption, further aggravating the environmental pollution problem [40].

It has been shown that broadening corporate financing tools and access can significantly enhance firms' willingness to innovate [41,42]. However, whether issuing green bonds can encourage innovation among firms is unknown. In addition, the green bond issuance policy favors green projects such as energy saving and emission reduction technology renovation, clean energy utilization, and pollution prevention technologies. Under the guidance of the green bond issuance policy, enterprises are more likely to allocate financial resources to developing green innovation. Therefore, the issuance of green bonds can help enterprises acquire external sources of capital and promote green innovation. As such, the following hypothesis is proposed.

Hypothesis 1. *Green bonds can significantly encourage companies to engage in green innovation.*

The financing behavior of enterprises is crucial for technical innovation and sustainability, as they need substantial and long-term financial support [43]. According to the Pecking Order Theory, when internal financing is restricted, corporations will choose to obtain external financing through debt financing to support technology development [44]. Among the exogenous financing, bank credit financing has an important impact on the innovation activities of enterprises [30,45–48]. The lack of bank credit significantly reduces firms' investment in innovation activities [45]. Nevertheless, easing bank lending restrictions can promote firm innovation [48].

Bond financing provides another choice of external financing. When compared with bank credit financing, bond financing has the characteristics of longer debt maturity and a lower financing cost. Therefore, bond financing can provide long-term financial support for the technological innovation activities of enterprises. However, at present, bank credit financing in China is dominant, there is severe credit rationing, and enterprises generally face financing constraints [49]. When compared to conventional innovation, green innovation is characterized by a high failure rate, a lengthy cycle time, and substantial investment. Therefore, green innovation projects are prone to suffer from a shortage of external financing [50].

On the contrary, the issuance of green bonds can alleviate the financing constraints faced by enterprises and thus promote their green innovation. First, compared to bank credit and conventional bonds, green bonds have a longer debt maturity, from three to five years, which fits well with the long cycle of green innovation and the requirement for stable financial support. Secondly, unlike the indirect financing method of bank credit, bond financing is a direct financing method, and enterprises are not required to pay excessive intermediary fees. In addition, because of their green characteristics, corporations can issue green bonds at a lower cost than conventional bonds [14] and easily acquire favorable policies such as decreased policy subsidies and tax benefits. This further improves the enterprise's performance [51,52] and enhances innovation. Based on this, the following hypothesis is proposed.

Hypothesis 2. *Enterprises' issuance of green bonds eases financing constraints and thus promotes corporate green innovation.*

The effect of green bonds on green innovation must account for the heterogeneous characteristics of enterprises. It may differ due to their characteristics, mainly reflected in three aspects: the nature of property rights, the scale of enterprises, and the characteristics of industries with heavy pollution.

Due to their close relationships with the government, state-owned enterprises tend to take on some social responsibilities [53]. Unlike non-SOEs, SOEs are responsible for national strategies, and when the government proposes an initiative for energy saving and emission reduction, SOEs tend to participate actively. Therefore, SOEs are more capable than non-SOEs of performing technical innovation to benefit society. Non-SOEs have a poorer innovation base than SOEs, although they are strongly motivated to innovate [54]. Due to their lack of innovation resources, low level of internal management, and risk aversion, non-SOEs have difficulty engaging in technological innovation, particularly green technology innovation. In addition, managers of state-owned enterprises regularly have the status of officials and have more centralized decision-making power [55]. With concerns about their political future, managers of state-owned enterprises are more willing to meet the demands of local governments for low-carbon green development and thus actively engage in green technology innovation. Based on this, the following hypothesis is proposed.

Hypothesis 3. *Compared to non-SOEs, green bonds issued by SOEs have a more significant effect on promoting green innovation.*

Large-scale enterprises usually have better resource endowments. Large enterprises usually have an advantage in talent, facilities, and capital. Due to their privileged position and scale effect, large enterprises have closer commercial relationships with financial institutions and are more likely to secure the necessary funds for technological innovation. In addition, according to the Bearbitt Hypothesis, there is a positive relationship between firm size and innovation, i.e., the larger the firm, the more innovative it is. Larger enterprises are more likely to be observed and monitored by the government, the media, and the public [21]. As a result, larger enterprises will respond more actively to the government's call for green innovation and thus achieve low-carbon development. Based on this, the following hypothesis is proposed.

Hypothesis 4. *Green bonds issued by large enterprises significantly impact green innovation more than those issued by small enterprises.*

Green innovation in high-pollution enterprises is often characterized by long R&D cycles, substantial investment amounts, and high uncertainty, causing it to rely on long-term debt support greatly. However, the green finance policy will restrict the allocation of financial resources for high-pollution enterprises [22] because they are major restriction targets of green finance. Thus, this exacerbates high-pollution industries' financing difficulties and makes them frequently face external financing constraints. Therefore, low-pollution enterprises are more likely to gain support from green financing than high-pollution businesses.

Hypothesis 5. *Green bonds issued by low-pollution enterprises significantly impact green innovation more than those issued by high-pollution enterprises.*

Based on the above theoretical analysis and research hypothesis, we determined the theoretical framework diagram shown in Figure 2.

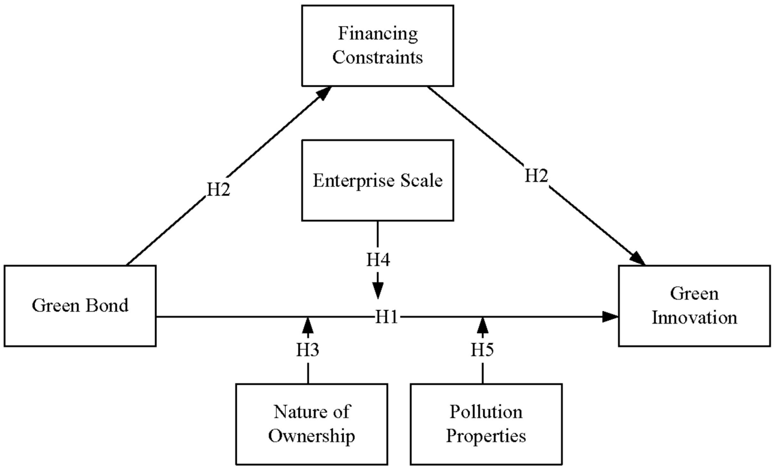

Figure 2. Theoretical framework diagram.

4. Data and Model

4.1. Data

This paper took the years of 2017–2019 as the observation period and uses all of China's listed companies as the initial research sample but excludes financial industries such as banking, securities, insurance, ST and *ST companies, and those with incomplete data (one is shares carrying "ST" (special treatment) or "*ST" tags, which suffer losses for two consecutive years or more, and the other is stocks that enter delisting procedures.). Consequently, we obtained 7835 firm-annual observations. Patent-related data in this paper were obtained from the Chinese Research Data Services (CNRDS) database and the China Stock Market & Accounting Research (CSMAR) database. Data on corporate governance, financial characteristics, and green bond issuance were obtained from the CSMAR database. All continuous variables were winsorized at the 1% and 99% levels to eliminate the influence of extreme values.

4.2. Variable and Empirical Model

At the end of 2016, the China Development and Reform Commission issued the Guidelines on Green Bond Issuance. Subsequently, in early 2017, the China Securities Regulatory Commission issued the "Guidance on Supporting the Development of Green Bonds." Since then, green bonds have been issued by relevant enterprises. A corporation's first green bond issuance can be considered to be an exogenous shock event to a firm's decision. For similar studies, many scholars use the difference in difference (DID) model to explore the impact of exogenous shock events on enterprises [10,14,22,56]. Considering that each firm issues green bonds at a different time, we used a multi-temporal difference in difference model to construct the model (1). In addition, some other scholars use the

Tobit or Logit model to test the impact of an event on enterprises' innovation [26,41]; thus, in Section 5.4 of this paper, we use the Tobit model as part of the robustness test. To avoid multicollinearity, only the interaction term $Green_{it} \times After_{it}$ is introduced as an explanatory variable in the model (1). In the regression result, we apply robust standard errors to reduce estimate errors, such as possible heteroskedasticity and autocorrelation issues. The specific model is as follows:

$$GreenInno_{i,t+2} = \alpha_0 + \alpha_1 \times Green_{it} \times After_{it} + \alpha_2 \times Control + \sum Year + \sum Ind + \varepsilon_{it} \quad (1)$$

In Equation (1), i and t indicate the firm and year, respectively, the dependent variable $GreenInno$ is the natural logarithm of the sum of 1 and the firm's green patents in the year $t+2$. Based on the green patent classification list given by the IPC Expert Committee of the World Intellectual Property Organization (WIPO) (The detailed list of green patent classifications can be found at the following URL: https://www.wipo.int/classifications/ipc/green-inventory/home (accessed on 25 May 2022)), the number of green patents obtained by listed companies per year can be used to measure the green innovation of companies ($GreenInno$). The explanatory variable in this paper is the interaction term $Green_{it} \times After_{it}$ between the green bond $Green_{it}$ and the time variable $After_{it}$, in which $Green_{it}$ denotes the green bond dummy variable. Specifically, if the listed company i has issued green bonds in the year t, the green bond dummy variable takes the value of 1 and enters the experimental group. Otherwise, it takes the value of 0 and enters the control group. $After_{it}$ is the policy time dummy variable. If the listed company i issued or has issued green bonds in the year t, the policy time dummy variable takes the value of 1 and enters the experimental group. Otherwise, the policy time dummy variable takes the value of 0 and enters the control group.

In addition, this paper selects the control variables that may affect corporate green innovation by following the literature related to corporate innovation and corporate green innovation. Specifically, the control variables include firm size (*Size*), debt levels (*Lev*), profitability (ROA), tangible assets ratio (*Tangibility*), listing year (*Age*), growth ability (*Growth*), percentage of independent directors' shares (*IndRatio*), management shareholding (*MH*), senior management position (*Dual*), and enterprise ownership (*SOE*), as detailed in Table 1.

Table 1. Variable definition.

Variable	Definition
GreenInno	The natural logarithm of the sum of 1 and the number of green patents of an enterprise in a year
GeneralInno	The natural logarithm of the sum of 1 and the number of general patents of an enterprise in a year
Green	A dummy variable equal to 1 if the enterprise issued green bonds and 0 otherwise
Bond	A dummy variable equal to 1 if the enterprise issued ordinary bonds and 0 otherwise
SOE	A dummy variable equal to 1 for SOEs, and 0 otherwise
lnSize	The natural logarithm of the total number of enterprise employees
Leverage	Total liabilities divided by total assets
ROA	Net income divided by total assets
Tangibility	Fixed assets divided by total assets
Age	Number of years since the enterprise was founded
Growth	Growth rate of sales revenue
IndRatio	The proportion of shares held by independent director
MH	The proportion of shares held by management
Dual	A dummy variable equal to 1 if the CEO and the Chairman are the same people, and 0 otherwise

5. Empirical Results

5.1. Summary Statistics

Table 2 reports the descriptive statistics for the main variables. After removing the missing values, 7835 "company-year" observations were obtained. Among the 7835 samples from 2017 to 2019, the mean of the green patent ($GreenInno$) is 0.37 (=exp (0.314) − 1). Among these, 513 green patents were received by CCRC in 2017, making 2017 the peak year. However, this year also saw a zero minimum and median GI, indicating a significant variation in green innovation levels among the China-listed companies, and most of them did not engage in green innovation. The mean of green bonds (*Green*) is 0.012, indicating that, on average, 1.2% of listed companies have issued green bonds during the sample period. For control variables, the means of the nature of ownership (*SOE*), firm size (*Size*), financial leverage (*Leverage*), return on assets (*ROA*), percentage of fixed assets (*Tangibility*), firm age (*Age*), growth (*Growth*), dual ownership (*Dual*), percentage of independent directors (*IndRatio*), and management shareholding (*MH*) are 0.336, 2328, 0.428, 0.033, 0.205, 20.483, 0.118, 0.278, 13.308, and 37.676, respectively.

Table 2. Descriptive statistics.

Variable	N	Mean	SD	Min	Median	Max
GreenInno	7835	0.314	0.744	0.000	0.000	6.242
Green	7835	0.012	0.108	0.000	0.000	1.000
SOE	7835	0.336	0.472	0.000	0.000	1.000
lnSize	7835	7.753	1.215	4.875	7.673	11.135
Leverage	7835	0.428	0.197	0.060	0.419	0.929
ROA	7835	0.033	0.074	−0.360	0.035	0.195
Tangibility	7835	0.205	0.155	0.002	0.172	0.697
Age	7835	20.483	5.316	7.000	20.000	53.000
Growth	7835	0.118	0.248	−0.339	0.073	1.835
MH	7835	37.676	5.304	33.330	36.360	57.140
Dual	7835	0.278	0.448	0.000	0.000	1.000
IndRatio	7835	13.308	18.811	0.000	1.005	70.207

The listed companies were divided into two sample groups based on whether they had issued green bonds. Table 3 reports the differences (*t*-test) between the two groups in obtaining general and green patents. As shown in Table 3, there is no significant difference in the general patents between the two groups. On the contrary, there is a significant difference in green patents. The average number of green patents for companies that did not issue green bonds was 1.537, and the value for the counterpart was 8.524, indicating that companies that issued green bonds averagely increased their green patents by a factor of 5.55. The *t*-test results also show a significant difference in the number of green patents obtained between the two groups, with the 1% significance level.

Table 3. Analysis of differences in the number of patents.

	No Green Bonds Issued	Have Issued Green Bonds	*t*-Value	*p*-Value
General Patents	29.872	62.857	−0.337	0.736
Green Patents	1.537	8.524	−3.173	0.001 ***

Note: *** indicates statistical significance at levels of 1%, and the analysis of differences reports the mean, *t*-test statistics and *p*-value.

5.2. Corporate General Bond Issuance and Corporate Green Innovation

First, we attempted to examine the general bonds' impact on corporate green innovation. Table 4 presents the basic regression results. Column (1) reports the impact of issuing general bonds on corporate green innovation without controlling fixed effects of year and industry, and column (2) demonstrates the impact of issuing general bonds on corporate green innovation when fixed effects of year and industry are controlled. The regression results show that issuing general bonds significantly affects corporate green innovation at the 5% level of significance after controlling for fixed effects of year and industry. Further comparison and analysis of the impact of issuing green bonds on corporate green innovation will be implemented using a difference in difference model in the present work.

The regression results were compared with and without controlling the fixed effects of year and industry. When compared to the issuance of general bonds, issuing green bonds significantly promotes corporate green innovation, with a 1% difference in significance level.

Therefore, both general and green bonds can promote the green innovation of corporations. Nevertheless, although issuing general bonds can promote corporate green innovation to some extent, issuing green bonds can promote corporate green innovation more than issuing general bonds in terms of significance and the absolute value of coefficients.

Table 4. Regression of corporate green innovation.

Variable	(1)	(2)	(3)	(4)
	GreenInno	**GreenInno**	**GreenInno**	**GreenInno**
Bond × After	0.042	0.148 **		
	(0.07)	(0.07)		
Green × After			1.415 ***	0.814 ***
			(0.29)	(0.30)
SOE	0.053	0.135 ***	0.047	0.117 **
	(0.05)	(0.05)	(0.05)	(0.05)
lnSize	0.261 ***	0.284 ***	0.257 ***	0.288 ***
	(0.02)	(0.02)	(0.02)	(0.02)
Leverage	0.737 ***	0.420 ***	0.730 ***	0.454 ***
	(0.12)	(0.12)	(0.11)	(0.12)
ROA	0.013	0.146	0.005	0.132
	(0.27)	(0.26)	(0.27)	(0.27)
Tangibility	−0.159	−0.195	−0.188	−0.209
	(0.14)	(0.15)	(0.14)	(0.15)
Age	−0.019 ***	−0.009 **	−0.017 ***	−0.009 **
	(0.00)	(0.00)	(0.00)	(0.00)
Growth	−0.139	−0.302 ***	−0.145	−0.309 ***
	(0.13)	(0.11)	(0.13)	(0.11)
Dual	0.013	0.063	0.020	0.066
	(0.05)	(0.04)	(0.05)	(0.04)
IndRatio	0.001	−0.001	0.001	−0.001
	(0.00)	(0.00)	(0.00)	(0.00)
MH	0.004	0.003	0.004	0.003
	(0.00)	(0.00)	(0.00)	(0.00)
Constant	−1.395 ***	−0.932 ***	−1.377 ***	−0.980 ***
	(0.25)	(0.31)	(0.26)	(0.32)
Year FE	No	Yes	No	Yes
Ind FE	No	Yes	No	Yes
Observation	2202	2202	2187	2187
R-squared	0.144	0.347	0.160	0.350

Note: *** and ** indicate statistical significance at levels of 1% and5%, respectively, with robust standard errors in parentheses.

Table 5 represents the estimation results of Equation (1) and compares the basic regression results with and without issuing green bonds. The explanatory variables in columns (1) and (2) are general innovation, which is the logarithm of the number of general patents filed by firms. The explanatory variables in columns (3) and (4) are green innovation, which is the logarithm of the number of green patents filed by firms. Columns (1) and (3) show the regression results without controlling the fixed effects of industry and year, while columns (2) and (4) show the regression results with the fixed effects of industry and year being controlled. When the explanatory variable is general innovation, issuing green bonds does not significantly promote corporate general innovation, regardless of the fixed effects of industry and year. When the explanatory variable is green innovation, issuing green bonds significantly promotes green innovation, regardless of the fixed effects of industry and year. Therefore, it is plausible to conclude that companies use the funds raised from the issuance of green bonds mainly for green innovations, which meet the green recycling and low carbon project requirements.

Table 5. Regression of corporate green innovation.

Variable	(1) GeneralInno	(2) GeneralInno	(3) GreenInno	(4) GreenInno	(5) Tobit
Green × After	0.359	0.242	1.150 ***	0.571 ***	
	(0.33)	(0.32)	(0.19)	(0.21)	
Green					0.675 ***
					(0.18)
SOE	0.031	0.182 ***	0.058 **	0.127 ***	0.127 ***
	(0.04)	(0.04)	(0.03)	(0.03)	(0.02)
lnSize	0.200 ***	0.186 ***	0.255 ***	0.271 ***	0.272 ***
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)
Leverage	−0.295 ***	−0.156	0.538 ***	0.372 ***	0.371 ***
	(0.09)	(0.10)	(0.06)	(0.06)	(0.06)
ROA	−0.352	−0.042	−0.249*	−0.038	−0.034
	(0.23)	(0.23)	(0.14)	(0.14)	(0.15)
Tangibility	−0.205 **	−0.232 *	−0.352 ***	−0.384 ***	−0.381 ***
	(0.10)	(0.14)	(0.07)	(0.08)	(0.08)
Age	−0.017 ***	−0.008 **	−0.014 ***	−0.008 ***	−0.009 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Growth	0.133 *	0.036	−0.151 ***	−0.217 ***	−0.219 ***
	(0.07)	(0.07)	(0.04)	(0.04)	(0.04)
Dual	−0.014	−0.014	−0.030	0.002	0.002
	(0.04)	(0.04)	(0.02)	(0.02)	(0.02)
IndRatio	0.000	−0.001	0.000	−0.001 ***	−0.001 **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
MH	−0.003	−0.005	0.002	0.001	0.001
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	−0.310	−0.278	−1.281 ***	−0.935 ***	−0.932 ***
	(0.20)	(0.25)	(0.12)	(0.15)	(0.13)
Year FE	No	Yes	No	Yes	Yes
Ind FE	No	Yes	No	Yes	Yes
Observation	7835	7835	7835	7835	7835
R-squared	0.028	0.098	0.148	0.323	0.139

Note: ***, ** and * indicate statistical significance at levels of 1%, 5% and 10%, respectively, with robust standard errors in parentheses.

5.3. Endogeneity

Although some literature considers corporate green bond issuance as an exogenous shock event, the regression may suffer from potential endogeneity problems, e.g., reverse causality [10]. If firms pay more attention to green innovation, they are incentivized to issue green bonds. To address this problem, the impact of green bonds on corporate green innovation was reexamined using a propensity score matching-based difference-in-difference method (PSM–DID). Similar to the literature [57], the steps of PSM–DID are as follows. First, the companies that have issued green bonds were defined as the experimental group. The control group samples were matched using three propensity matching score approaches: k-nearest neighbor matching, caliper radius matching, and k-nearest neighbor matching within caliper radius methods (covariates are the ten control variables in Table 1). In this step, similar samples in companies that have never issued green bonds were matched as control groups. At last, the matched samples were regressed on the DID model.

The probability density function plot can evaluate the performance of the PSM method. If the probability density functions of the experimental and control groups overlap, it implies that the matching is successful. Figure 3 depicts the probability density distributions of the control and experimental groups before and after matching. Panel (a) shows the probability density functions before matching is performed, and panels (b), (c), and (d) show the probability density functions of the control and experimental groups after employing three propensity matching score approaches. Figure 3 shows that the skewness and kurtosis of the probability density function of the control group differed dramatically from that of the experimental group before PSM. After PSM was performed, the skewness and kurtosis of the probability density functions of the control group differed less from those of the experimental group. In particular, the probability density functions of the two groups of samples were close to overlapping after using the k-nearest neighbor matching method. Based on the above analysis, the samples are well-matched.

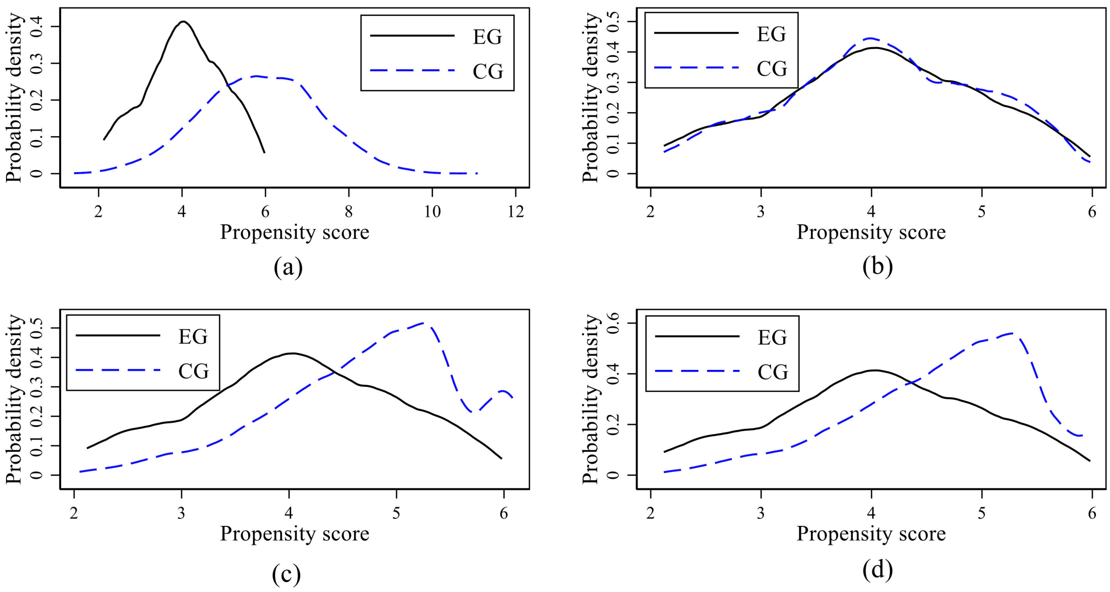

Figure 3. Probability density function diagram after propensity score matching. Panel (**a**) is the probability density function of the experimental groups (EG) and control groups (CG) before propensity score matching was performed. Panels (**b**–**d**) are the probability density functions of the experimental groups (EG) and control groups (CG) after using k-nearest neighbor matching, caliper radius matching, and k-nearest neighbor matching within caliper radius methods, respectively.

The results of the PSM balance test are reported in Appendix A Table A1. The samples obtained using the three matching approaches did not differ significantly for all variables between the experimental and control groups. Furthermore, the standardized bias of most of the variables after matching was less than 10%, indicating that the matching process was effectively balanced. Table 6 shows the results of the DID regression using the matched samples. Column (1) lists the results of using the 1:1 matching method for the nearest neighbor kernel, and the regression coefficient of the explanatory variable $Green \times After$ is significantly positive at the 5% level. Column (2) lists the results of using the caliper radius matching method, and the regression coefficient of the explanatory variable $Green \times After$ is also significantly positive at the 5% level. Column (3) lists the results of using k-nearest neighbor matching within the caliper radius method, and the regression coefficient of the explanatory variable $Green \times After$ is significantly positive at the 10% level. In summary, the test results support the findings of this paper well.

5.4. Robustness Test

For robustness tests, Table 7 shows the results of the counterfactual tests, where the green bond issuance time is postponed one or two years to replace the actual issuance time. The explanatory variables in columns (1) and (2) are denoted using one period $L1.Green \times After$, whose estimated coefficients indicate the impact of a hypothetical one-year delay in enterprises' issuance of green bonds on green innovation. The explanatory variables in columns (3) and (4) are denoted using two-period $L2.Green \times After$, whose estimated coefficients indicate the impact of a hypothetical two-year delay in enterprises' issuance of green bonds on green innovation.

Table 6. Propensity scores matching regression.

Variable	(1)	(2)	(3)
	Method 1	**Method 2**	**Method 3**
Green × After	0.516 **	0.441 **	0.431 *
	(0.22)	(0.22)	(0.23)
Constant	−1.390 ***	−1.217 ***	−1.216 ***
	(0.26)	(0.25)	(0.29)
Control Variable	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Observation	4125	3785	3507
R-squared	0.356	0.367	0.368

Note: ***, ** and * indicate statistical significance at levels of 1%, 5% and 10%, respectively, with robust standard errors in parentheses. Method1, Method2 and Method3 denote the use of k-nearest neighbor matching, caliper radius matching and k-nearest neighbor matching within caliper radius methods, respectively.

Table 7. Counterfactual tests.

Variable	(1)	(2)	(3)	(4)
	GreenInno	**GreenInno**	**GreenInno**	**GreenInno**
L1. Green × After	1.134 ***	0.375		
	(0.26)	(0.26)		
L2. Green × After			1.042 **	0.103
			(0.43)	(0.37)
Constant	−1.391 ***	−0.970 ***	−1.540 ***	−1.085 ***
	(0.17)	(0.20)	(0.26)	(0.31)
Control Variable	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes
Ind FE	No	Yes	No	Yes
R-squared	0.147	0.334	0.153	0.349

Note: *** and ** indicate statistical significance at levels of 1and 5%, respectively, with robust standard errors in parentheses.

Suppose the estimated coefficients $L1.Green \times After$ or $L2.Green \times After$ are still significant and in the same direction as the original coefficients. In that case, it suggests that the green innovation behavior of enterprises is affected by other reasons rather than issuing green bonds. As can be seen from the regression results in Table 7, the coefficients of the explanatory variables $L1.Green \times After$ and $L2.Green \times After$ in columns (1) and (3) without controlling for industry and year fixed effects are significantly positive and consistent with the original facts. However, after controlling for industry and year fixed effects, the coefficients of $L1.Green \times After$ and $L2.Green \times After$ are insignificant and inconsistent with the original fact. It means that only issuing green bonds at the actual points in time can promote green innovation by firms, and the counterfactual test is passed.

Furthermore, the Tobit regression model was employed as a robustness test to assess the impact of green bonds on corporate green innovation, with whether the firm issues green bonds or not serving as a dummy variable. The regression results are displayed in column (5) of Table 5, where the dummy variable *Green* is significantly positive, and the regression findings are consistent with the basic regression results.

6. Additional Analysis and Tests

6.1. Plausible Channel

The issuance of green bonds by firms can increase their medium and long-term stable cash flows, alleviate their financing constraints, and thus financially support their green innovation. For this reason, this paper refers to Hadlock and Pierce [58] to calculate the index SA as an indicator of financing constraints, which is formed from two relatively exogenous variables: firm size and age. Models (1), (2), and (3) were used to test whether the issuance of green bonds by enterprises can promote corporate green innovation by alleviating financing constraints.

$$SA_{it} = \beta_0 + \beta_1 \times Green_{it} \times After_{it} + \beta_2 \times Control + \sum Year + \sum Ind + \varepsilon_{it} \quad (2)$$

$$GreenInno_{i,t+2} = \gamma_0 + \gamma_1 \times Green_{it} \times After_{it} + \gamma_3 \times SA_{it} + \gamma_4 \times Control + \sum Year + \sum Ind + \varepsilon_{it} \quad (3)$$

Table 8 reveals plausible mechanisms for the test results. In this table, column (1) shows the regression results of model (2), in which the coefficient of $Green \times After$ for green bond issuance is significantly negative at the 5% level. It indicates that green bond issuance can alleviate the problem of corporate financing constraints. Column (2) shows the regression results of model (3), where the regression coefficient of $Green \times After$ controlling for financial constraints is significantly negative at the 1% level. The z-value of the Sobel test is 2.314. The above results prove that green bond issuance by enterprises promotes green innovation by easing financial constraints.

Table 8. Mediation test.

Variable	**(1)**	**(2)**
	SA	**GreenInno**
SA		−0.595 ***
		(0.06)
Green × After	−0.104 **	0.688 ***
	(0.04)	(0.24)
Constant	3.948 ***	2.947 ***
	(0.04)	(0.25)
Control Variable	Yes	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Observations	7815	7815
R-squared	0.117	0.263
Sobel Z		2.314 **

Note: *** and ** indicate statistical significance at levels of 1% and 5%, respectively, with robust standard errors in parentheses.

6.2. Heterogeneity Test

6.2.1. Dynamic Heterogeneity

To analyze the dynamic impact of corporate green bond issuance on corporate green innovation, model (4) was set up by referring to Beck et al.'s (2010) [59] dynamic heterogeneity analysis method. For brevity, the treatment variable of whether to issue green bonds is denoted by D. The superscript $D_{i,t}$ indicates the number of delayed or advanced periods. For example, after two years of the enterprise issuing green bonds, $D^2_{i,t}$ equals 1, otherwise it equals 0. To avoid the dummy variable trap, Equation (4) does not include a dummy variable for the actual point (benchmark time point) of the firm's green bond issuance.

$$\begin{aligned} GreenInno_{i,t+2} = \delta_0 + \delta_1 \times D^{-2}_{i,t} + \delta_2 \times D^{-1}_{i,t} + \delta_3 \times D^{1}_{i,t} + \delta_4 \times D^{2}_{i,t} + \delta_5 \times D^{3}_{i,t} + \delta_6 \times D^{4}_{i,t} + \\ \delta_7 \times Control + \sum Year + \sum Ind + \varepsilon_{i,t} \end{aligned} \quad (4)$$

Figure 4 shows the visualization results of the dynamic heterogeneity analysis of Equation (4). The horizontal axis plots years from the green bond issuance, and the vertical axis is the regression coefficient. The solid black dots in the figure represent the coefficients of the corresponding advanced and delayed terms. The vertical dashed lines connecting the upper and lower forks indicate the 95% confidence intervals for each of these terms. If the confidence interval contains a zero, the regression coefficient of the dummy variable is not significant, and vice versa.

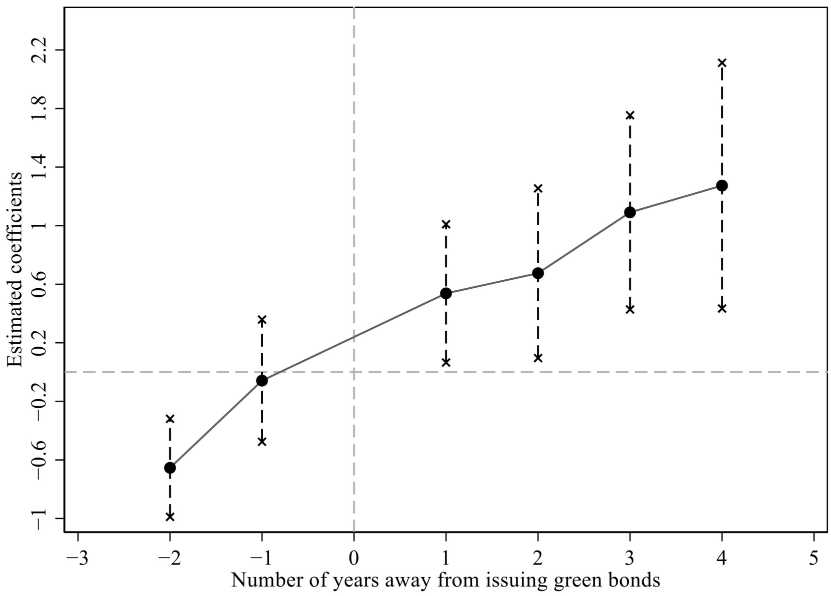

Figure 4. Results of dynamic heterogeneity analysis.

According to the results in Figure 4, the coefficients from the advanced green bond issuances (one and two years) are negative. In comparison, the regression coefficients from delayed issuances (one to four years) are positive. The coefficients from the one-year advance are insignificant, and the coefficients from the three-year delay are significant. Therefore, we can conclude that the difference between the experimental and control groups in green innovation becomes significant only after firms have issued green bonds. From the perspective of dynamic heterogeneity, green innovation shows an incremental trend after firms issue green bonds. The fastest growth in the number of green patents occurs two to three years after the issuance of green bonds. After the third year, the long-term impact of issuing green bonds on corporate green innovation begins to decline. In summary, it is feasible to conclude that green bonds have a dynamic and sustainable effect on promoting green innovation activities.

6.2.2. Enterprise Heterogeneity

In Section 6.2, the sample is firstly divided into two groups: state-owned and non-state-owned firms, and then we conducted regressions on each group. As a result, we can examine the conditioning effect of the nature of property rights. Columns (1) and (2) in Table 9 show the regression findings. The regression coefficient $Green \times After$ in the sample group of SOEs is considerably positive at the 1% level, indicating that the issuance of green bonds by SOEs can promote green innovation. However, in the sample of non-SOEs, the regression coefficient is statistically insignificant, indicating that green bonds issued by non-SOEs do not promote green innovation. Accordingly, green bonds issued by state-owned firms have a more significant impact on promoting green innovation than they do when issued by non-state-owned firms.

Secondly, the sample was divided into two groups based on the mean firm size. Specifically, if a firm's size is larger than or equal to the mean value, the firm is classified as a large enterprise. Otherwise, it is classified as a small enterprise. The regression findings for two sets of samples, large and small firms, are shown in columns (3) and (4) of Table 9. The regression coefficient $Green \times After$ in the sample group of large firms is considerably positive at the 1% level, indicating that the issuance of green bonds by large firms can promote green innovation. On the contrary, in the sample of small firms, the regression coefficient is statistically insignificant, indicating that green bonds issued by small firms do not promote green innovation. Accordingly, green bonds issued by large enterprises have a more significant impact on green innovation than small enterprises.

Table 9. Enterprise heterogeneity test.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	SOEs	Non-SOEs	Large	Small	Non-HPEs	HPEs
Green × After	0.773 ***	0.328	0.675 ***	0.001	0.638 ***	0.175
	(0.23)	(0.35)	(0.25)	(0.33)	(0.24)	(0.27)
lnSize	0.326 ***	0.228 ***	0.462 ***	0.162 ***	0.276 ***	0.268 ***
	(0.02)	(0.01)	(0.03)	(0.01)	(0.01)	(0.02)
Leverage	0.169	0.445 ***	0.422 ***	0.291 ***	0.493 ***	0.004
	(0.11)	(0.07)	(0.11)	(0.07)	(0.07)	(0.12)
ROA	−0.089	0.050	0.178	−0.097	0.096	−0.395
	(0.37)	(0.15)	(0.28)	(0.15)	(0.16)	(0.30)
Tangibility	−0.357 ***	−0.198 *	−0.379 ***	−0.285 ***	−0.477 ***	0.038
	(0.13)	(0.11)	(0.14)	(0.09)	(0.10)	(0.14)
Age	−0.014 ***	−0.005 **	−0.006 *	−0.011 ***	−0.006 **	−0.011 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Growth	−0.277 ***	−0.193 ***	−0.263 ***	−0.159 ***	−0.262 ***	−0.087
	(0.10)	(0.04)	(0.07)	(0.04)	(0.04)	(0.08)
Dual	−0.012	0.013	−0.036	−0.015	−0.007	−0.051
	(0.06)	(0.02)	(0.04)	(0.02)	(0.02)	(0.04)
IndRatio	−0.005	−0.001 ***	−0.002 **	−0.002 ***	−0.003 ***	−0.001
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
MH	0.011 ***	−0.005 **	0.002	−0.003	0.001	0.005
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	−0.720 ***	−0.751 ***	−2.233 ***	−0.110	−0.950 ***	−1.335 ***
	(0.28)	(0.16)	(0.33)	(0.17)	(0.16)	(0.23)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Observation	2632	5203	3711	4124	6109	1726
R-squared	0.404	0.285	0.384	0.198	0.328	0.271

Note: ***, ** and * indicate statistical significance at levels of 1%, 5% and 10%, respectively, with robust standard errors in parentheses.

Lastly, we use the emission charge levy to identify the high-pollution industries. Specifically, the high-pollution industries include chemical manufacturing, pharmaceutical manufacturing, gold mining, coal mining, petroleum processing, paper manufacturing, beverage manufacturing, non-gold mining, and black gold processing. Accordingly, the sample was divided into high-pollution enterprises (HPEs) and low-pollution enterprises (Non-HPEs). The regression findings for the two sets of samples are shown in columns (5) and (6) of Table 9. The regression coefficient $Green \times After$ in the sample group of low-pollution firms is considerably positive at the 1% level, indicating that issuing green bonds by low-pollution firms can promote green innovation. However, in the HPEs' sample, the regression coefficient is statistically insignificant, indicating that green bonds issued by HPEs do not promote green innovation. Accordingly, green bonds issued by Non-HPEs have a more significant impact on promoting green innovation.

7. Conclusions

This paper investigated the impact of green bonds on corporate green innovation and the mechanism of its effect, using a sample of Chinese listed companies and taking 2017 to 2019 as the observation period, and yields various exciting findings. First and foremost, a significant positive relationship exists between issuing green bonds and corporate green innovation, indicating that green bonds can promote corporate green innovation. This result considers the endogeneity issue and passes a series of robustness tests. Second, the mechanism test demonstrates that enterprises alleviate financing constraints by issuing green bonds, which stimulates green innovation. Thus, we can conclude that alleviating financing constraints is a mediating path for green bonds to promote green innovation. Third, we group firms according to the nature of property rights, firm size, and industrial pollution attributes and then regress each group of samples. The results show that the issuance of green bonds by state-owned enterprises, large enterprises, and low-pollution enterprises has a more significant effect on green innovation than non-state-owned enterprises, small enterprises, and high-pollution enterprises.

This paper provides strong evidence that green bonds positively impact corporate green innovation and provide more confidence and reason to encourage governments to develop the green bonds market. Our study also reveals that high-pollution enterprises have weaker incentives to issue green bonds for green innovation. However, green innovation by high-pollution enterprises is the top priority for achieving green development. Therefore, green bond issuance policies should be more favorable to high-pollution enterprises. According to our results, the government needs to improve the green bond issuance policy further to enhance the allocation efficiency of financial resources and provide timely funding for corporate green innovation.

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Appendix A

Table A1. Balance test for PSM.

Variable	Match Method	Mean		Bias		*t*-Test	
		EG	CG	Bias	Reduction	*t*	*p*-Value
SOE	Unmatched	0.544	0.334	43.0		3.340	0.001
	Method 1	0.544	0.579	−7.2	83.2	−0.370	0.709
	Method 2	0.544	0.545	−0.1	99.6	−0.010	0.993
	Method 3	0.544	0.544	−0.2	99.8	−0.010	0.996
lnSize	Unmatched	8.877	7.745	93.0		7.030	0.000
	Method 1	8.877	8.861	1.3	98.7	0.070	0.942
	Method 2	8.877	8.844	2.7	97.1	0.150	0.885
	Method 3	8.877	8.836	3.4	96.4	0.180	0.855
Leverage	Unmatched	0.614	0.426	125.5		7.200	0.000
	Method 1	0.614	0.607	4.7	96.3	0.290	0.770
	Method 2	0.614	0.622	−4.7	96.3	−0.300	0.762
	Method 3	0.614	0.622	−4.8	96.1	−0.310	0.755
ROA	Unmatched	0.022	0.033	−19.2		−1.090	0.275
	Method 1	0.022	0.028	−9.9	48.4	−0.610	0.543
	Method 2	0.022	0.023	−0.5	97.2	−0.030	0.974
	Method 3	0.022	0.023	−1.2	93.7	−0.080	0.940
Tangibility	Unmatched	0.298	0.204	55.9		4.550	0.000
	Method 1	0.298	0.324	−15.6	72.2	−0.740	0.460
	Method 2	0.298	0.291	4.1	92.6	0.200	0.845
	Method 3	0.298	0.292	3.7	93.3	0.180	0.860

Table A1. *Cont.*

Variable	Match Method	Mean		Bias		*t*-Test	
		EG	CG	Bias	Reduction	*t*	*p*-Value
Age	Unmatched	19.684	20.489	−14.8		−1.140	0.255
	Method 1	19.684	19.789	−1.9	86.9	−0.110	0.912
	Method 2	19.684	19.766	−1.5	89.9	−0.080	0.936
	Method 3	19.684	19.712	−0.5	96.6	−0.030	0.978
Growth	Unmatched	0.165	0.118	20.0		1.420	0.156
	Method 1	0.165	0.110	23.4	−16.6	1.430	0.155
	Method 2	0.165	0.168	−1.4	93.1	−0.060	0.951
	Method 3	0.165	0.168	−1.3	93.5	−0.060	0.953
Dual	Unmatched	0.246	0.278	−7.4		−0.550	0.583
	Method 1	0.246	0.263	−4.0	46.4	−0.210	0.832
	Method 2	0.246	0.247	−0.4	94.5	−0.020	0.982
	Method 3	0.246	0.247	−0.3	95.8	−0.020	0.987
IndRatio	Unmatched	9.680	13.334	−20.7		−1.460	0.144
	Method 1	9.680	7.943	9.9	52.5	0.560	0.578
	Method 2	9.680	9.315	2.1	90	0.120	0.908
	Method 3	9.680	9.092	3.3	83.9	0.190	0.851
MH	Unmatched	36.740	37.682	−16.4		−1.340	0.181
	Method 1	36.740	36.131	10.6	35.3	0.620	0.538
	Method 2	36.740	36.660	1.4	91.5	0.080	0.939
	Method 3	36.740	36.675	1.1	93.1	0.060	0.950

Note: EG and CG denote the experimental and control groups, respectively. The bias in the table is standardized bias. Method 1, Method 2 and Method 3 denote the use of k-nearest neighbor matching, caliper radius matching and k-nearest neighbor matching within caliper radius methods, respectively.

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