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Leverage effect or crowding out effect: the impact of green bonds on corporate green innovation

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Abstract: Green bonds are an important part of the green financial system, and their dual attributes of external supervision and market allocation are crucial to corporate green innovation. Based on the panel data of Chinese A-share listed companies from 2009 to 2023, this paper uses the progressive difference-in-differences model to explore the impact of green bond issuance on corporate green innovation. It is found that enterprises can improve the level of green innovation by issuing green bonds. The issuance of green bonds achieves the leverage effect on green innovation on the basis of existing innovation activities by encouraging enterprises to increase R&D investment and human capital.

Keywords: Green bonds; Enterprise green innovation; Difference-in-differences model.

1. Introduction

Compared with other forms of technological innovation, green technological innovation is characterized by long payback periods, high initial costs, and high failure risks, which result in a lack of sufficient incentives for firms to engage in green innovation activities [1]. To address this incentive issue, government agencies have successively introduced a series of environmental policies to incentivize firms to pursue green innovation. However, some scholars have found that, due to constraints on limited production resources, resource allocation toward green innovation may crowd out resources intended for non-green innovation [2]-[3]. At the same time, if environmental policies rely solely on government efforts and lack financial support from market mechanisms, they will struggle to fundamentally resolve the problem of resource constraints for enterprises. Consequently, green innovation activities may crowd out non-green innovation resources, creating a "crowding-out effect" on non-green innovation. This would hinder the improvement of enterprises' overall innovation performance, leading to a decline in operating profits and market competitiveness, and consequently affecting the comprehensive green transition of the economy and society. It is evident that enhancing enterprises' green innovation levels without compromising other innovation activities—and achieving a leverage effect built upon existing innovation efforts—requires addressing resource constraints. The capital support provided by market mechanisms is an effective means of directly increasing external resources for enterprises and alleviating constraints on endogenous production resources. Consequently, what kind of environmental policy can introduce market-based capital while maintaining regulatory oversight, effectively resolving the resource constraints on green innovation to achieve the "leverage effect" of corporate green innovation?

Green bonds are debt instruments issued to promote corporate green development, primarily channeling social capital through low-carbon project bonds into green projects such as energy-saving and emission-reduction technological upgrades and the clean and efficient use of energy. As a market-based green financial instrument issued at the discretion of enterprises, green bonds possess dual attributes of "green" and "financial," creating conditions to address the aforementioned issues. Under external oversight by stakeholders such as the government and third-party institutions, issuers of green bonds restrict the use of raised funds to government-defined green projects, ensuring that capital precisely supports the green sector[4]; simultaneously, by leveraging the market allocation advantages of financial instruments to guide capital flows toward green development sectors, they play a crucial role in addressing financing challenges for projects related to green innovation, energy conservation and emissions reduction, and clean energy . This paper will therefore examine, from both theoretical and empirical perspectives, the incentive and leverage effects of green bond issuance on corporate green innovation. This provides new empirical evidence regarding the role of green bonds in enhancing corporate green innovation levels.

The marginal contributions of this paper are as follows: (1) This paper examines the impact of green bond issuance on corporate green innovation is reflected in the "leverage effect" superimposed on the existing overall innovation activities, rather than the "crowding out effect" on other innovations, which provides a new idea for the subsequent exploration of the development motivation of the "leverage effect" of green innovation. Secondly, from the perspective of external financing and R & D resource investment, this paper reveals the potential impact mechanism of green bond issuance on the leverage effect of enterprise green innovation, and provides empirical evidence for effectively solving the problem of enterprise green innovation resource constraints. Thirdly, from the perspective of innovation behavior choice, it is found that enterprises prefer to carry out strategic and joint green innovation activities after issuing green bonds, which provides new practical experience for the strategic behavior and cooperative behavior of green bonds in the field of green innovation.

2. Theoretic hypothesis

Theoretically, green bonds differ from traditional command-and-control or market-based environmental regulatory tools; they are the product of the synergy between green finance and external regulation, and can effectively

drive enterprises to enhance their level of green innovation through the interaction between market mechanisms and regulatory attributes.

The theory of resource allocation states that markets guide the flow of factors through price mechanisms to achieve optimal resource allocation. Green bonds use price mechanisms to channel capital toward green innovation sectors, alleviating the challenges enterprises face during green transition—such as difficulty in securing financing, high financing costs, and maturity mismatches. First, issuing green bonds helps enterprises achieve excess returns in capital markets, reduces the risk of sharp stock price declines, attracts investor attention, and thereby improves financing conditions. At the same time, the issuance of green bonds sends a positive signal to the market, alleviating investors' concerns about the high-risk nature of green projects and promoting the concentration of capital in green innovation sectors[6]. Second, green innovation projects typically involve long cycles and high risks, leading to higher risk premiums for enterprises in traditional credit markets. However, because green bonds benefit from government support, they can effectively reduce these risk premiums, thereby lowering financing costs. Finally, the repayment terms of green bonds align with the long-term nature of green innovation activities, helping to alleviate the issue of financing maturity mismatches and strengthening enterprises' motivation to sustainably invest in green innovation.

From a regulatory perspective, green bonds mitigate issues of technology spillovers and adverse selection through rigorous compliance reviews and disclosure mechanisms, thereby enhancing corporate green innovation capabilities. On the one hand, projects funded by green bonds must undergo certification and verification by government and third-party institutions, and issuers are required to disclose environmental information across the entire value chain. This strict oversight helps maintain market fairness, alleviates the decline in corporate innovation incentives caused by technology spillovers, and encourages enterprises to increase investment in green technology R&D[7]. On the other hand, through the combined effects of government "endorsement" and information disclosure mechanisms, green bonds help alleviate information asymmetry between financial institutions and enterprises, reduce the risk of adverse selection, thereby improving the corporate financing environment and alleviating the financial pressure associated with pursuing green innovation. Therefore, we propose that:

Hypothesis 1. Corporate issuance of green bonds helps enhance the level of green innovation.

A further question is whether the promotional effect of green bonds on corporate green innovation is a "leverage effect" or a "crowding-out effect." According to the biased technological progress model, there is a substitution relationship between non-green innovation and green innovation. Mandatory environmental regulations often exacerbate resource constraints for enterprises, forcing them to divert resources from non-green innovation to fund green innovation, thereby creating a "crowding-out effect." However, under the synergistic interaction of market mechanisms and regulation, green bonds can effectively alleviate resource constraints, provide financial support for new R&D investments, and layer green innovation onto existing innovation efforts, thereby generating a "leverage effect." However, if non-compliance such as greenwashing erodes investor confidence in green bonds, leading to a decline in market valuations and preventing firms from maximizing their financing benefits, they may be forced under regulatory pressure to reduce general innovation investments to support green innovation, thereby generating a "crowding-out effect". Based on this, Hypothesis 2 of this paper is proposed:

Hypothesis 2a. The green innovation induced by firms issuing green bonds is a "leverage effect" built upon existing innovation activities.

Hypothesis 2b. The green innovation induced by corporate issuance of green bonds constitutes a "crowding-out effect" on non-green technological innovation.

3. Research design

3.1. Data source and sample selection

This study utilizes annual data on green patents and financial data from 2009 to 2023 for companies listed on the A-share markets in China. Companies that issued green bonds are designated as the treatment group, while companies that issued conventional bonds are designated as the control group to mitigate endogeneity issues arising from sample selection bias. The corporate patent data and green patent data used in this study were first obtained from the China Research Data Service Platform (CNRDS) database. Green bond data was classified based on the green bond classifications in the Wind database and the CSMAR database. Corporate financial data was sourced from the Wind database and the CSMAR database.

After collecting data for the sample period, the raw data was processed as follows: (1) Exclude ST and ST* companies within the sample period; (2) Samples with missing observations for core variables (including corporate patent data and corporate green patent data) were removed, and data sets with fewer than three consecutive years of data were excluded; (3) All continuous variables were trimmed at the top and bottom 1% to control for the abnormal influence of outliers; (4) To mitigate random errors caused by individual differences and enhance the comparability of estimated pre- and post-policy effect differences: the control group sample retained only the 24 major industry categories in which the treatment group companies were located, with industry classification referencing the 2017 "National Economic Industry Classification Standard" (GB/T 4754-2017). Ultimately, a total of 1997 listed companies were identified, providing 14950 annual observations.

3.2. Model design and variable definitions

The timing of green bond issuances varies across firms, exhibiting a self-selection characteristic across periods. To effectively estimate the pre- and post-policy difference effects influenced by the timing of bond issuances and to mitigate endogeneity issues in traditional difference-in-differences regression, this study adopts the approach of Dong et al.[5] to establish a progressive difference-in-differences model, with the specific specification given in Equation (1):

$$Green_{it}=\alpha_0+\alpha_1 GB_i\times Post_t+\alpha_2 X_{it}+\delta year_t+\gamma industry_{it}+\mu firm_{it}+\varepsilon_{it} \quad (1)$$

where the dependent variable is the firm's level of green innovation ($Green_{it}$). This study uses the number of corporate patent grants to measure green innovation, specifically calculated as the sum of green invention patent grants and green utility model patent grants, plus one, taken as the logarithm. Subsequently, corporate patent applications are

used to replace patent grants for robustness tests. The core explanatory variable is $GB_i \times Post_t$, representing the difference in treatment effects before and after the policy in the model. Specifically, when a firm is the issuer of a green bond, GB_i takes the value 1 and enters the treatment group; when the firm is an issuer of conventional bonds, GB_i takes the value 0 and is assigned to the control group. $Post_t$ is a time dummy variable; if firm i in the treatment group issues a green bond at time t, it takes the value 1 at time t and thereafter, otherwise it takes the value 0; for firms in the control group, all take the value 0. Xit represents a series of control variables. We also include the firm, industry, and year fixed effect firmit, industryit and yeart. Standard errors in all specifications are clustered by firm.

Furthermore, to verify whether the issuance of green bonds exerts a leverage effect or a crowding-out effect on firms' green innovation levels, this study selects the following mechanism test variables: total innovation (Total), non-green innovation level (Non-Green), proportion of green innovation (Rate-Green), R&D expenditure (R&D), human capital (Employee), and external financing (Longdebt). The specific variable definitions are shown in Table 1.

Table 1. Variable Definition

Type	Name	Variable	Definition
Dependent	Corporate Green Innovation	Green	Ln (Number of green patents granted to the company + 1)
Independent	Issue green bonds	$GB_i \times Post_t$	dummy variables
Control	Company Size	Size	Natural logarithm of total assets
	Financial Leverage	Lev	Total liabilities / Total assets
	Company Age	Age	Years since IPO (years)
	Profitability	ROA	Return on total assets (%)
	Board Independence	Independent	Percentage of independent directors
	Shareholding Concentration	shareholders	Number of shares held by the chairman
	Nature of Ownership	SOE	dummy variables
	Dual Role (CEO and Chairman)	Position	dummy variables
	Audited by the Big Four	Audit	dummy variables
Mechanism	Total Corporate Innovation	Total	Ln (Total number of patents granted to the firm + 1)
	R&D Expenditures	R&D	Natural logarithm of R&D expenditure
	Human Capital	Employee	Natural logarithm of the firm's number of employees
	Level of Non-Green Innovation	Non-Green	Ln(Number of non-green patents granted to the firm + 1)
	Share of Green Innovation	Rate-Green	Number of green patents granted to the firm / Total number of patents granted to the firm
	Amount of External Financing	Longdebt	Long-term debt / Total assets

4. Empirical results

4.1. Baseline results

Table 2. Baseline results: green bonds and corporate green innovation.

Variables	(1)	(2)	(3)
$GB_i \times Post_t$	1.5441***(0.0668)	0.6337***(0.0579)	0.2784***(0.0658)
Size		0.4664***(0.0083)	0.4340***(0.0180)
Lev		-0.2795***(0.0547)	-0.2537***(0.0720)
Age		0.0099***(0.0014)	-0.0144(0.0548)
Independent		0.0066***(0.0015)	0.0064***(0.0018)
SOE		-0.0666***(0.0213)	-0.0114(0.0502)
Position		0.0303(0.0191)	0.0054(0.0215)
Audit		-0.0260(0.0347)	-0.0408(0.0634)
ROA		-1.0578***(0.1729)	-0.3997**(0.1559)
Shareholders		0.0004(0.0007)	0.0054***(0.0011)
_cons	1.2607***(0.0096)	-8.3304***(0.1793)	-8.5036***(0.6894)
Firm FE	No	No	Yes
Industry FE	No	No	Yes
Year FE	No	No	Yes
N	14950	14950	14950
Adj.R2	0.0345	0.3167	0.7105

Notes: The robust standard errors, clustered by company, are shown in parentheses. The significance levels are denoted as follows: "***" signifies a 1 % significance level, "**" signifies a 5 % significance level, and "*" signifies a 10 % significance level (Similarly hereinafter).

Table 2 reports the baseline regression results. Column (1) presents the regression results without control variables or fixed effects. Column (2) includes control variables, while Column (3) further adds firm, industry, and time fixed effects. In all three columns, the coefficients of the core independent variable are positive and statistically significant at the 1% level. This indicates that after issuing green bonds, the number of green patent grants increases significantly; that is, issuing green bonds helps enterprises enhance their level of green innovation, supporting Hypothesis 1. Furthermore, this indirectly suggests that resource misallocation issues in the development of China's green bond market are not significant.

4.2. Robustness checks

4.2.1. Parallel trend test

The core identification assumption of the DID model is the parallel trends assumption. By setting a 95% confidence interval and plotting the dynamic effect regression coefficients with the period immediately preceding policy implementation as the base period, the test results are shown in Fig. 1: Before firms issued green bonds, the regression coefficient remained positive around zero and was not significantly different from zero; however, after policy implementation (t>0), the regression coefficient generally remained positive and was significantly different from zero, satisfying the parallel trends test. Furthermore, the results of the dynamic effects analysis indicate that the regression coefficient is generally significantly positive and exhibits an increasing trend, suggesting that the policy effect strengthens to some extent over time. The positive incentive effect of green bond issuance on green innovation demonstrates long-term stability and can drive a sustained improvement in enterprises' green innovation levels.

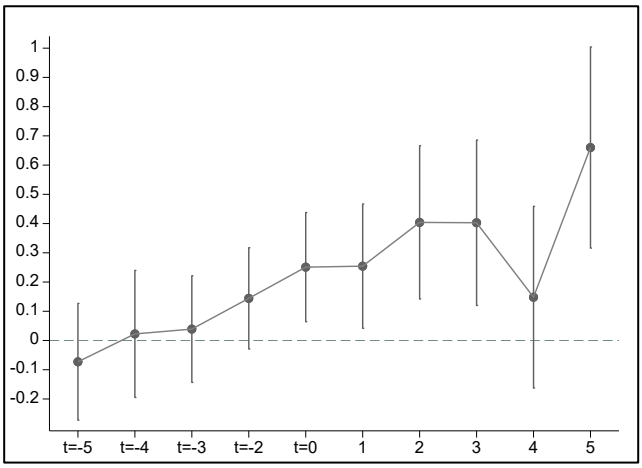

Fig. 1 Parallel trend test.

4.2.2. Placebo test

This paper adopts a randomization inference method to confirm that the baseline result is not attributable to random chance. Specifically, 1000 random samples were drawn to construct pseudo treatment and control groups, and model (1) was re-estimated to examine the distribution of regression coefficients and p-values. As shown in Fig. 2, the average coefficient obtained from the 1000 randomized simulations is close to zero and much smaller than the actual coefficient. The distribution of coefficients approximates a normal distribution, and the majority of p-values are larger than 0.1, indicating insignificance at the 10% level. The results indicate that the baseline result is due to the actual policy rather than other random factors.

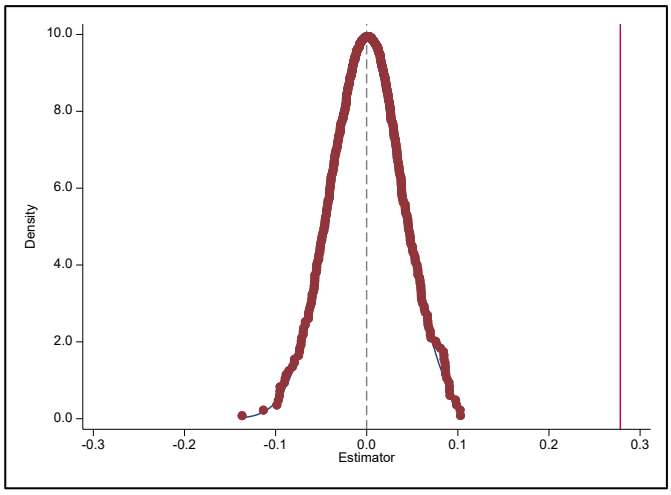

Fig. 2 Placebo test.

4.2.3. Other Robustness Checks

Table 3. Other robustness test results.

Variables	An alternative Corporate Green Innovation measure	Lagged by one period	The Environmental Protection Tax Law of the Peoples Republic of China
	(1)	(2)	(3)
$GB_i \times Post_t$	0.2379***(0.0726)	0.1937**(0.0770)	0.2538***(0.0674)
_cons	-9.5999***(0.6719)	-7.6200*** (0.5568)	-9.4995***(0.3820)
Time trend term	No	No	Yes
controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	14950	11857	14950
Adj.R2	0.7078	0.7178	0.7059

Note: Due to space limitations, the results for control variables are not reported but are available upon request. The same applies to all subsequent tables.

To further enhance the robustness of the baseline regression results in Model (1), this study conducts the following three robustness tests: First, we use the number of green patent applications filed by firms. We replace the measurement of the dependent variable with ln(number of green invention patent applications + number of green utility model patent applications + 1)—that is, the number of green patent applications—as a proxy for firms' green innovation levels, and repeat the regression. The results are consistent with those of the baseline regression. Second, we lag the independent and control variables by one period. Considering the lag in policy implementation effects and corporate innovation outcomes, we repeat the regression after lagging the independent and control variables by one period; the results are consistent with those of the baseline regression. Third, we control for the influence of other competing policy factors. On January 1, 2018, the Environmental Protection Tax Law of the People's Republic of China officially came into effect,

which may have influenced firms' decisions regarding green innovation activities. We introduced a dummy variable for 2018. Since the original model included time-fixed effects, we replaced these with a time-trend term to avoid multicollinearity issues. We then repeated the regression, and the results were consistent with those of the baseline regression, demonstrating robustness.

4.3. Mechanism analysis: leverage effect or crowding-out effect

This paper conducts separate regressions on the dependent variables in Model (1), including overall innovation, R&D investment, human capital, the share of green innovation, non-green innovation, and the volume of external financing. The treatment of these variables follows the definitions provided earlier. In this context, the proxy variable for the volume of external financing is measured by the proportion of long-term loans, as long-term loans are more critical to corporate innovation investment than short-term loans. An increase in the proportion of long-term loans indicates that firms have obtained funds from external financing channels, making it easier for them to increase innovation investment.

First, we verify whether a "crowding-out effect" exists. As shown in Column (1) of Table 4, the regression coefficient for non-green innovation is significantly positive, indicating that the volume of non-green innovation has not decreased; thus, the green innovation induced by green bonds has not produced a "crowding-out effect" on non-green innovation activities. Furthermore, this study conducts a regression analysis on the share of green innovation. As shown in column (2), the regression coefficient for the proportion of green innovation is significantly negative, indicating that green innovation has not displaced the share of non-green innovation in overall innovation; that is, the issuance of green bonds has not produced a "crowding-out effect" on non-green innovation activities. Hypothesis H2b is not supported. The above results indicate that corporate green innovation induced by green bond issuance has not displaced resources from non-green innovation, leading to the reduction or postponement of non-green innovation projects. This also indirectly reflects that the "greenwashing" phenomenon in China's green bond market is not significant, and the market demand and value prospects for green bonds are promising.

Second, we examine whether a "leverage effect" exists. As shown in Column (3) of Table 4, the regression coefficient for the volume of corporate external financing is significantly positive, indicating that the market mechanism of green bonds has been effective in increasing the volume of external social capital for enterprises. As shown in columns (4) through (6), the impact coefficients for overall corporate innovation levels, R&D expenditures, and human capital are all significantly positive. This indicates that following the issuance of green bonds, enterprises' overall innovation activities, R&D expenditure levels, and human capital investment have all increased significantly. This suggests that the market and regulatory attributes of green bonds have been effectively integrated, attracting sufficient social capital to effectively alleviate enterprises' resource constraints, thereby incentivizing them to increase innovation resources—such as R&D investment and human capital—to expand the scale of their innovation activities. Furthermore, the increased investment in innovation resources allows firms to avoid diverting production resources from their existing innovation activities. This triggers a "leverage effect" where green technological innovation is layered onto existing innovation activities, thereby validating Hypothesis H2a. This also implies that "greenwashing" behavior is not significant in China's green bond market. The combined forces of the external regulatory and market attributes of green bonds can effectively resolve firms' constraints on green innovation resources, driving green innovation toward a more robust trajectory.

Table 4. Mechanism test results.

Variables	crowding-out effect test		leverage effect test			
	(1)	(2)	(3)	(4)	(5)	(6)
	Non-green innovation	Share of green innovation	External funding	Overall innovation	R&D investment	Human capital
$GB_i \times Post_t$	0.0304***(0.0729)	-0.0234** (0.0105)	0.0203*** (0.0045)	0.2918*** (0.0722)	0.2852*** (0.0768)	0.0714*** (0.0265)
_cons	-10.3328(0.8589)	-0.0083 (0.0825)	-0.5212*** (0.0353)	-10.5244*** (0.8808)	0.8351 (0.5346)	-8.9136*** (0.7927)
controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	14950	14456	14950	14950	13680	14950
Adj.R2	0.7948	0.5945	0.7573	0.7911	0.8843	0.9468

Notes: Between-group coefficient differences in the heterogeneity analysis are obtained using Fisher's combined probability test with 500 resamples.

5. Conclusions

Green bonds, leveraging the advantages of external regulation and market-based financing, have become a vital pillar for alleviating resource constraints on green innovation, addressing climate change, and promoting the sustainable development of the economy and society. Therefore, this study utilizes data from Chinese A-share listed companies from 2009 to 2023 and employs an incremental difference-in-differences model to examine the impact of green bond issuance on corporate green innovation and its enhancement mechanism (whether through a leverage effect or a crowding-out effect). The study finds that: (1) Green bond issuance exerts a significant positive incentive effect on corporate green innovation. (2) The green innovation induced by green bond issuance represents a "leverage effect" superimposed on existing innovation activities. The mechanism of this effect manifests as green bond issuance increasing external

financing, which helps alleviate corporate resource constraints and thereby incentivizes firms to increase R&D investment and human capital to advance green innovation.

Based on this, this paper offers the following two insights:

First, fully tap into the development potential of the green bond market to expand its scale. On the one hand, strengthen fiscal policy support to encourage more entities to adopt green bonds as a financing method, thereby broadening the scope of green bonds' impact on green innovation and their leverage effect. On the other hand, enhance the service capabilities of rating agencies and third-party certification bodies to better serve a diverse range of issuers, helping more types of enterprises gain market recognition and unlock market development potential.

Second, greater efforts should be made to alleviate resource constraints on enterprises, thereby boosting the leverage effect of their green innovation. The key to enhancing enterprises' green innovation capabilities—without compromising their normal operations or growth—lies in alleviating resource constraints. For financial institutions such as banks, this requires strengthening liquidity management capabilities to ensure the funding needs of more green bond issuers are met, thereby helping enterprises overcome resource constraints and achieve breakthroughs in green innovation. At the same time, we should actively promote the development of green bond derivatives and innovative green bond products, such as sustainability bonds, transition bonds, and green bond ETFs. By leveraging product diversity to expand financing capacity, we can mitigate the substitution effect between non-green innovation and green innovation caused by resource constraints, thereby achieving a leverage effect for corporate green innovation.

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