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Exploring the Role of Green Bonds in Advancing Corporate Innovation

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Abstract: This investigation examines the repercussion of green bond issuance on corporate eco-innovation, utilizing a sample of A-share companies listed on the Shanghai and Shenzhen stock exchanges between 2008 and 2022 through the Difference-in-Differences (DID) model. The findings indicate that green bond issuance significantly boosts a company's eco-innovation level, a conclusion supported by robust evidence from parallel trend tests, dependent variable adjustments, and placebo analyses. Secondly, through mechanism analysis, it is found that the promotion of corporate eco-innovation by green bonds is driven by two mechanisms: increased R&D investment and enhanced external supervision. Considering heterogeneity, the repercussion of green bond issuance on enhancing eco-innovation is particularly significant for state-owned enterprises, firms in non-heavy-pollution industries, and high-tech companies.

Keywords: Sustainable Bonds, Eco-Innovation, Difference-in-Differences Approach

1. Introduction

In the context of increasing global ecological and environmental pressures and the growing importance of sustainable development, enterprises, being central to economic activities, hold a crucial role in advancing eco-innovation. Enterprises require substantial financial investment to engage in eco-innovation initiatives, which aim to enhance the green added value of products and services and improve market competitiveness. Green bonds, as an emerging financial instrument, have emerged to meet this need. With clear usage of funds and environmental benefits, green bonds have attracted widespread attention from both investors and enterprises, providing new sources of funding for corporate eco-innovation. Simultaneously, governments around the world have introduced policies such as "Guidelines for Green Bond Issuance" and "Guiding Opinions on Building a Green Financial System," offering subsidies and incentives for eco-innovation, thereby creating a favorable policy environment for enterprises to engage in eco-innovation. The demand for green investments among investors is steadily increasing, prompting financial institutions to intensify the issuance and promotion of green bonds, further facilitating the financing and development of green enterprises. According to the latest data from Wind, in 2023, China issued 802 green bonds totaling 1.11805 trillion yuan, marking the second consecutive year in which the issuance scale exceeded one trillion yuan.

The specific repercussion of green bond issuance on corporate eco-innovation remains unclear. A thorough investigation of this issue is of significant theoretical and practical importance for

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optimizing the allocation of green financial resources, promoting corporate innovation, and achieving sustainable economic growth. Currently, academic investigations into green bonds predominantly address their issuance mechanisms, pricing strategies, and effects on macroeconomics and financial markets [1-3]. Relatively few studies have been conducted on how green bonds specifically affect corporate eco-innovation at the micro level, and there are some controversies and gaps in the existing literature.

This investigation examines the mechanisms and practical implications of green bond issuance on corporate green technological advancement, using A-share companies listed on the Shanghai and Shenzhen stock exchanges from 2008 to 2022 as a sample. Through empirical investigation of a large number of corporate samples, combined with relevant theories and practical cases, this research reveals the role of green bonds in promoting eco-innovation in areas such as corporate R&D and external supervision. At the same time, it will analyze potential constraints and risks that may exist.

The key improvements and novel ideas of this analysis are highlighted in the following aspects: This investigation applies the Difference-in-Differences (DID) model to analyze the supporting effect of green bond issuance on the green technological advancement of A-share listed companies from 2008 to 2022, expanding the breadth and depth of studies examining the connection between green bonds and corporate eco-innovation [4]. First, a more comprehensive and refined set of indicators is used to measure corporate eco-innovation, improving the accuracy and reliability of the research. Second, a new research perspective is introduced, considering the mediating effects of factors such as internal R&D and external supervision on the connection between green bonds and eco-innovation. Finally, through a comparative analysis of enterprises with different ownership structures and industries, this analysis studies the differential repercussion of green bonds on different types of enterprises.

The remainder of this investigation is structured as follows: Section 2 discusses the literature and develops the core hypotheses. Section 3 details the research methodology, including data collection, sample framework, model construction, and variable definitions. Section 4 presents the empirical findings with comprehensive investigation and discussion. Section 5 delves into further exploratory analysis. The final section summarizes the main findings, offers policy recommendations and strategies for enterprises, and discusses future research directions.

2. Literature Review and Hypothesis Development

2.1. Literature Review

2.1.1. Research on Green Bonds

Current research on green bonds mostly focuses on two aspects: issuance pricing and economic consequences.

From the perspective of issuance pricing, most studies examine the effect of conditions such as public issuance, government support, credit ratings, and market factors on the pricing of green bonds [5]. Xiya Yang et al. pointed out that green bonds issued publicly tend to have more significant financing advantages compared to privately issued green bonds [6]. Enterprises receiving more government subsidies typically enjoy lower financing costs when issuing green bonds compared to general credit bonds. The research by Yongdong Shi et al. supports this view, indicating that during periods of strong policy support and high market enthusiasm for green investments, the pricing of green bonds tends to be more favorable [7]. The investigation by Karpf et al. shows that green bonds issued by highly rated firms or firms from specific industries (such as renewable energy) tend to secure more favorable pricing conditions [8]. Zerbib's research found that, compared to traditional bonds, green bonds demonstrate some distinct characteristics in terms of risk-adjusted returns [9].

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Issuers of green bonds frequently benefit from reduced financing costs, likely due to investors' inclination toward environmental sustainability. Tobias et al. found, through empirical analysis, that the pricing of green bonds is influenced by factors such as overall market liquidity, macroeconomic conditions, and the bond's maturity structure [10].

From the perspective of economic consequences, Tang et al. conducted empirical research and found that the issuance of green bonds attracts more investor interest, leading to better performance in the stock market. The companies' stock prices and market value tend to rise [11]. The investigation by Caroline et al. indicates that issuing green bonds enhances a company's reputation and image, boosting investor confidence in the company, thereby increasing its value [12]. While most investigations on the economic consequences of green bond issuance focus on its effect on corporate value and ESG performance, fewer studies address the correlation between green bonds and eco-innovation.

2.1.2. Research on Corporate Eco-Innovation

Current research on corporate eco-innovation predominantly addresses two key aspects: the drivers of corporate green technological advancement and its economic outcomes.

In terms of the influencing factors of eco-innovation, the primary factors are the internal and external environment of the enterprise [13]. On the one hand, the internal environment of the enterprise plays a crucial role. Kesidou et al. pointed out that corporate size is positively correlated with the level of eco-innovation. Larger enterprises tend to have more advantages in terms of funding and other resources, which positively effects eco-innovation [14]. Agan et al. argued that a company's approach to environmental issues is influenced by the attention its management pays to these issues. On the other hand, the external environment also plays an important role. Jiancheng Wang et al. found that the stronger the media supervision of a company and the more coverage it receives, the greater the informal legitimacy pressure the company faces. As a result, the company is more likely to engage in green technological advancement, leading to better eco-innovation performance [15]. Peng Wang et al. suggested that strict environmental policies and regulations, such as higher pollution emission standards and environmental subsidies, place constraints on companies and provide incentives, urging them to engage in eco-innovation to meet policy requirements and gain policy support [16]. Furthermore, Lina Zhang emphasized that intense industry competition forces companies to pursue eco-innovation in order to gain a competitive advantage, thereby establishing and expanding their market position [17].

In terms of the economic consequences of eco-innovation, the effects are mainly seen in environmental benefits and economic benefits. Miao et al. found that green technological innovation can promote the reprocessing of greenhouse gases and slow down the growth rate of regional carbon emissions [18]. Chan et al. pointed out that companies engaged in green technological advancement are more likely to be recognized by investors, as eco-innovation helps listed companies achieve risk compensation, enhance stock returns, and increase corporate value [19]. Hanjun Xu argued that the level of innovation in listed companies is inversely related to their environmental governance cost ratio and positively related to their production efficiency [20].

2.2. Hypothesis Development

Yang Yang et al. indicated that corporate R&D investment is a major influencing factor for corporate innovation capability [21]. The "specificity" characteristic of green bond funds ensures that the funds raised by companies have a clear intended use, namely green projects. This allows the funds to be directed precisely to areas with environmental benefits and sustainable development potential [22]. Since the funds are restricted to green projects, the funds raised through green bonds from various

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enterprises are concentrated, resulting in a resource concentration effect. This concentration can lead to economies of scale in specific green sectors, reducing unit costs and improving resource utilization efficiency. Therefore, the lower financing cost of green bonds can increase a company's willingness to invest in additional R&D, thereby promoting eco-innovation.

Green bond issuance helps to mitigate information asymmetry between companies and their investors (Ran et al.) [23]. Under the market mechanism, investors typically have higher attention and expectations for companies issuing green bonds. This market oversight and reputational pressure may encourage companies to increase their efforts in eco-innovation to meet investors' environmental responsibility expectations and enhance their market image and competitiveness [24].

Moreover, the issuance of green bonds often involves stricter information disclosure requirements, allowing investors to gain more information about the company's environmental performance, thus enabling them to make more accurate investment decisions (Ghoul et al.) [25]. Therefore, to demonstrate the feasibility and benefits of their green projects to investors, companies have the incentive to increase R&D investment and engage in more eco-innovation activities, providing strong performance support, enhancing environmental competitiveness, and further promoting eco-innovation [26].

Drawing from theoretical frameworks, empirical evidence, and market dynamics, this study puts forward the following hypothesis:

H1: Green bond issuance promotes corporate green technological advancement.

3. Research Design - Model Construction and Variable Explanation

Following the approaches of Beck et al. and Ying Wang et al., this analysis adopts the Difference-in-Differences (DID) model, which is specified as follows:

$$Greenpatent_{i,t+1} = \beta_0 + \beta_1 DID + \gamma X_{i,t} + \mu_i + \varphi_j + \lambda_t + \varepsilon_{i,t} \quad (1)$$

In model (1), the dependent variable $Greenpatent_{i,t+1}$ indicates the level of eco-innovation of company i in year t+1, with t ranging from 2008 to 2022. In the investigation by Wenjing Li et al., the overall level of corporate eco-innovation was measured using ln (Green technological advancement patent applications + Green utility model patent applications + 1). Building upon this, this analysis extends the measurement by using ln(Green utility model patent applications + 1) to measure the "quantity" of corporate eco-innovation, and ln(Green invention patent applications + Green utility model patent applications + 1) to measure the overall level of corporate green technological advancement [27].

In the equation, $DID=TG_i \times GB_{i,t}$ is the core independent variable of this analysis. If a company belongs to the treatment group, TG_i takes the value of 1; otherwise, it takes the value of 0. For companies in the treatment group, if they issued green bonds in the year or any prior year, $GB_{i,t}$ takes the value of 1; otherwise, it takes the value of 0. μ_i、φ_j、λ_t indicate fixed effects at the individual, industry, and time levels, respectively. β_1 is the repercussion multiplier of green bond issuance on the level of corporate eco-innovation [28].

$X_{i,t}$ indicates the control variables. Based on existing literature, the following variables are selected: company size (Size), leverage ratio (Lev), return on assets (ROA), operating cash flow (OCF), revenue growth rate (Growth), fixed asset ratio (Far), board size (Board), duality (Duality), and the proportion of independent directors (Ind). The specific calculation methods are detailed in Table 1. To eliminate the effect of outliers on the results, the above continuous variables were Winsorized at the 1% level.

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Table 1: Variable Definitions

Variable Type	Variable Name	Variable Symbol	Calculation Method
Dependent Variable	Eco-Innovation "Quality"	Greenpatent1	ln(Number of Green Invention Patents + 1)
	Eco-Innovation "Quantity"	Greenpatent2	ln(Number of Green Utility Model Patents + 1)
	Overall Eco-Innovation Level	Greenpatent3	ln(Number of Green Invention Patents + Number of Green Utility Model Patents + 1)
Independent Variable	Firm Variable	TG	1 if the firm is in the treatment group, otherwise 0
	Bond Issuance Time Variable	GB	1 if the firm issued green bonds in the year or after, otherwise 0
Control Variables	Firm Size	Size	Natural log of total assets of the firm
	Debt-to-Asset Ratio	Lev	Total liabilities / Total assets
	Return on Assets	ROA	Net profit / Total assets
	Operating Cash Flow	OCF	Net operating cash flow / Total assets
	Revenue Growth Rate	Growth	(Current period revenue - Previous period revenue) / Previous period revenue
	Fixed Asset Ratio	Far	Net fixed assets / Total assets
	Board Size	Board	Natural log of the number of directors at the end of the year
	Dual Position Status	Duality	1 if the chairman also serves as the CEO, otherwise 0
	Proportion of Independent Directors	Ind	Number of independent directors / Total number of directors

4. Empirical Analysis

4.1. Descriptive Statistics

Table 2 displays the descriptive statistics, incorporating data from both green bond-issuing companies and the corresponding control group.

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Table 2: Descriptive Statistics

Variable	N	Mean	p50	SD	Min	Max
Greenpatent1	6894	0.2990	0	0.6900	0	5.2570
Greenpatent2	6894	0.3290	0	0.7100	0	5.7140
Greenpatent3	6894	0.4910	0	0.8980	0	5.9560
DID	6894	0.0040	0	0.0670	0	1
Size	6894	21.9200	21.7400	1.3190	19.3100	26.1300
Lev	6894	0.4490	0.4560	0.2110	0.0490	0.9150
ROA	6894	0.0490	0.0460	0.0720	-0.2280	0.2690
OCF	6894	0.0430	0.0450	0.0820	-0.2400	0.2700
Growth	6894	0.8280	0.1470	3.5870	-0.6350	30.0900
Far	6894	0.2220	0.1870	0.1720	0.0020	0.7180
Board	6894	2.1560	2.1970	0.1980	1.6090	2.7080
Duality	6894	0.2390	0	0.4260	0	1
Ind	6894	0.3689	0.3333	0.0512	0.2857	0.5714

4.2. Benchmark Regression Results

Table 3 provides the regression results, where Greenpatent1 represents the number of green invention patent applications, reflecting the "quality" dimension of corporate eco-innovation. Greenpatent2 measures the number of green utility model patent applications, capturing the "quantity" aspect of eco-innovation. Greenpatent3, as the sum of green invention patents and green utility model patents, represents the overall level of corporate eco-innovation. The coefficients for the core explanatory variable are significantly positive across all dependent variables, with values of 1.639, 2.088, and 2.228, respectively. Furthermore, the significance level of the core explanatory variable is consistent at 1% for Greenpatent1, Greenpatent2, and Greenpatent3. These results demonstrate that green bond issuance not only enhances the "quality" and "quantity" of eco-innovation but also elevates its overall level.

Table 3: Benchmark Regression Results

	(1) Greenpatent1	(2) Greenpatent2	(3) Greenpatent3
DID	1.6387***	2.0882***	2.2277***
	(5.4851)	(6.7396)	(5.8751)
_cons	-1.7354***	-2.6722***	-2.9771***
	(-3.6110)	(-5.3615)	(-4.8810)
N	6894	6894	6894
adj. R^2	0.5120	0.5040	0.5360
year	Yes	Yes	Yes
firm	Yes	Yes	Yes
controls	Yes	Yes	Yes

Note: The numbers in parentheses indicate t-values; * ** and *** denote significance at the 10%, 5%, and 1% levels, respectively.

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5. Research Conclusion

This analysis leverages data from A-share companies listed on the Shanghai and Shenzhen stock exchanges between 2008 and 2022, applying a Difference-in-Differences (DID) model to examine the effects of green bond issuance on corporate eco-innovation and its underlying mechanisms. The key findings are summarized as follows: First, empirical results indicate that green bond issuance significantly enhances both the "quality" and "quantity" of eco-innovation, as well as the overall level of eco-innovation. This conclusion is validated through a series of robustness checks, including parallel trend tests, alternative dependent variable analyses, and placebo tests. Second, the study investigates the heterogeneity of these effects from three dimensions: ownership structure, industry pollution levels, and technological intensity. The results reveal that green bonds have a more pronounced impact on eco-innovation in state-owned enterprises, firms in non-heavy-pollution industries, and high-tech companies. Third, the promotion of eco-innovation by green bonds operates through two key mechanisms: improvements in the internal corporate environment and the influence of external factors.

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