Green Bond Issuance and Firm Green Innovation

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Abstract. To examine whether the issuance of green bond by firms can promote the issuers' green innovation,this paper selects A-share listed firms from 2016 to 2021 as the research object, uses the number of green patents to measure the level of green innovation, then establishes a fixed effect model.The research shows that issuing Green bond can improve the level of green innovation of firms, and this transmission effect is realized through resource effect and efficiency mechanism,the supervision effect does exist but not very important.Moreover,by establishing DID and PSM models, it was found that the results are robust to the alternative model setting and endogeneity concerns.

Keywords: green bond, green patents, green innovation, DID.

1. Introduction

Green innovation is an investment activity of firms, which can not only enhance market competitiveness through differentiated product supply, but also an driving force for achieving sustainable environmental development. According to Martin's moral matrix theory (2002), green innovation activities are a kind of CSR activities in strategic area of matrix, which are beneficial to society and shareholders. In recent years, the green behavior of firms has received widespread attention from the media and investors, with many funds specifically investing in stocks with high firm ESG ratings. However, the R&D of green and low-carbon technologies are characterized by long cycle, high risk, and high cost, so it is difficult to meet the funding requirement. To achieve China's carbon neutrality goal, it is necessary to develop green finance to help China's entity economy achieve low-carbon transformation and upgrading.

Since the announcement of the "double carbon" goal in September 2020, China has successively introduced a number of relevant green financial policies to promote green economic development, among which green bonds have been widely concerned. The People's Bank of China (PBOC), the National Development and Reform Commission (NDRC) and the China Securities Regulatory Commission (CSRC) issued the "*Green Bond Support Project Catalog (2021* edition*)*", which defines and expands the industries and projects supported by green bonds. The Shanghai Stock Exchange and Shenzhen Stock Exchange respectively require special person management and special audit for specific varieties of corporate bonds and green bonds, the audit process should not exceed 30 working days in principle. Funds raised by green debt financing instruments are required to be 100% invested in the green field, no less than 70% of the funds of green corporate bonds should be used in the green field.

According to the International Climate Bonds Initiative, China has now become the world's second largest issuer of green bonds, after the United States. Since China began to establish green finance system in 2016, green bond market achieved the largest annual increase in 2021, with onshore issuance increasing 231% year-over-year. As is showed in Figure 1, issuance growth mainly coming from non-financial companies. By the end of 2021, nearly 1.3 trillion yuan has been issued, and according to the ownership, China's green bond issuance is mainly from state-owned firms.

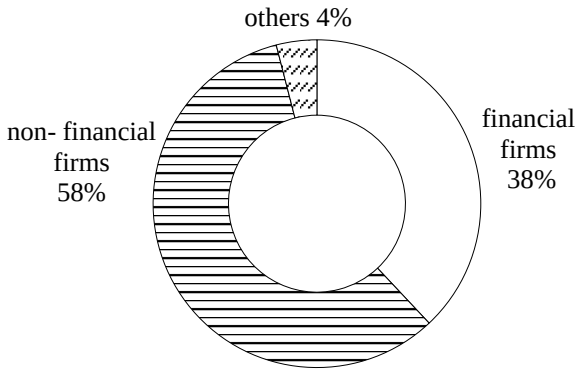


Figure 1. Growth in green bond issuance in 2021

Data source: Climate Bonds Initiative

With the rapid development of green bonds, whether the bonds can increase the resources of firms and help them engage in green innovation activities? It is the focus of this paper. This paper tries to provides good evidence for green finance to support firms' green transformation and give relative advise about how to better support green innovation. In this research, green bonds refer to securities that like common bonds but the funds exclusively used to support green industries, green projects or green economic activities. The green bonds studied in this paper are all types of green bond financing instruments except green financial bonds. The green innovation refers to reduce resource consumption and develop green technologies and products.

Existing studies have explored the incentive factors of green innovation from the perspective of green credit policies (Wang Ying and Wang Xin, 2021) [1] and environmental regulation tools (Li Qingyuan and Xiao Zehua, 2020) [2].A small number of scholars believe that firms' enthusiasm for green innovation comes from issuing green bonds (Zhang Xueying and Wu Duowen et al., 2022) [3], and few scholars have explored the impact of green bonds on the green behaviors of other firms in the same industry (Wu Yuhui and Tian Yanan et al., 2022) [4].

There is not much discussion on the relationship between green bond issuance and green innovation. On this basis, the main contributions of this paper are mainly reflected in the following aspects: Firstly, this paper connects the green bonds with the green investment decisions of firms, from green financing aspects to give advice on how to improve firms green innovation; Moreover, extends the sample period as much as possible, and besides establishing the fixed effect model, it also uses the DID and PSM model for verification; Finally, this paper makes a detailed analysis in the theoretical part, and points out that issuing green bonds does reduce agency costs, but agency cost reduction has no significant effect on green innovation.

This paper adopts literature analysis and empirical analysis method, taking China's A-share listed companies from 2016 to 2021 as the research object. Section 2 reviews the related literature. Section 3 develops testable hypotheses. Section 4 focus on variables definition and data collection. Section 5 focus on fixed effect regression, robustness test and channel analysis conducted by DID and PSM models. While Section 6 concludes the paper. Finally, it is concluded that issuing green bonds affects the level of green innovation. Issuing green bonds increases firms' financial resources and stakeholder support, reduces the agency cost of firms, thus improve green innovation. The employees are more willing to innovate and improve work efficiency, thus the company's level of green innovation has increased. However, different from previous literature, the issuance of green bonds is mainly to increase corporate resources and internal innovation efficiency, and the reduction on agency costs does little effect on green innovation.

2. Literature Review

2.1. Green Bond Issuance

With the development of economy, financial support for zero-carbon transformation has gradually become the consensus of all countries. Green finance has its necessity, but it can not replace green policies. Wen Shuyang and Zhang Lin et al. (2021) [5] took 31 countries as research objects and pointed out that green finance has the optimal scale and capital stock threshold. Green policies should domain the early stage of economic development, then green finance domain the advanced stage of economic development. In addition, green credit subsidies can reduce the threshold of green investment for firms and help green investment activities.

The issuance of green bonds is influenced by factors such as geography, policy incentives and urban financial base level. Zhu Xiangdong and Zhou Xinyi et al. (2021) [6] adopted panel data model and spatial Durbin model to measure the development level of urban green finance with green bonds. They pointed out that the financial development modes of the east and west of China were unbalanced, the issuance scale of green bonds in the eastern part of China was larger than that in the central and western parts of China from 2016 to 2019.In addition, the level of policy incentives and financial base are positive to the issuance scale of urban green bonds, while environmental pollution will inhibit the development of local green finance.

Other scholars have studied the spread of green bonds and the correlation with other financial assets. Financing through green bonds can reduce the financing cost. Zhang Lihong and Liu Jingzhe et al. (2021) [7] take listed companies in China from January 2016 to May 2020 as research objects and believe that the yield spread of green bonds is 17bp lower than that of ordinary bonds, but the third-party certification results in a higher yield spread.This is mainly due to the non-standard operation, lack of authority and adverse selection in China's green bond market.At the same time, the paper also points out that China's private enterprises to participate in the green bond market vitality is insufficient.From the perspective of spillover effect, Ma Yamin and Hu Chunyang et al. (2020) [8] use Tobin's Q to measure enterprise value and point out that issuing green bonds will affect the investor sentiment of stocks and thus decrease the financing cost of enterprises, increasing the enterprise value, and this phenomenon will continue to exist for one year and stabilize after one year.

2.2. Green Innovation

Green innovation is of practical importance and can create new economic growth points while improving environmental performance.Wen Shuyang and Liu Hao et al. (2022) [9] used the provincial panel data from 2005 to 2017 to study and concluded that green finance can overcome market failure and improve welfare by supporting green innovation.Similarly, Xie Xuemei and Zhu Qiwei (2021) [10], based on the duality legitimacy theory, point out that green innovation can become a strategy for enterprises to build legitimate image, so that enterprises can easily obtain support.Engaging in green innovation can improve the financial performance of enterprises, and also improve environmental and social responsibility performance.

In addition to improving environmental performance, Fang Xianming and Na Jinling (2020) [11]take Growth Enterprise Market listed companies as research objects and believe that companies engaged in green innovation can improve the excess return of stocks, but investors generally pay attention to the short-term practicality of green innovation and ignore green invention patents with long-term potential value.However, environmental policies such as pollution charges and environmental subsidies can affect firms' willingness to innovation.Li Qingyuan and Xiao Zehua (2020) [2] believe that environmental protection subsidies cannot promote enterprises to engage in green innovation because of opportunism, so it is very important to require disclosure and monitoring of the funds raised.

2.3. Green Bond Issuance and Green Innovation

Wang Ying and Feng Jiahao (2022)[12] have researched non-financial listed enterprises which issued green bonds from 2016 to 2017,they believed that green bond financing could improve the enthusiasm of green innovation and have a sustainable promoting effect on the future.Similarly, Zhang Xueying and Wu Duowen et al. (2022) [3] took A-share listed companies from 2016 to 2020 as research objects,they emphasized the impact of green bond information transparency on firms' green innovation behavior.It is believed that the issuance of green bonds is not a "green washing" behavior, but a real use of raised funds for green activities.As a tool to convey credibility and green image, it helps firms to be accurately evaluated and obtain policy or financial support.

Many scholars believed that policies related to green credit largely promote enterprises to engage in green innovation activities.Wang Xin and Wang Ying (2021) [1] pointed out that the promulgation and implementation of *Green Credit Guidelines (2012)* reduced agency costs, increased investment efficiency of firms, and improved level of green innovation.Based on the learning perspective of the same industry, Wu Yuhui and Tian Yanan et al. (2022) [4] took ordinary corporate bonds, corporate bonds and medium-term notes issued from 2009 to 2019 as research objects.They show that green bonds have a lower yield spread than ordinary bonds. Issuing green bonds will reduce the financing cost of ordinary bonds of other enterprises in the same industry, and promote other enterprises in the same industry to adopt green behaviors and carry out green innovation.

To sum up, existing scholars mainly discuss the factors of green bond issuance,pricing and linkage with other assets, the discussion on green innovation mainly focuses on the performance or environmental policies on green innovation.There are few researches on the effect of green finance on green innovation in terms of quantity and theory. Even if this topic is discussed, credit policies rather than green financing tools are mainly discussed.

In terms of the mechanism by which green bonds affect green innovation, existing scholars mainly believe that issuing green bonds with low cost can increase the resources, and enterprises can build their reputation and win more support of stakeholders. However, some scholars believe that issuing certified green bonds cannot reduce the financing cost of firms.Some scholars believe that green bonds can reduce the agency costs, while others believe that the green bond market in our country is currently not standardized and lacks authority.So this paper tries to enrich the existing theoretical framework and introduce the efficiency mechanism.On this basis, the impact of green bond issue on firms green innovation are demonstrated in order to help firm realize more green innovation.It provides good evidence for green finance to support firms' green transformation.

3. Theoretical mechanism

3.1. Resource Effect

Green innovation activities face the risk of environmental uncertainty, high probability of failure and long cycle.Green bonds are essentially a financing tool,the interest rate of green bonds is lower than that of ordinary bonds (Wu Yuhui and Tian Yanan et al., 2022) [4]. Therefore, the funds incorporated can increase the resources required for innovation activities,firms are more motivated to invest in green innovation projects.Green bond financing breaks the financing constraints in the past, as long as the firm have the technology and confidence to carry out green innovation activities, they can raise funds through external financing, because sustainable development issues now win more attention than ever.Green bonds have a transparent use of funds to inform investors, so the degree of information asymmetry is low, so lower the cost of capital,thus effectively reduce the financing constraints of firms.

Green innovation activities are regarded as the performance of social responsibility, which is easy to be favored by investors and institutions. Therefore, as long as enterprises actively disclose their green behaviors, they are more likely to obtain the support of investors, suppliers and customers, and financial institutions such as banks are more trusted by the company.Therefore, the following hypothesis is proposed:

H0: Issuing green bonds improves green innovation

H1: Issuing green bonds increases the resources,thus improves green innovation

3.2. Supervision Effect

The agency problems between managers and shareholders mainly fall into two categories: First, managers make insufficient investment,because give up projects with NPV>0 but high risk in order to keep their positions;the second is managers make excessive investment in NPV<0 projects,through active mergers and acquisitions to establish their own kingdom.However,issuing bonds can reduce this agency problem, so that managers can engage in the work related to the interests of shareholders.

Bonds will not dilute the ownership of the stockholders,the managers who hold shares and the shareholders are in one mind, so the managers will work hard for their own interests and invest in the projects that are beneficial to the company.Bonds need to repay the principal and interest, which reduces the free cash flow of the company. Managers also need to consider whether they will fall into financial crisis before they want to make privileged consumption, so the agency cost between managers and shareholders will be reduced.Creditors are the supervisors, so managers will no longer give up projects with NPV>0 in order to keep their positions or not lose assets, and actively invest in projects that are beneficial to the company. Thus, issuing green bonds can encourage managers to engage in behaviour that is good for the company and not to avoid taking risks in order to cling to their positions.Managers will actively engage in green innovation activities and no longer under-invest, despite the risk.Managers will also retain their interests and make the company enjoy a green reputation.

Green bonds has disclosure and restrictions on the use of funds, so that company must engage in environmental protection activities.Therefore, the following hypothesis is proposed:

H2: Issuing green bonds reduce agency costs, thus improve green innovation

3.3. Efficiency Mechanism

Green innovation activities depend on the knowledge level and innovation ability of employees.In green innovation activities, enterprises show a good image of fulfilling social responsibilities to the public, which helps to build the reliability and credibility,making it easy for firms to obtain support from stakeholders and improve their risk tolerance for enterprises.For example, banks are willing to provide low-interest loans to enterprises engaged in green activities (Zhang Xueying and Wu Duowen et al., 2022) [3].Such a tolerant innovation environment and a responsible social image are conducive to satisfying employees' self-value realization needs, encouraging employees to break through the existing thinking framework and achieve breakthrough results.Sustainable development has been widely valued, especially at present and in the future, employees' recognition of enterprises' green behaviors helps to improve the efficiency of division of labor and cooperation,finally enhance the level of human capital of enterprises.

Green bonds spread the concept of green and the idea of taking care of other stakeholders within enterprises, thus enhances employees' sense of identity with enterprises.The open and inclusive business environment improves the efficiency of capital use and the enthusiasm of employees, opens the inherent thinking framework of employees, and enhances the willingness and efficiency of innovation.Therefore,the hypothesis follows:

H3: Issuing green bonds enhance employees' innovation efficiency,thus improve green innovation

4. Variables and data

4.1. Sample and Data

This paper takes all China's A-share listed companies as the research object. Since corporate green bonds have been firstly officially issued since 2016, and patent data only for 2022, so the sample period is from 2016 to 2021.Between 2016 and 2021, a total of 2,539 green bonds were issued, of which 2,082 were issued by non-listed firms and 457 were issued by listed firms.Among the listed firms, 243 were issued by financial firms and 214 were issued by non-financial.

The samples are excluded as follows: bonds issued by non-listed companies, financial companies and *ST and ST companies, companies that issue green bonds earlier than the listing time, and missing data.In order to avoid the influence of outliers, the continuous variables are winsorized by 1%.The green innovation data of enterprises came from the China Research Data Service Platform (CNRDS), and the rest of the data came from the CSMAR.

4.1. Variables and Descriptive Statistics

To explore the impact of green bond issuance on green innovation, the dependent variable is firms' green innovation, and the total number of green patents plus 1 is taken as logarithm to represent green innovation.The core independent variable is the issuance of green bonds, which is measured by dummy variables. If firm i issues or has green bonds at the end of t, it takes 1; otherwise, it takes 0.Based on the practice of Wu Yuhui and Tian Yanan et al. (2022) [4], the control variable selects the ratio of fixed assets to total assets to measure the capital density or technical efficiency; the logarithm of total assets (yuan) is used to measure the scale of an enterprise; the asset-liability ratio is used to measure the leverage of an enterprise; and the turnover ratio of total assets is used to measure the operation capability.The growth rate of operating income measures the growth ability of the enterprise, ROA measures the profitability, and the cash holding level measures the asset management level.The variables and their descriptions are shown in the Table 1.

Table 1 Variable definition

Variable	Definition
FixAss	Net Fixed Assets/Total Assets
Size	ln(Total Assets(yuan))
Lev	Total Liabilities/Total Assets
Assturn	Operating Revenue/Total Assets
Oper	(Operating Revenue-Previous Operating Revenue)/Previous Operating Revenue
ROA	Net Profit/Total Assets
Cash	Operating Net Cash Flow/Total Assets
GreInnov	ln(Green Invention Patent+Green Utility Model Patent+1)
GreIssue	firm i in year t Issue or Exist Green Bond take 1,else 0

Table 2 shows the distribution of the original data before winsorize.It can be seen that there are a total of 20,294 observations in the sample. The minimum of GreInnov is 0, the maximum is 7.25, and the average is 0.91, indicating that there is a large difference in the green innovation capability of different firms, but the green innovation level of firms is generally low.The average value of GreIssue was 0.0081, indicating that 0.81% of listed non-financial firms issued green bonds on average, indicating that the participation rate of listed enterprises in issuing green bonds was relatively low. Judging from the original data, it was mainly financial institutions that participated in issuing green bonds.

Table 2 Descriptive statistics

Variable	Observation	Mean	S.D.	Minimum	Maximum
FixAss	20294	0.1963	0.1530	0.0000	0.9542
Size	20294	22.2491	1.3121	17.7785	28.5016
Lev	20294	0.4070	0.2062	0.0084	3.9191
Assturn	20294	0.6503	0.5294	-0.0479	11.9755
Oper	20294	0.3667	8.3297	-1.3092	944.0995
ROA	20294	0.0429	0.0873	-1.8719	0.9686
Cash	20294	0.0503	0.0734	-0.7443	0.8739
GreInnov	20294	0.9089	1.1982	0	7.2506
GreIssue	20294	0.0081	0.0898	0	1

From Table 2,The minimum of FixAss is 0, the maximum is 95.42%, and the average value is 19.63%, indicating that the sample firms have a large difference in the level of fixed assets.The average value of Size is 22.25, the minimum is 17.78, the maximum is 28.50, and the standard deviation is 1.31, indicating that there is a large difference in the scale of different firms.The average level of Lev is 40.70%, the maximum is 3.92, and the minimum is 0.008. The difference of Lev is large, indicating that there are extreme values and data beyond common sense in the samples, which should be shrunk and eliminated.The minimum of Assturn is -0.05 and the maximum is 11.98, indicating that there are firms with poor operation capacity and firms with good operation capacity in the sample, and the average operation capacity level is 0.65.The maximum growth rate of operating income is 944.10, the minimum is -1.31, and the average is 36.67%, indicating that there are great differences in the growth ability of different firms, but the overall growth ability is low.The average value of ROA is 4.29%, indicating that the profitability of firms is low, but the influence of extreme values cannot be excluded.The average level of Cash is 5.03%, indicating that the average level of operating cash flow held by firms is low.In order to avoid the influence of extreme values, the continuous variables were winsorized by 1% before regression.

5. Regression Analysis

5.1. Benchmark Regression

The benchmark model established in this paper is a fixed effect model, and the expression is as follows:

$$GreInnov_{it} = \beta_0 + \beta_1 GreIssue_{it} + \beta_2 Controls_{it} + u_i + \gamma_t + \varepsilon_{it}$$

Among it, the $GreInnov_{it}$ represents the green innovation of firm i in year t, which is measured by the logarithm of the total number of green patents plus 1; the $GreIssue_{it}$ is a dummy variable,means firm i issues or maintains green bonds in year t, it takes 1; otherwise, it takes 0.$Controls_{it}$ contains a series of control variables mentioned previously, including Size,FixAss,Assturn, Lev, ROA, Oper and Cash, the control variables are all in year t.u_i represents the individual fixed effect,γ_t represents the time fixed effect.ε_{it} is an unexplained random disturbance.This paper mainly focuses on β_1,if it is significantly positive, it means that the issuance of green bonds can promote the green innovation of firms; if it is negative, it means that the issuance of green bonds can reduce the level of green innovation of firms.

Robust standard error was adopted in all regression models. The baseline regression results are shown in column 2 of Table 3,as a contrast, and the third is the OLS regression results without fixed effects.It can be seen from the 3 column that the coefficient of GreIssue is 1 and is significant at the level of 0.1%,*ceteris paribus*,the issuance of green bonds will improve the level of green innovation of firms.After controlling for individual and time fixed effects,

the results were significant at the 5% level.After controlling a series of firm characteristics, the green innovation level of firm will be increased by 20.6%.So,**H0** is verified.

As can be seen from the results in column 2 of Table 3 , other conditions remain unchanged, there is a significant positive relationship between Size and GreInnov, indicating that large-scale firms will engage in more green innovation activities, because large-scale firms have sufficient capital, manpower, technology and other resources for green R&D activities.In addition, managers of large firms are relatively willing to engage in high-risk innovation activities and will not have the problem of insufficient investment, because managers of large firms usually have high abilities and generally do not worry about their career, so they do not worry about the risks brought by green innovation activities.

Table 3 Benchmark regression results

Variable	GreInnov	
	[1]	[2]
GreIssue	0.206*	1.000***
	[0.0929]	[0.1070]
FixAss	0.0444	-0.407***
	[0.1233]	[0.0525]
Size	0.366***	0.381***
	[0.0298]	[0.0080]
Lev	-0.151	0.259***
	[0.0800]	[0.0482]
Assturn	0.0712*	-0.0361
	[0.0340]	[0.0192]
Oper	0.0041	-0.0469*
	[0.0150]	[0.0210]
ROA	-0.300*	0.337**
	[0.1191]	[0.1236]
Cash	-0.0399	-0.480***
	[0.0905]	[0.1263]
constant	-7.308***	-7.570***
	[0.6542]	[0.1657]
individual fixed	Yes	No
time fixed	Yes	No
observation	20294	20294
adjusted R-sq	0.0934	0.2041

Note:[ ]is robust standard error, * p<0.05, ** p<0.01, *** p<0.001

In Table 3 column 2,there is a positive correlation between Assturn and GreInnov at the 5% level, indicating that the higher the operational efficiency of the firm, the higher the green innovation capability,ceteris *paribus*.The possible reason is that the financial management level of firms and that of green development are the same, the operation management level of firms is high, the corresponding green innovation management level is also better.ROA and GreInnov is negatively correlated,*ceteris paribus*, ROA increase of 1 unit, will reduce the firm green innovation level by 30%.The possible reason is that firms with good profitability have more abundant funds, and cash flow is more likely to be invested in short-term activities with considerable profitability, and less will be invested in long-term green innovation activities with high risks.The remaining control variables are not significant, and the reason may vary with the model setting and variable selection.Column 2 is the benchmark regression model with adjusted R^2 of 9.34%, indicating that the total explanatory variables can explain 9.34% of the change in the level of green innovation.

5.2. Robust Test

To more accurately determine the positive relationship, the model is replaced with the policy time-point inconsistent differential model, which is set as follows:

$$GreInnov_{it} = \alpha_0 + \alpha_1 Treat_{it} \times Period_{it} + \alpha_2 Controls + u_i + \gamma_t + \varepsilon_{it}$$

Where the dependent variable is unchanged, $Treat_{it}$ indicates whether the firm is in the treatment group. If the firm has issued green bonds from 2016 to 2021, it takes 1 and enters the treatment group; otherwise, the firm has no green bonds from 2016 to 2021, it takes 0 and enters the control group.$Period_{it}$ means that if firm i issues or holds bonds in year t, it takes 1; otherwise, it takes 0. The remaining variables are consistent with the benchmark model, and both individual and time fixed effects are controlled.The core of the differential model is the coefficient α_1.

It can be seen from Table 4 below that the coefficient of cross terms is significantly positive regardless of whether control variables are added, indicating that issuing green bonds will indeed improve green innovation ability.In the absence of control variables, issuing green bonds can increase the green innovation level of firms by 24.9%, and the effect is significant at 1%.The adjusted R^2 of the model is 6.78%, so only the change of green bond issuance can explain the change of green innovation level by 6.78%.However, there are other variables that can also explain corporate green innovation. The coefficient value of 24.9% is likely to contain the explanatory power of variables not included. Therefore, after control other variables in column 3, the coefficient drops to 20.6%, and the explanatory power of the significant model rises to 9.34% at the 5% level.To sum up, the positive influence of green bonds on green innovation is about 20% ,*ceteris paribus*.

Table 4 DID Roubst Test Results

Variable	GreInnov	
	[1]	[2]
Treat×Period	0.249**	0.206*
	[0.0948]	[0.0929]
ROA		-0.300*
		[0.1191]
Size		0.366***
		[0.0298]
Assturn		0.0712*
		[0.0340]
Lev		-0.151
		[0.0800]
FixAss		0.0444
		[0.1233]
Oper		0.0041
		[0.0150]
Cash		-0.0399
		[0.0905]
constant	0.712***	-7.308***
	[0.0122]	[0.6542]
individual fixed	Yes	Yes
time fixed	Yes	Yes
observation	20294	20294
adjusted R-sq	0.0678	0.0934

Note:[ ]is robust standard error, * p<0.05, ** p<0.01, *** p<0.001

Furthermore, considering that the treatment group and the control group were not comparable before the experiment due to their different firm characteristics,propensity score matching was chosen to test the positive relationship between green bond issuance and green innovation.In addition, in this sample, fewer firms issued green bonds and more firms did not issue green bonds.Therefore, through PSM, it can be more accurate to observe whether the

improvement of green innovation is caused by issuing green bonds.Through the PSM approach, the endogenous problem caused by selection bias also can be further alleviated.

Logistic regression was used in this paper to estimate propensity score. Whether an enterprise issues green bonds is closely related to its profitability, size, operation and growth ability, etc. Therefore, this paper adopts control variables to calculate propensity score for matching, and adopts one-to-one and put-back matching.As can be seen from the logistic regression in the following Table 5, the main control variables are significantly related to the issuance of green bonds, except that the Oper and the Cash are unrelated to the GreIssue.

The matching results are shown in the second half of Table 5, where difference represents the average causal effect, which means the expected difference between the green innovation performance under green bond issuance and without green bond issuance, under the condition that firm i issues or maintains green bonds(ATT).Situations without green bonds are obtained through PSM matching.It can be found that the green innovation level of the treatment group is 2.8461 and that of the control group is 2.1627, and the difference is 0.6835 and significant, indicating that after excluding endogenous and incomparable factors, the issuance of green bonds can indeed improve the green innovation ability of firms.

Table 5 PSM Robust Test Results

Variable	Cofficient	standard error	P-value
logistic regression:y=GreIssue			
ROA	5.0669***	1.6773	0.003
Size	0.6886***	0.0574	0.000
FixAss	2.7790***	0.4149	0.000
Lev	2.9582***	0.5877	0.000
Assturn	-1.4315***	0.2987	0.000
Oper	-0.0812	0.1292	0.530
Cash	-2.0930	1.6381	0.201
constant	-22.1369***	1.2732	0.000
individual fixed	Yes		
time fixed	Yes		
observation	18211		
Pseudo R-sq	0.2467		
PSM result(ATT)			
treat group	control group	differene	t-value
2.8461	2.1627	0.6835	3.65

Note:* p<0.05, ** p<0.01, *** p<0.001

To check whether PSM makes a good comparison between the treatment group and the control group.As can be seen from Table 6, the standardized deviation (%) of all variables is less than 10%, and matching reduces the deviation of each feature between the treatment group and the control group, making the treatment group and the experimental group comparable, and ensuring that the improvement of green innovation is caused by the issuance of green bonds by firms.Except for the significant P-value of Oper, the remaining variables were not significant, indicating that the H0 of no systematic difference was not rejected, there was no systematic difference between the treatment group and the control group (except for Oper), PSM balanced the data well, and the results were consistent with the benchmark results.

Table 6 PSM Balance Degree

Variable	Mean		bias(%)	t-value	p-value
	treat	control			
ROA	0.0328	0.0316	1.7	0.24	0.811
Size	24.4450	24.4760	-2.6	-0.22	0.825
Lev	0.5967	0.6001	-2.1	-0.22	0.829
FixAss	0.3326	0.3339	-0.8	-0.06	0.952
Assturn	0.4806	0.5073	-6.3	-0.74	0.459
Oper	0.1878	0.1121	1.2	2.76	0.006
Cash	0.0552	0.0539	2.1	0.21	0.835

5.3. Mechanism Analysis

5.3.1. Resource Effect

As the above model shows that issuing green bonds can significantly improve the level of green innovation, in order to verify **H1**, the following intermediary effect model is first established with R&D investment as intermediary variables:

$$R\&D_{it} = \omega_0 + \omega_1 Treat_{it} \times Period_{it} + \omega_2 Controls + u_i + \varepsilon_{it}$$

$$GreInnov_{it} = \varphi_0 + \varphi_1 R\&D_{it} + \varphi_2 Controls + u_i + \gamma_t + \varepsilon_{it}$$

Among them,$R\&D_{it}$ represents research and development investment, which is measured by the logarithm of the number of R&D investment of the firm, and the data is from CSMAR database.Remaining variables is consistent with the previous paragraph.

As can be seen from Table 6 below, the cross-term coefficient of column 2 is significantly positive at the 5% level, indicating that the issuance of green bonds can increase the innovation input of firms, because the issuance of bonds, as a means of financing, increases the available resources.According to column 3, the increase in R&D investment can further improve the level of green innovation.Therefore, the issuance of green bonds increases the available resources for research and development, so as to promote the green innovation activities of enterprises.

In Table 7 Column 2, ROA has a significantly negative impact on R&D. *Ceteris paribus*, the improvement of profitability will reduce R&D investment, the expansion of enterprise scale will increase R&D investment, and the increase of Assturn will increase R&D investment. The results are consistent with the above.*Ceteris paribus*, the increase of Lev will reduce the R&D investment, because with the financial risk of enterprises is increasing, so in order to avoid the default, they are less likely to engage in high-risk R&D activities.The FixAss and the Cash are positively related to R&D investment, because both fixed assets and cash increase the resources available to firms, and increasing fixed assets can improve the technical efficiency.

Table 7 R&D input resource effect

Variable	R&D	GreInnov
R&D		0.123***
		[0.0156]
Treat×Period	0.287*	
	[0.1127]	
ROA	-0.351***	-0.154
	[0.0823]	[0.0964]
Size	0.813***	0.288***
	[0.0248]	[0.0319]
Assturn	0.318***	0.00139
	[0.0380]	[0.0315]
Lev	-0.409***	-0.0618
	[0.0746]	[0.0798]
FixAss	0.447***	0.117
	[0.1081]	[0.1233]
Oper	-0.000367	0.000543*
	[0.0003]	[0.0002]
Cash	0.195*	-0.0886
	[0.0935]	[0.0936]
constant	-0.134	-7.679***
	[0.5497]	[0.6852]
individual fixed	Yes	Yes
time fixed	No	Yes
observation	17510	18069
adjusted R-sq	0.9099	0.1058

Note:[ ]is robust standard error, * p<0.05, ** p<0.01, *** p<0.001

Taking SA index as the intermediary variable, the following intermediary effect model is established:

$$SA_{it} = \omega_0 + \omega_1 Treat_{it} \times Period_{it} + \omega_2 Controls + u_i + \varepsilon_{it}$$

$$GreInnov_{it} = \varphi_0 + \varphi_1 SA_{it} + \varphi_2 Treat_{it} \times Period_{it} + \varphi_3 Controls + u_i + \varepsilon_{it}$$

Where, SA_{it} denotes the Financing Constraint SA index, which was created by Hadlock and Pierce(2010). The SA index data in this paper are from the CAMAR.Remaining variables is consistent with the previous paragraph.

Table 8 column 2 show that the cross-term coefficient is significantly negative at the level of 0.1%, indicating that issuing green bonds reduce financing constraints.Column 3 shows a significant negative relationship between SA index and green innovation, indicating that firms with lower SA index have higher green innovation, indicating that issuing green bonds does reduce firms' financing constraints.The reduction of financing constraints can effectively improve the green innovation level.So,**H1** has been verified.Firms can obtain resource effect by issuing green bonds. Compared with ordinary bonds, the interest rate of green bonds is lower, which increases the resources required for green innovation activities and makes it easier to meet the needs of innovation investment.Therefore, issuing green bonds promotes firms to carry out green innovation activities through resource effect channels.

Table 8 SA resource effect

Variable	SA index	GreInnov
SA index		-0.268**
		[0.0865]
Treat×Period	-0.0505***	0.162
	[0.0077]	[0.1013]
ROA	0.00612	0.1000
	[0.0185]	[0.1010]
Lev	-0.249***	0.274**
	[0.0216]	[0.1020]
Assturn	-0.00682	-0.0458
	[0.0063]	[0.0342]
Oper	0.0000941	0.000409
	[0.0001]	[0.0004]
Cash	-0.0912***	0.212*
	[0.0143]	[0.0997]
constant	-3.740***	-0.144
	[0.0098]	[0.3187]
individual fixed	Yes	Yes
time fixed	No	No
observation	18247	18247
adjusted R-sq	0.0910	0.0035

Note:[ ]is robust standard error, * p<0.05, ** p<0.01, *** p<0.001

5.3.2. Supervision Effect

In order to verify **H2**, the proportion of management and marketing expenses to operating revenue is used to measure agency costs, and the model is as follows:

$$Cost_{it} = \omega_0 + \omega_1 Treat_{it} \times Period_{it} + \omega_2 Controls + \varepsilon_{it}$$

$$GreInnov = \varphi_0 + \varphi_1 Cost_{it} + \varphi_2 Treat_{it} \times Period_{it} + \varphi_3 Controls + \varepsilon_{it}$$

$Cost_{it}$representative agent cost,through measure of the proportion of management and marketing expenses in operating income, which is calculated according to the data in CSMAR.

Results are shown in Table 9 below. As can be seen from the column 2, the cross term is significantly negative 0.0512, indicating that ,c*eteris paribus*, issuing green bonds can significantly reduce the agency cost.According to column 3, c*eteris paribus*, the decrease of agency costs not very promote the increase of green innovation activities.The reason why issuing bonds can reduce agency costs is that on the one hand, bond issuance will not reduce the concentration of ownership, so shareholders will exercise the right of supervision for their own interests, and managers who hold company shares will also work hard for their interests and positions.On the other hand, the bond requires the repayment of principal and interest, which not only reduces the available cash flow of the firm, but also the creditor will supervise the operation of the firm.The agency costs between management and shareholders are reduced, and managers will not under-invest because they are thinking about how to keep their positions, so they will engage in green innovation behavior that is beneficial to the interests of the company and shareholders.Therefore, **H2** is confirmed that the issuance of green bonds can indeed reduce agency costs, and the reduction of agency costs can promote the green innovation activities of firm.However,the reduction of cost only improve 0.256% the green innovation,which means the agency costs does not the key factor to improve green innovation.

Table 9 agency costs effect

Variable	Cost	GreInnov
Cost		-0.00256***
		[0.0005]
Treat×Period	-0.0512**	0.896***
	[0.0168]	[0.1197]
ROA	-3.032	0.278**
	[1.9804]	[0.0986]
Size	0.017	0.432***
	[0.0276]	[0.0088]
Lev	-0.796	0.408***
	[0.4656]	[0.0497]
Cash	-1.173	-0.867***
	[1.0220]	[0.1221]
constant	0.345	-8.759***
	[0.3677]	[0.1832]
individual fixed	No	No
time fixed	No	No
observation	18050	18050
adjusted R-sq	0.0046	0.2549

Note:[ ]is robust standard error, * p<0.05, ** p<0.01, *** p<0.001

5.3.3. Efficiency Mechanism

In order to verify **H3**, this paper takes innovation efficiency as an intermediary variable and refers to the practice of Fang Xianming and Hu Ding (2023) [13] to measure enterprise innovation efficiency by the ratio of the total number of patents to the number of employees.

$$Efficient_{it} = \omega_0 + \omega_1 Treat_{it} \times Period_{it} + \omega_2 Controls + \varepsilon_{it}$$

$$GreInnov_{it} = \varphi_0 + \varphi_1 Efficient_{it} + \varphi_2 Treat_{it} \times Period_{it} + \varphi_3 Controls + \varepsilon_{it}$$

Where,$Efficient_{it}$denotes innovation efficiency, other variables are consistent with the previous, data from CSMAR.

From Table 10 column 2, the cross-term is significantly positive, indicating that the issuance of green bonds can improve the innovation efficiency of employees. The column 3 shows that the improvement of employees' innovation efficiency is crucial to the level of green innovation.It is not only reflected that the improvement effect of innovation efficiency on green innovation is much higher than that of issuing green bonds, but also reflected that the adjusted R^2 of the model in column 3 is 50.38%, which can explain the change of green innovation to a large extent.Therefore, **H3** is confirmed, indicating that the issuance of green bonds by firms can add the green innovation activities through the channel of improving the innovation efficiency of employees.

Table 10 innovation efficiency mechanism

Variable	Efficient	GreInnov
Efficient		93.30***
		[6.2454]
Treat×Period	0.00418***	0.476***
	[0.0007]	[0.0899]
ROA	0.00357***	0.0263
	[0.0008]	[0.0868]
Size	-0.0000491	0.440***
	[0.0001]	[0.0080]
Assturn	-0.00129***	-0.0201
	[0.0001]	[0.0161]
Lev	0.00264***	0.277***
	[0.0004]	[0.0473]
FixAss	-0.00467***	-0.210***
	[0.0003]	[0.0533]
Oper	0.00000742	-0.000950**
	[0.0000]	[0.0003]
Cash	-0.00547***	-0.0018
	[0.0011]	[0.1052]
constant	1.004***	-102.4***
	[0.0011]	[6.2584]
individual fixed	No	No
time fixed	No	No
observation	18211	18211
adjusted R-sq	0.0294	0.5038

Note:[ ]is robust standard error, * p<0.05, ** p<0.01, *** p<0.001

6. Conclusion

In conclusion, by establishing a fixed effect model, the benchmark regression results are obtained.Then, by changing the model, DID and PSM models are used to further verify the research hypothesis in this paper, which accords with the baseline regression results.The results show that: (1) the issuance of green bonds by China's A-share listed non-financial companies is conducive to improving the green innovation level of enterprises;(2) Issuing green bonds has a lower interest rate, which can promote the level of green innovation of enterprises by increasing their resources, reducing their agency costs and improving innovation efficiency channels;(3) Reducing agency costs has little effect on improving green innovation, while improving innovation efficiency has a greater effect on green innovation.

In view of this, this paper believes that in order to improve firms green innovation, from the perspective of green bonds supporting low-carbon transformation, we should start from two aspects: improving the green bond issuance market, increasing the transparency of the use of green funds, and improving the innovation efficiency of firm employees.

We should improve the system and process for issuing green bonds, because the issuance of green bonds will help enterprises engage in innovative activities and enhance the quality and efficiency of social and environmental development.In terms of information, approval agencies need to strictly examine the use of green bond funds, restrict enterprises from using funds for other purposes, and ensure that special funds are used exclusively.firms should actively disclose their green innovation activities and the use of loan funds, because the behavior of enterprises actively engaged in environmental improvement is a performance of corporate social responsibility, which helps to obtain resources brought by external attention.The reduction of agency costs has a limited effect on promoting green innovation,

mainly because the green bond market lacks authority, and there may be phenomena such as "green bleaching" and misappropriation of funds.

After issuing green bonds, firms should internally implement the concept of improving the quality of green environmental protection, improve the efficiency of the use of funds, vigorously support R&D projects, and improve the participation rate of employees in innovation activities, so as to help improve the level of green innovation.Green innovation activities build the image of social responsibility, firms can attract a group of high-quality talents with public awareness, and improve the level of human capital of enterprises.

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