How does carbon emission trading scheme affect enterprise green technology innovation:Evidence from China's A-share non-financial listed companies

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Research Article

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Abstract

More and more emphasis is placed on the common development of economy and ecological environment in China's development strategy, and one of the key solution is green technology innovation of enterprises. This paper takes the carbon emission trading scheme carried out in China in 2013 as a quasi-natural experiment, uses the data of China's A-share non-financial listed companies and the DID method to empirically test the impact of the scheme on enterprise green technology innovation from the micro level. The results suggest that the carbon emission trading scheme has a significant role in promoting enterprise green technology innovation, mainly through the innovation of green practical patents and alternative energy-based patent. Using a series of robustness tests such as dynamic effect test, placebo test and PSM-DID etc., it is found that the results are still valid. Further analysis finds that debt financing will weaken the role of carbon emission trading scheme in promoting enterprise green technology innovation. And the carbon emission trading scheme plays a greater role in promoting green technology innovation in state-owned enterprises, enterprises belonging to areas with strong pollution control intensity and high pollution industry.

1. Introduction

Since China's economic growth has entered the new normal, its development concept also altered from "focusing only on GDP" to the new concept of "innovation, coordination, green, openness and shared". However, during the process of economic transformation, environmental problems especially the increase in carbon dioxide volume and air pollutant emissions not only reduce social welfare, but also cause serious damage to national health and ecological environment, which have a negative impact on the sustainable development of China's economy in the long run. To achieve the goal of low-carbon emission reduction, China implemented the carbon emission trading market policy during 2013–2014, and successively established pilot projects in Beijing, Shanghai, Guangdong, Shenzhen, Tianjin, Chongqing and Hubei. And "The 13th Five-Year Plan" clearly states: "China will establish and improve the initial allocation system for energy use rights, water rights, pollution rights, and carbon emission rights, and cultivate and develop the trading market". In September 2020, General Secretary Xi Jinping formally proposed the "dual carbon goal" at the UN General Assembly, which shows that resource and environmental issues have become the bottleneck restricting the high-quality development of China's economy, and have risen to major issues in national politics, people's livelihood, diplomacy, and strategic development (Wang and Wang, 2011).

Traditional technology innovation has failed to achieve the goal of reducing environmental pollution, and cannot meet the needs of green economy and sustainable development. As a method of technology innovation, green technology innovation has the dual advantages of environmental protection and high-quality economic development (Yuan and Chen, 2019; Albrizio et al, 2017). Ernest Braun et al. (1994) firstly proposed the concept of green technology innovation, which refers to the sum of technologies or products that reduce energy, raw material consumption and reduce pollutant emissions. Green technology innovation includes green product innovation and green process innovation (Wang and Jiang, 2015), and existing literature explore the factors affecting green technology innovation from various aspects on this basis, such as environmental regulation, green credit, foreign direct investment, board governance, etc. (Zhang et al., 2019; Lu et al., 2021; Li et al., 2016; Wang and Chen, 2015). In order to implement the ecological concept of " Clear waters and green mountains are as good as mountains of gold and silver ", the Chinese government has also vigorously encouraged green technology innovation. The report of the 19th CPC National Congress in 2017 proposed "building a market-oriented green technology innovation system", which showed that the concept of green technology innovation entered the highest programmatic document of the party for the first time; In 2019, the National Development and Reform Commission and the Ministry of Science and Technology jointly issued the "Guiding Opinions on Building a Market-Oriented Green Technology Innovation System", which marked that green technology innovation has officially become a special government policy document. To sum up, environmental regulation and green technology innovation have become topics of common concern in academia and practice.

The main contributions of this paper are as follows: This article takes the pilot policy of carbon emission trading as the entry point to explore its effect on green technology innovation of enterprises, which enriches the research in carbon emission trading scheme. This paper objectively and roundly evaluates the policy effect of the carbon emission trading scheme, from the aspects of green technology innovation structure, enterprise nature, environmental regulation intensity and industry nature, etc. which has important policy implications for further improving and deepening the carbon emission trading scheme.

1. **Literature review**

2.1. Analysis of the impact of carbon emission trading scheme on enterprise green technology innovation

As China's contribution to the world economy grows, it has become the largest contributor to global carbon emissions. The rising carbon emissions are important part of environmental problems, which cause the greenhouse effect to trigger various natural disasters. To a large extent, carbon emission problems come from technologies in the production process of industry especially the manufacturing industry, while green technology innovation is the key to fundamentally solve this environmental problem, and a significant approach to a win-win path of economic development and environmental protection (Liao et al,2018). Most of the technological innovation of enterprises is based on the perspective of cost-effectiveness and strategic development, while the green technology innovation of enterprises generally has characteristics such as large capital investment, long construction period, high adjustment cost and low initial income. At the same time, enterprise green technology innovation has dual positive externalities of environment and innovation lead to market failure (Bian et al., 2021), and the short-term economic and long-term social benefits brought about by enterprises' green environmental protection strategies are not always achieved concurrently (Peng, 2021), which leads to insufficient motivation to rely solely on enterprises for green technology innovation and needs external forces, in other word, the government influences enterprise decision-making through environmental regulation. With the specific connotation of environmental regulation changing with the change of new social cognition or situation (Jiang et al,2020), traditional economics believes that environmental regulation will lead to the rising transaction cost of enterprises, which is not conducive to the improvement of productivity, it will also reduce market competitiveness and financial performance and produces follow-cost effect that inhibit green technology innovation to a certain extent. Some scholars found that environmental regulation has a positive effect on enterprise technology innovation (Blackman and Kildegarrd, 2010; Kneller et al, 2012; Yuan and Xiang, 2018). The Porter Hypothesis (Porter ME, 1991) holds that strict and appropriate environmental regulation helps enterprises to innovate technologically and reduce production costs, and the compensation effect of innovation can partially or completely offset environmental regulation. Environmental regulation can induce “Innovation Compensation effect” and finally achieve the win-wins of environment and economy (Chakraborty and

Chatterjee, 2017). Environmental regulation doesn't cause a decline in corporate productivity and generate net benefits. The Porter effect can be measured from technological innovation (Yang et al., 2020), economic dividend and environmental dividend (Dong et al., 2019). Existing literature confirmed the Porter hypothesis from SO2 Emission rights trading policy, low-carbon city policy, policy of raising emission fees and the monitoring ,disclosure program, regulations of air pollution (Qi et al., 2018; Xu and Cui, 2020; Chen et al., 2021; Yu et al,2022; Nie et al, 2022), which fully demonstrates that the direction of technological progress is path-dependent, as well as reasonable environmental regulation can change the direction of technological progress and guide it into a green track.

There are three different types of environmental regulation, namely imperative type, market incentive type and voluntary type, which are valid within limits (Peng et al, 2021). They have obvious differences in the mechanism on technological innovation, among which the market type is more flexible and effective(Anderson et al, 2010; Johnstone et al, 2017). Market incentive environmental regulation is different from strict environmental management and control, it guide the environmental management behavior of enterprises based on clear price signals, which can be realized through direct price control, such as environmental protection tax (Bovenberg and DE Mooij, 1997) and green technology subsidies, it can also be realized through quantity control such as emission rights trading (Fare et al, 2013). Regardless of the realizing form, market incentivized environmental regulation can solve the negative externalities of pollution, provide greater flexibility and freedom in the process of reducing emissions, and help enterprises avoid losses and ensure that costs are minimized in the process of green technology innovation, to achieve the goal of encouraging enterprises to save energy and reduce environmental pollution.

As a market environmental regulation, carbon emission trading scheme has developed rapidly in recent years, it defines the subject and quota of carbon emission rights and sets up a corresponding punishment mechanism. Enterprises can obtain the emission allowances through the initial allocation by the government as well as sell or buy emission allowances through the carbon emission rights trading market. The carbon emission trading scheme can induce green technology innovation of enterprises because it brings the firm significant cost pressure or economic incentives (Yuan and Chen 2019). In terms of production cost, the carbon emission trading scheme increases the firm's production cost by increasing the price of exogenous energy, forcing enterprises to carry out green technology innovation. In terms of incentives, enterprises can store excess pollution indicators for backup or sell them for profit. Driven by profit maximization, enterprises will consciously seek green technology innovation to reduce the production and emission of their own pollutants, and trade the remaining emission rights to other enterprises with sewage needs, which provide continuous "dynamic incentives" for enterprises (Ren et al., 2019). The carbon trading mechanism will bring certain cost pressure to enterprises in the short term, it can stimulate enterprises through compliance pressure and economic compensation effects in the long run.

2.2. Analysis of the adjustment effect of debt financing

Schumpeter's innovation theory believes that the availability of funds plays an important role in innovation, sufficient and continuous supply of funds is a prerequisite for technological innovation of enterprises. The Priority-Order Financing Theory (Myers, 1984) further believes that equity financing can effectively make up for the shortage of funds for enterprise innovation activities and pay more attention to the sustainable growth of enterprises brought about by technology research and development, and ensure the continuity of future innovation investment of enterprises. However, debt financing relying on fixed income has a fierce contradiction with the high-risk characteristics of innovation, thus plays an inhibitory effect on technological innovation. The specific manifestation is that the contract rigidity of debt financing puts forward higher requirements on the solvency of the company. When a company has problems paying off its debt, creditors tend to resort to the law instead of tolerance. This behavior increases the risk of bankruptcy of the company and the career anxiety of company executives, reduces the firm's motivation to carry out green technology innovation. When debt financing gives company executives higher control rights and less supervision, managers are in pursuit of opportunistic behavior and pleasure, while enterprise results in lower corporate governance. In conclusion, debt financing is detrimental to the development of corporate green technology innovation (Jiang et al., 2021).

The financing matching mechanism points out that the inherent characteristics of debt financing matches the innovation activities of enterprises without considering other factors, and debt financing can effectively promote enterprise green technology innovation. The debt financing is in line with the long-term technological innovation cycle of enterprises, and meets the needs of enterprises for R&D funds in a certain period of time because of low financing cost. Compared with bank loans, corporate debts meet the needs of most investors on account of stronger liquidity and flexibility. At the same time, relational creditors are gradually showing the characteristics of innovation and inclusiveness, and achieve win-win goal by promoting firm green technology innovation (Wen et al., 2011; David and T. Yoshikawa, 2008). In order to achieve the dual goals of protecting the ecological environment and economic development, the carbon trading scheme should be effectively passed on to enterprises to guide enterprise green technology innovation. This requires not only the continuous improvement of the carbon trading scheme and the strict law enforcement by local governments, but also the active cooperation of enterprises. On the one hand, the debt financing weakens the role of the carbon trading scheme in promoting enterprises green technology innovation because of its characteristics of fixed income and low corporate governance. On the other hand, the debt financing enhances the role of the carbon trading scheme in promoting enterprises green technology innovation due to its characteristics of long term and low cost.

3. Research Model

3.1. Definition of variables

3.1.1. Dependent variable

There are many measurement indicators for enterprise green innovation in the existing research. Because patent data is the direct result of enterprise technology innovation, it can better measure the degree and quality of enterprise innovation activities, so this paper refers to the practice of Li and Zheng (2016), Tao et al. (2021), and uses the number of green patent authorizations of enterprises to expresses it.

3.1.2. Explanatory variables

From 2013 to 2014, China implemented the carbon emission trading market policy and successively established pilot projects in seven provinces and cities, including Beijing, Shanghai, Guangdong, Shenzhen, Tianjin, Chongqing and Hubei. This paper uses $treat$ as a dummy variable. If the enterprise is located in a pilot area where the carbon trading scheme implemented in 2013 and 2014, the value is 1, otherwise it is 0; $time$ is also a dummy variable, which is assigned to each year after 2013 is 1, otherwise it is 0.

3.1.3. Control variables

This article refers to relevant literature (Qi et al., 2018; Jiang et al., 2021; Zeng et al., 2021; Wang and Wang, 2021) and select the following control variables, including: (1) Tobin Q value (Tobin Q); (2) Enterprise size (Cap), measured by the logarithm of the total of each item of shareholders' equity; (3) Age of the enterprise (Age); (4)Asset-liability ratio (Debt); (5) Enterprise number of employees (Labor); (6) Net profit margin on assets (ROA); (7) Capital intensity (Cap_inten), expressed by the ratio of total assets to operating income;(8) Cash ratio (Cash); (9) Board size (Board); (10) Proportion of independent directors (Ind).

3.2. Data

The green patent data and financial data of listed companies used in this paper are from the CSMAR database, and the content of the pilot policy of the carbon emission trading scheme is from the China Carbon Emissions Trading Network. This paper takes 2009–2017 Chinese Shanghai and Shenzhen A-share non-financial listed companies as a sample and excludes ST and * ST listed companies. In data processing, the data of corporate green patents as null values are assigned as 0, and the corporate financial data is null values are imputed by interpolation, resulting in 13,851 company-year sample data.

3.3. Model establishment

In order to examine the impact of the carbon trading scheme on firm green technology innovation, this paper constructs the following difference-in-differences model:

$$Green_{i,t} = \beta_0 + \beta_1 treat_i \times time_t + \beta_i CVs_{i,t} + \Sigma Year + \Sigma Indcd + \epsilon_{i,t} (1)$$

Among them, $Green_{i,t}$ is the dependent variables, which indicate the degree of green technology innovation of enterprise in year t, and it is expressed by the number of green patents authorized by the enterprise in that year; the double difference item $treat_i \times time_t$ is explanatory variable to measure whether the enterprise is affected by the carbon trading scheme; $CVs_{i,t}$ is the control variables, this paper also controls year (Year) and industry (Indcd), $\epsilon_{i,t}$ is random error term.

4. Empirical Results And Analysis

4.1. Benchmark regression results

This paper uses the double-difference model to evaluate the impact of carbon emission trading scheme on firm green technology innovation. The benchmark regression results are shown in Table 1. The estimated coefficient of column (1) is significantly positive, that is, carbon emission trading scheme will promote enterprise green technology innovation.

4.2. Effects on enterprise green technology innovation structure

The carbon emission trading scheme not only affects the number of green patents granted by enterprises, but also affects their structure. According to the practice of Xu and Cui (2020), Qi et al. (2018), green patents include green invention patents (Green_I) and green practical patents (Green_P), and green invention patents have more requirements and higher innovation content. The other classification is the based on *the United Nations*

Framework Convention on Climate Change, where green patents include seven types and the green technology innovation effect of enterprises is mainly reflected in alternative energy patents (Green_Sub) and energy saving patents (Green_Eco). As shown in Table 1, the regression coefficient in columns (2) and (3) is positive and significant at the 1% level, which indicates that the carbon emission trading scheme has a positive effect on both green invention patents and green practical patents, and the positive effect on green practical patents is stronger. The regression coefficients in columns (4) and (5) are also significantly positive, and the regression coefficient in column (4) is larger, which indicates that the carbon emission trading scheme mainly promotes enterprise green technology innovation by increasing alternative energy patents.

Table 1

Carbon emission trading scheme and enterprise green technology innovation.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	Green	Green_I	Green_P	Green_Sub	Green_Eco
$treat_i \times time_t$	3.8507***	1.8786***	1.9721***	1.3424***	0.6685***
	(7.6171)	(5.9196)	(6.7612)	(4.9287)	(6.1888)
Constant	-53.9631***	-20.3950***	-33.5680***	-14.8704***	-14.6389***
	(-10.9159)	(-6.5720)	(-11.7689)	(-5.5834)	(-13.8586)
Control variables	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes
Observation	13851	13851	13851	13851	13851
R^2	0.2430	0.2676	0.1359	0.2784	0.1136

Notes: ***, ** and * indicate passing the test at the significance level of 1%, 5% and 10%. The figures in parentheses are t-statistics.

4.3. Robustness test

4.3.1. Dynamic effect test

Through the dynamic effect test, this paper not only verifies the parallel trend hypothesis, but also studies the dynamic effect of the carbon emission trading scheme on enterprise green technology innovation. Figure 1 shows that there was no significant difference between the experimental group and the treatment group in terms of enterprise green patent authorization before 2013, which satisfies the parallel trend assumption. After the implementation of carbon emission trading scheme, There is a significant difference between the experimental group and the treatment group in terms of enterprise green technology innovation, The influence of carbon emission trading scheme on enterprise green technology innovation reached a peak after four years, which indicates the implementation of the policy has a certain time lag.

4.3.2. Placebo test

The policy implementation time in the research sample is 2013, and the number of enterprises in the experimental group is 576. In order to eliminate the influence of omitted variables or artificial settings, this paper conducts a placebo test. The implementation time of the carbon emission trading scheme remains unchanged, and 576 listed companies are randomly selected as the experimental group to re-estimate the model (1). This paper repeats the above process 500 times, thus obtains 500 estimated coefficients of $treat_i \times time_t$. Fig. 2 shows that the mean of the regression coefficients of the double difference term is close to 0. The result shows that the random selection of treatment groups makes no difference on enterprise green technology innovation, and confirms that the carbon emission trading scheme has a positive effect on enterprise green technology innovation from a counterfactual perspective.

4.3.3. PSM-DID robustness test

In order to overcome the bias caused by sample selection, this paper refers to the method of Shi et al. (2018) and uses the PSM-DID model. In this paper, banks in the treatment group and control group are matched according to 10 observable variables such as Tobin Q, Cap, Age, Debt, Labor, ROA, Cap_inten, Cash, Board, Ind. When the PSM-DID method is used in this paper, the logit regression is performed on the control variables through the dummy variable of whether it is an enterprise in the pilot area of carbon trading, and the propensity score value is obtained. The enterprise with the closest propensity score value is the enterprise paired in the carbon trading pilot area. Figures 3 and 4 show that the total bias decreases significantly after sample matching and is less than the 10% red line standard stipulated by the balance test, and there is no systematically significant difference between the new samples after matching by the PSM method. The propensity score matching method can effectively reduce the difference in the distribution of explanatory variables between the control group and the treatment group, and eliminate the sample estimation bias caused by self-selection. The coefficient of $treat_i \times time_t$ is still positive at the 1% level in Table 2, and supports the results of the benchmark regression that carbon emission trading scheme will promote enterprise green technology innovation.

Table 2

PSM-DID robustness test.

	(1)
	Green
$treat_i \times time_t$	2.7181***
	(4.0971)
Constant	-67.3543***
	(-9.5212)
Control variables	Yes
Year fixed effect	Yes
Industry fixed effect	Yes
Observation	6817
R^2	0.2207

Notes: ***, ** and * indicate passing the test at the significance level of 1%, 5% and 10%. The figures in parentheses are t-statistics.

4.3.4. Excluding the influence of other policies.

In order to achieve the coordinated development of environment and economy, the Chinese government has formulated various environmental regulations to promote energy conservation and emission reduction of enterprises. However, different policies may overlap and the level of corporate green technology innovation may be affected by multiple policies. To exclude the influence of other policies, this paper mainly considers the following two environmental regulations: (1) 2010 Pilot Policies for Low-Carbon Provinces and Low-Carbon Cities. Its goal is to reduce carbon dioxide emissions in line with the carbon trading scheme, thus it is important to exclude the policy. (2) 2007 SO_2 emissions trading pilot policy. As the first market-based environmental regulation, the pilot policy of SO_2 emissions trading in 2007 will inevitably affect carbon emission trading scheme, thus it is necessary to exclude the policy. In order to reduce the interference of the above two policies, this paper constructs the following model on the basis of model (1).

$$Green_{i,t} = \alpha_0 + \alpha_1 treat_i \times time_t + \alpha_2 DID01_{i,t} + \alpha_3 DID02_{i,t} + \alpha_i CVs_{i,t} + \Sigma Year + \Sigma Indcd + \epsilon_{i,t} (2)$$

In model (2), DID01 and DID02 are the difference-differences estimates of the pilot policies for low-carbon provinces and cities in 2010, and 2007 SO_2 emissions trading pilot policy respectively. If province i becomes a low-carbon province and low-carbon city pilot area in year t, then province i in year t and later years $DID01_{i,t}$=1, otherwise it is 0. $DID02_{i,t}$are obtained based on the same approach. Table 4 reports the corresponding estimation results. This paper finds that the net effect of the carbon emission trading scheme on enterprise green technology innovation is still significantly positive, and it is promoted.

Table 3

Excluding the influence of other policies.

	(1)	(2)	(3)
	Green	Green	Green
$treat_i \times time_t$	4.5370***	3.7363***	4.4489***
	(8.5911)	(7.2974)	(8.2924)
$DID01_{i,t}$	-1.9356***		-1.9009***
	(-4.5137)		(-4.4160)
$DID02_{i,t}$		-0.5669	-0.4020
		(-1.3189)	(-0.9324)
Constant	-53.6650***	-53.7234***	-53.4435***
	(-10.8626)	(-10.8554)	(-10.8053)
Control variables	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes
Observation	13851	13851	13851
R^2	0.2441	0.2431	0.2441
Notes: ***, ** and * indicate passing the test at the significance level of 1%, 5% and 10%. The figures in parentheses are t-statistics.			

4.3.5. Substitution of dependent variable

Referring to the practice of Tao et al. (2021) and He et al. (2019), this paper chooses to use the number of green patent applications (Green Apply) and the ratio of R&D investment to operating income (RD) as the dependent variables to replace the number of green patent authorizations (Green). They are substituted into model (1) for regression respectively, and the results are shown in Table 4. The estimated coefficients in columns (1) and (2) are all significantly positive, which indicates that the carbon trading scheme has a significant positive effect on enterprise green technology innovation.

Table 4

Substitution of dependent variables.

	(1)	(2)
	Green Apply	RD
$treat_i \times time_t$	2.9923***	0.2575**
	(5.3943)	(1.9693)
Constant	-79.6607***	8.1829***
	(-13.7254)	(4.7406)
Control variables	Yes	Yes
Year fixed effect	Yes	Yes
Industry fixed effect	Yes	Yes
Observation	13138	6993
R^2	0.2508	0.3220
Notes: ***, ** and * indicate passing the test at the significance level of 1%, 5% and 10%. The figures in parentheses are t-statistics.		

5. Deep Analysis

5.1. Heterogeneity analysis

The impact of the implementation of the carbon trading scheme on enterprises with different ownership varies wildly. Relying on their strong financial strength and strong government support, state-owned enterprises have less financing constraints in obtaining green credit support. The capital advantages, talent advantages and standardized technology paradigms owned by state-owned enterprises ensure the multi-level and continuous investment in enterprise green technology innovation, and achieve good control of innovation risks. In the process of pursuing wealth maximization, state-owned enterprises often face greater public opinion and supervision, so they are more sensitive to environmental problems. However, state-owned enterprises are often insensitive to efficiency improvement information and technological innovation incentives provided by external market in the implementation process of environmental regulation policy, thus they have insufficient motivation for green technology innovation. Therefore, according to the different nature of enterprise ownership, this paper divides the research sample into state-owned enterprises and non-state-owned enterprises and conducts regressions respectively. The results are shown in columns (1) and (2) of Table 5. The regression coefficient of column (1) is 5.5135, which is significant at the level of 1%. The regression coefficient of column (2) is significantly positive at the level of 10%. The results show that carbon emission trading scheme promotes enterprise green technology innovation mainly through state-owned enterprise.

In order to protect local interests, there are some local officials who cover up stealthily emissions and leaks of high pollution companies, which results in the failure of the normal implementation of emission rights. Therefore, this paper argues that a high level of environmental regulation is required for the carbon emission trading scheme to fully play its role. The greater the intensity of environmental regulation faced by enterprises, the lower the chance of choosing illegal environmental behaviors. In this paper, the 30 provinces are divided into two groups: strong and weak pollution control intensity based on the difference in pollution control level. The division standard is the completed investment in industrial pollution control per unit of GDP. Provinces above the average are areas with strong pollution control intensity, while provinces below the average are areas with weak pollution control intensity. They are regressed respectively and the results are shown in columns (3) and (4) of Table 5. It illustrates that carbon emission trading scheme promotes enterprise green technology innovation and have a positive effect on both strong pollution control and weak pollution control areas, and the effect is larger in strong pollution control areas.

The implementation of the carbon emission trading scheme leads to an increase in the production cost of enterprises, which is solved by cost transfer or self-digestion. The difficulty of cost transfer depends on the price elasticity of demand and economic growth. The short-term demand of high pollution industries is rigid and the rising costs are passed on to consumers. However, consumers will change their consumption behavior and choose cleaner products in the long run. Thus the carbon emission trading scheme would cause the result that enterprises have to bear the increased costs by themselves and would have a negative impact on improving productivity and competitiveness, which forces enterprises to carry out green technology innovations. In order to examine the industries differences, this paper divides the samples. Based on the relevant regulations on pollution prevention and control in Chap. 4 of *The Environmental Protection Law of the People's Republic of China*, combined with the definition of high pollution industry in *The Guidelines for Environmental Information Disclosure of Listed Companies* (Draft for Comment) promulgated by the former Ministry of Environmental Protection (now the Ministry of Ecology and Environment) in 2010, this paper divides the samples into high pollution industries and low pollution industries, and regressed the samples separately. The results are shown in Table 5, and the coefficient of $treat_i \times time_t$ is significant and positive at the level of 1% in columns (5) and (6). But the coefficient in the high pollution industry is higher than in the low pollution industry, which indicates that the green technology innovation effect of enterprises in the high pollution industry is higher than that in the low pollution industry.

Table 5

Heterogeneity analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
	State-owned	Non-state-owned	Strong control	Weak control	High pollution	Low pollution
$treat_i \times time_t$	5.4227***	0.2993*	11.7766***	1.0668***	6.9417***	2.4928***
	(5.6767)	(1.7550)	(7.0888)	(4.7283)	(6.0594)	(4.8457)
Constant	-44.9635***	-17.1997***	-69.8463***	-29.0086***	-66.9169***	-53.4378***
	(-4.8565)	(-8.9432)	(-5.0026)	(-11.8314)	(-4.6765)	(-10.6414)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observation	6840	6588	4287	9564	4887	8964
R^2	0.3136	0.1762	0.3390	0.1349	0.3291	0.1118
Notes: ***, ** and * indicate passing the test at the significance level of 1%, 5% and 10%. The figures in parentheses are t-statistics.						

5.2. Moderating effect analysis

Another important area of enterprise green technology innovation research that needs to be more discussed is the moderating effect between various influencing factors (Liao et al, 2018). In order to examine the moderating effect of debt financing with environmental regulation on enterprise green technology innovation, this paper constructs model (3) and focuses on the regression coefficient of the interaction term $treat_i \times time_t \times DebtFin$.

$$Green_{i,t} = \gamma_0 + \gamma_1 treat_i \times time_t + \gamma_2 treat_i \times time_t \times DebtFin + \gamma_i CVs_{i,t} + \Sigma Year + \Sigma Indcd + \epsilon_{i,t} \quad (3)$$

Model (3) introduces the new variable debt financing on the basis of model (1). Referring to the practice of Wang and Chu (2019), this paper selects the asset-liability ratio to measure debt financing, which is the ratio of liabilities to total assets. As shown in Table 6, The regression coefficient of $treat_i \times time_t \times DebtFin$ is significant and negative at the level of 1%, which indicates that the increase of debt financing will weaken the promotion effect of carbon emission trading scheme on enterprise green technology innovation. At different quantile levels of debt financing, the role of $treat_i \times time_t$ in promoting enterprise green technology innovation continues to decline with the increase of debt financing. It means that the smaller the debt financing is for enterprises, the greater the role of carbon emission trading scheme is in promoting green technology innovation.

Therefore, changing the financing structure of enterprises and reducing their reliance on debt financing can effectively ensure the positive effect of carbon emission trading scheme.

Table 6

The moderating effect of debt financing on enterprise green technology innovation.

	(1)
	Green
$treat_i \times time_t$	4.4221***
	(7.7631)
$treat_i \times time_t \times DebtFin$	-9.8884**
	(-2.2110)
$treat_i \times time_t + treat_i \times time_t \times DebtFin$	
$DebtFin$ 25% Quantile results	4.4221***
	(7.76)
$DebtFin$ 50% Quantile results	4.2787***
	(7.88)
$DebtFin$ 75% Quantile results	-4.1709 *
	(-1.14)
Constant	-68.1344***
	(-12.2699)
Control variables	Yes
Year fixed effect	Yes
Industry fixed effect	Yes
Observation	13849
R^2	0.2433
Notes: ***, ** and * indicate passing the test at the significance level of 1%, 5% and 10%. The figures in parentheses are t-statistics.	

6. Conclusions And Policy Implications

This paper takes the 2013 carbon emission trading market pilot policy as a quasi-natural experiment and studies its impacts by establishing a DID model. The research finds that: The carbon trading scheme has a significant role in promoting enterprise green technology innovation, mainly through green practical patents and alternative energy patents, and the results are still significant after a series of robustness tests. In terms of heterogeneity analysis, this paper finds that the carbon trading scheme has a more significant role in promoting green technology innovation in state-owned enterprises, enterprises belonging to areas with strong pollution control intensity and high pollution industry. Deep research finds that the increase of debt financing will weaken the promotion effect of carbon emission trading scheme on enterprise green technology innovation.

This paper highlights specific recommendations in order to ensure the effectiveness of the implementation of carbon emission trading scheme and improve enterprise green technology innovation. Establish a comprehensive combination system of environmental regulation with market incentives environmental regulations as the dominance and the others as supplement. The carbon trading scheme is of great significance to the realization of China's "dual carbon" goal and the construction on the emerging development concept of coordinated development of environment and economy. However, China carbon emissions trading market started late and is still developing in comparison to the degree of marketization in other developed countries. So it requires imperative and voluntary environmental regulation in conjunction with market incentive type. Reduce dependence on external financing and promote sustainable enterprise green technology innovation. In terms of financing, enterprises can reduce their reliance on debt financing and use more internal financing to ensure the sustainability of R&D investment. At the same time, the government should vigorously develop green finance to help enterprises gain stable and sufficient R&D funds. According to the heterogeneity of enterprise, they can formulate differentiated environmental policies and transform environmental regulation into advantageous resources to enhance the initiative of enterprise green technology innovation. Strengthen environmental law enforcement and improve the policy supervision. To a large extent, whether the carbon emission trading scheme is effective depends on supervision and punishment system. After the implementation of the carbon trading scheme, the government should strictly enforce the law to ensure the effectiveness of policy, and continuously improve the supervision and punishment system, and increase violation cost to force enterprises to embark on enterprises green technology innovation.

Declarations

Author contribution：All authors made significant contributions to the study conception and design. Data collection and methodology were performed by Yongxuan Xue. The first draft of the manuscript was written by Xiaodong Ma and Yongxuan Xue, and both the authors commented on the previous versions of the manuscript. All the authors read and approved the final manuscript.

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Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Competing interest: The authors no competing interests

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Figures

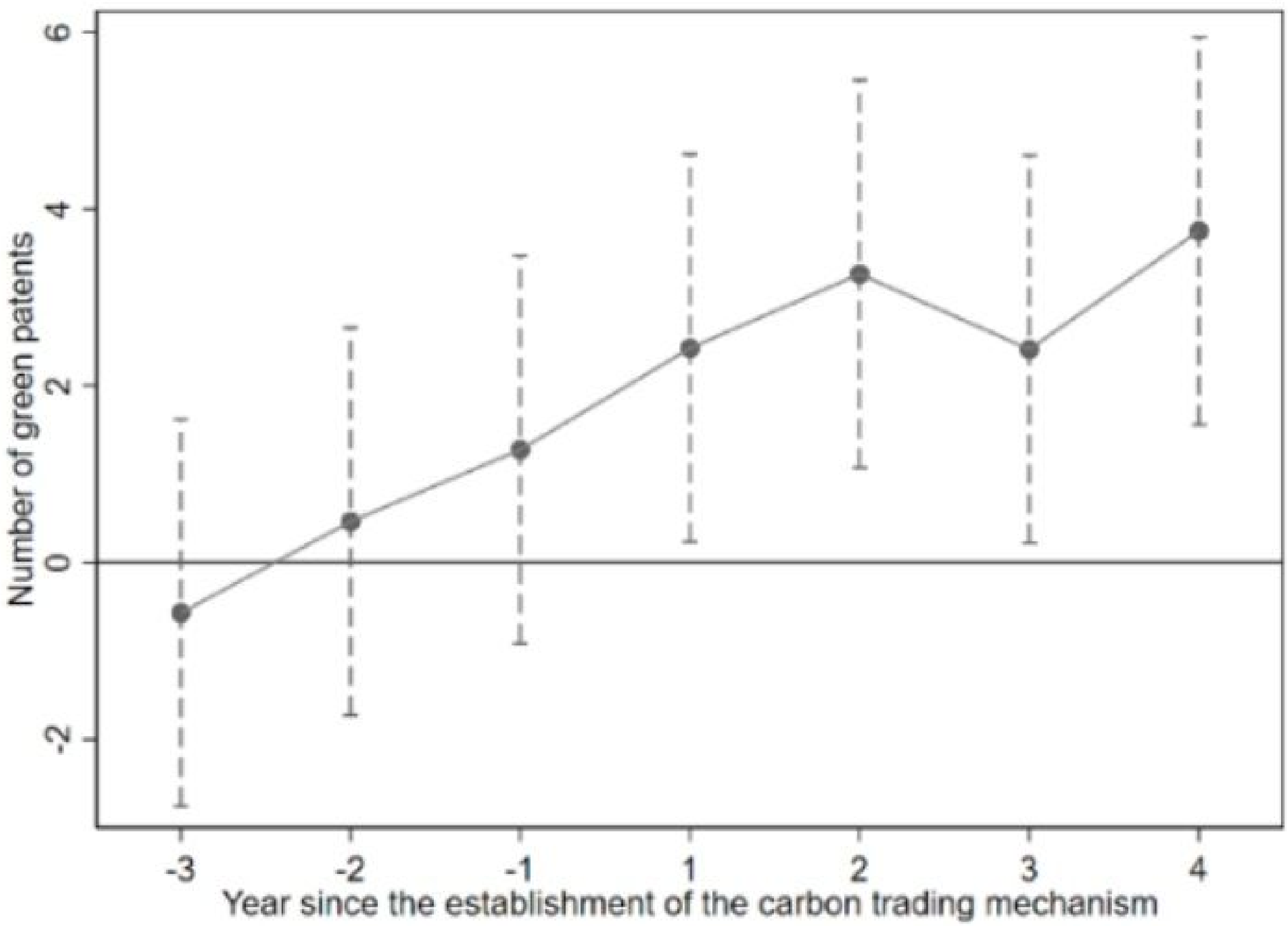

Figure 1

Dynamic effect test.

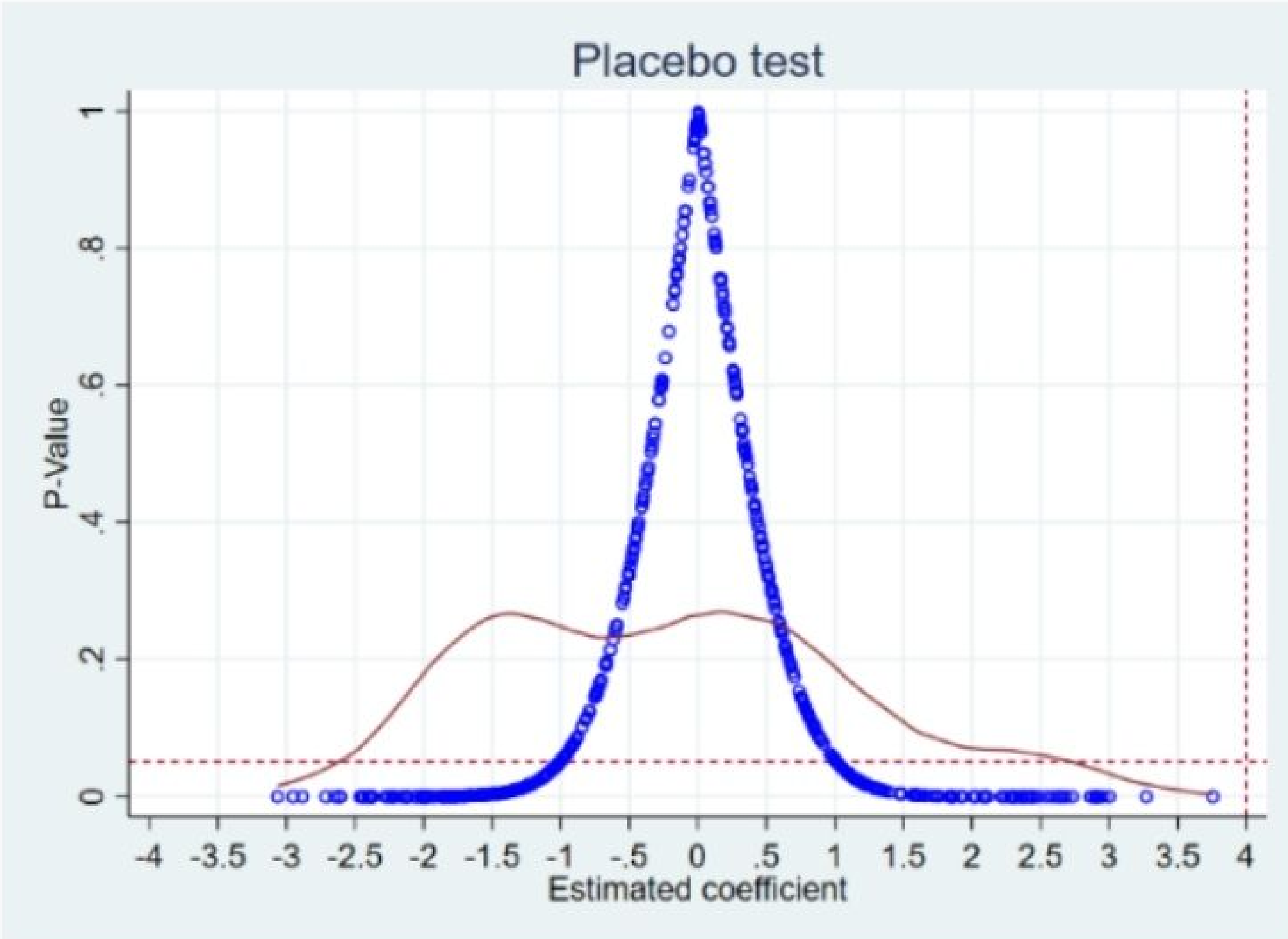

Figure 2

Placebo test.

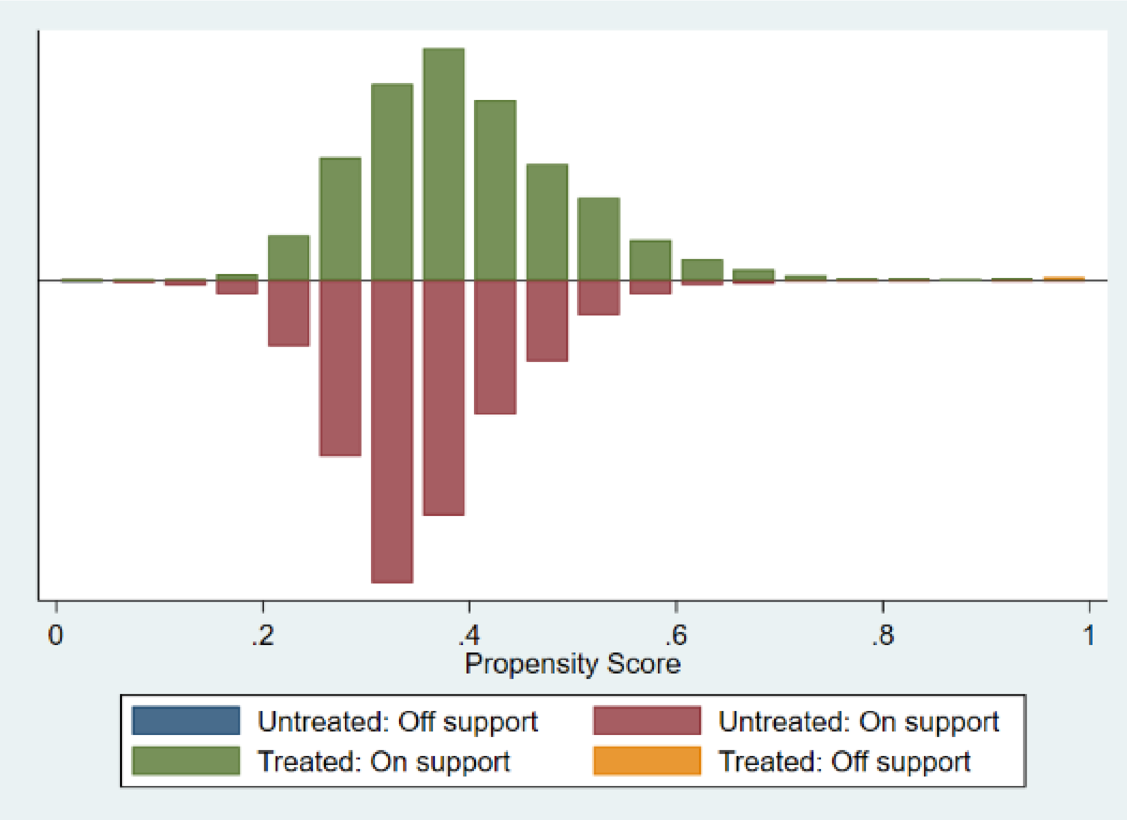

Figure 3

Standardized deviation of each variable

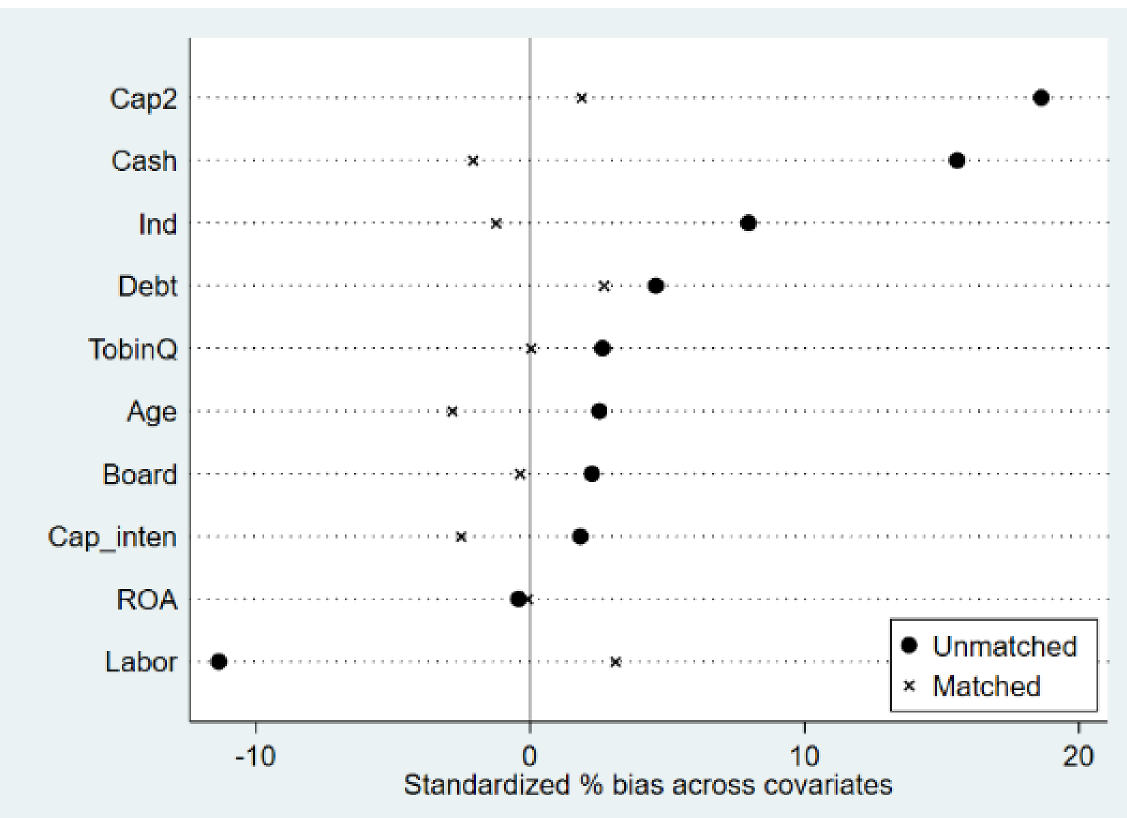

Figure 4

Common value range of propensity scores