

# Can Environmental Regulatory Policies Promote Green Technology Innovation of Enterprises?

## -- Based on China's Carbon Trading Pilot Policy

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### Abstract

Carbon trading, encompassing greenhouse gas emissions trading, leverages market mechanisms to address emissions of carbon dioxide and other greenhouse gases. This study utilizes panel data from Chinese listed firms spanning 2009 to 2023 and applies the Difference-in-Difference (DID) panel model along with the mediation effect model to examine the impact of China's carbon emission trading pilot policy on firms' green innovation. The findings indicate that the carbon trading policy positively influences enterprises' green technological innovation. From the perspective of enterprise type, the policy significantly promotes green technological innovation in state-owned enterprises. Regionally, the policy is particularly effective in encouraging green technological innovation among enterprises in central and western China. The implementation of the carbon trading pilot facilitates green technological innovation by alleviating financing constraints faced by enterprises.

### Keywords

Carbon Trading Policy Pilots; Corporate Green Innovation; Financing Constraints; R&D Investment.

## 1. Introduction

Carbon trading encompasses the exchange of rights to emit greenhouse gases, a concept first introduced by the Kyoto Protocol, an initial supplementary agreement to the United Nations Framework Convention on Climate Change established in Kyoto, Japan, in December 1997. This market-based approach addresses greenhouse gas emissions, such as carbon dioxide, by treating carbon as a tradable commodity, thereby facilitating the trading of carbon dioxide emission rights. In pursuit of China's climate targets, the National Development and Reform Commission announced a pilot program for carbon emission trading in October 2011. During the 75th session of the United Nations General Assembly in September 2020, China formally committed to achieving a carbon peak by 2030 and attaining carbon neutrality by 2060. The pilot program was initially launched in seven regions: Beijing, Shanghai, Guangdong, Shenzhen, Hubei, Tianjin, and Chongqing. By June 2021, the national carbon emission trading market officially opened.

Research has shown that carbon trading mechanisms can incentivize firms to adopt more sustainable technologies, thereby enhancing their environmental efficiency. By leveraging the trading system, businesses can meet emission reduction targets more cost-effectively, which in turn boosts their overall operational performance (Tian et al., 2022). Scholars have examined the effects of emission trading policy on various aspects, including carbon emission reduction (Zhang et al., 2020), green technology innovation (Luo & He, 2022), low-carbon transition (Wang et al., 2022), and corporate operating difficulties (Pu & Ouyang, 2023). However, there

are few studies that explore the relationship between China's carbon trading pilot policies and green innovation from a micro-level perspective, particularly given that the pilot phase of carbon trading is still in an exploratory and developmental stage.

The contributions of this paper are summarized as follows. Firstly, it employs panel data from Chinese publicly listed companies spanning from 2009 to 2023, utilizing a Difference-in-Differences (DID) model and a mediation model to conduct empirical analysis. The findings suggest that the carbon trading pilot policy positively influences firms' R&D and green innovation. Secondly, the research indicates that the carbon trading policy significantly boosts innovation in private companies. Additionally, the policy more effectively facilitates green technological innovation in the central and western regions, contributing to the literature on the regional impact of carbon trading policies at a micro level. Lastly, the paper identifies that the implementation of carbon trading pilots can foster green technological innovation by easing corporate financing constraints, thus offering a new perspective for studies on corporate financing and green innovation.

The rest of the paper is organized as follows: Section 2 presents the literature review and research hypotheses. Section 3 details the research design. Section 4 provides the analysis of empirical results. The final section offers the conclusions.

## 2. Literature Review and Research Hypotheses

Effectively increasing the green innovation rate (GIE) in manufacturing is crucial for overcoming environmental and energy constraints. Carbon trading can promote GIE by increasing government subsidies, R&D investment, and alleviating financing constraints (Wang et al., 2024). Continuous education and training policies can also effectively promote green innovation. As resource allocation and market factors are continuously optimized, the positive impacts of carbon trading policies are enhanced. However, these positive impacts can be suppressed during periods of business difficulties for enterprises, highlighting the boundary conditions of policy effects (Pu et al., 2023). Moreover, market distortions during such periods can significantly weaken the direct positive benefits while enhancing the indirect positive effects, although the overall trend may be downward (Xu et al.). In comparison, low-carbon innovation is more apparent in green patent authorizations, and the low-carbon city pilot has a more significant impact on state-owned enterprises and related political factors (Luo et al., 2022).

Additionally, the establishment of the carbon trading market has increased the market demand for green technologies and low-carbon products. To leverage market competition, enterprises are likely to increase their R&D investment in green products and technologies, thereby promoting innovation. Accordingly, this paper proposes the following hypotheses.

Hypothesis 1: The implementation of carbon trading pilot policy may promote enterprise green technology innovation.

State-owned enterprises typically possess strong capabilities for accessing resources, including capital, technology, and policy support. This enables them to more easily invest in the development and application of green technologies in the carbon trading market. State-owned enterprises frequently have access to financial support from multiple sources, including state budget allocations, policy-directed loans, and capital markets. This diverse financial backing provides a robust foundation for their research, development, and technological innovation. State-owned enterprises, as a crucial component of the national economy, benefit from easier access to government policy support and financial subsidies. This advantage can significantly lower the risks and costs associated with green technology innovation.

Being typically larger in size, state-owned enterprises can achieve economies of scale, thereby reducing unit costs. This efficiency enables them to invest more effectively in green technology

innovation. In critical industries and sectors like energy, transportation, and communications, state-owned enterprises frequently hold a dominant position. This dominance enables them to achieve economies of scale by exerting control over the entire industrial chain.

State-owned enterprises, by embracing their social responsibilities, leverage economies of scale to enhance production efficiency, minimize costs, and provide improved services to society and the public. Through strategic integration of resources and optimization of operations, these enterprises aim to deliver greater value while maintaining a commitment to social welfare. As a result, they must prioritize social responsibility in their operations to uphold their public image and maintain the trust of the community (Cunningham, 2011).

State-owned enterprises (SOEs) typically possess strong capabilities for accessing resources, including capital, technology, and policy support. This enables them to more easily invest in the development and application of green technologies within the carbon trading market. SOEs frequently benefit from financial support from multiple sources, including state budget allocations, policy-directed loans, and capital markets. This diverse financial backing provides a robust foundation for their research, development, and technological innovation. As a crucial component of the national economy, SOEs have easier access to government policy support and financial subsidies. This advantage can significantly lower the risks and costs associated with green technology innovation.

SOEs, by embracing their social responsibilities, leverage economies of scale to enhance production efficiency, minimize costs, and provide improved services to society and the public. Through strategic integration of resources and optimization of operations, these enterprises aim to deliver greater value while maintaining a commitment to social welfare. Consequently, they prioritize social responsibility in their operations to uphold their public image and maintain the trust of the community (Cunningham, 2011).

Hypothesis 2: Compared to non-state-owned enterprises, carbon trading policies are more conducive to promoting green technology innovation in SOEs.

Due to the high risk, long cycle, information asymmetry, and other characteristics of innovation projects, enterprises are extremely vulnerable to financing constraints in green technology innovation activities. Financing constraints refer to the inability of enterprises to ensure internal R&D funding needs while also being unable to access external channels of funding. This financing constraint can significantly inhibit the development of enterprise innovation (Hall and Lerner, 2010). When an enterprise cannot strengthen its R&D activities through external financial support, it experiences a significant negative impact on its overall innovation capacity (Cornaggia et al., 2015). At this point, positive policy interventions are extremely important (Shi et al., 2018). However, sometimes, the additional costs arising from environmental regulations can lead to a reduction in the amount of funds allocated by firms to technological research, which can be counterproductive to their innovation capacity (Johnstone et al., 2010). Strengthening policies and regulations in areas such as environmental regulations can effectively mitigate the financing constraints faced by enterprises, thus further promoting green development (Miao et al., 2019). For example, carbon trading policies can improve the level of corporate carbon information disclosure and enhance information transparency, allowing investors to better understand the enterprise. This reduces information asymmetry and the risk of uncertainty in future development, attracting more investors to focus on the low-carbon environmental protection industry, thereby alleviating financing constraints (Shen et al., 2019). Accordingly, this paper proposes:

Hypothesis 3: The implementation of carbon trading pilot can promote green technological innovation of enterprises by alleviating their financing constraints.

### 3. Study Design

#### 3.1. Data

In this paper, China's listed companies in Shanghai and Shenzhen were selected as the research sample from 2009 to 2023, with data obtained from the CSMAR database. The data were processed to exclude ST\* and ST company samples and to remove samples with missing key variables. To mitigate the impact of extreme values, a 1% Winsorization process was applied, resulting in panel data of listed companies for each year.

#### 3.2. Variable Selection

##### 3.2.1. The Explained Variables

Enterprise green patents (Lnpatents): Drawing on previous references, this paper uses the number of green patent applications by listed companies to measure their green technology innovation and applies a logarithmic transformation to this data.

Enterprise R&D investment (Lnrdspend): This paper uses the amount of R&D investment by listed companies as an index of enterprise innovation investment and applies a logarithmic transformation to the numerical values.

##### 3.2.2. Core Independent Variable

Whether it is affected by the policy (DID) interaction item, affected by the carbon trading pilot policy is 1, otherwise 0. 1 before being affected, and 0 otherwise.

##### 3.2.3. Mediating Variables

Financing constraint (FC) is an indicator used to measure the degree of financing constraint of a company, which refers to the difficulties or restrictions that a company faces when obtaining external funds.

##### 3.2.4. Control Variables

Company size (Lnsize) represents the size of the enterprise. The company and size is logarithmically treated to eliminate the difference between different enterprise sizes, making the analysis more comparable.

Asset to liability ratio (Lev) measures the ratio of total liabilities to total assets. The asset-liability ratio reflects the debt level of an enterprise. When the asset-liability ratio is too high, the enterprise is facing a high debt repayment pressure, which will affect the value level of the enterprise.

Equity concentration degree (Topten) calculates the total proportion of shares held by the top ten shareholders of the company.

The proportion of the top ten shareholders reflects the shareholding structure of the company, which has a certain impact on the governance and value of the enterprise.

Market account ratio (PB) is a financial indicator that measures the relationship between the market value of a listed company and its book value. The market book ratio reflects the market price paid by investors for each unit of book value. The calculation of the ratio of market accountsThe formula is  $\text{market account ratio} = \text{market price per share} / \text{book value per share}$

The separation rate of two rights (Separation). Separation of powers is the distribution of power between the owners and operators of a business. Separation of powers may reflect the soundness of a company's governance structure, which has an impact on business decisions and enterprise value.

Whether the Big4 accounting firms audit (Big4): The four largest professional services networks: pricewaterhousecoopers (PwC), Deloitte (Deloitte), Ernst & Young (EY) and KPMG (KPMG). The big four accounting firms have extensive influence and authority in the fields of audit, tax, consulting and financial advisory services.

The year of business operation ( $\ln age$ ) refers to the number of years of continuous operation since its establishment. It is an important indicator reflecting the accumulation of experience, resources and credibility of enterprises in the market. Specific variables are as shown in Table 1:

**Table 1.** Description table of variables

| type                  | variables                                             | notation       | Definitions/formulas                                                                                                                                                               |
|-----------------------|-------------------------------------------------------|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Explained variables   | Enterprise green patent                               | $\ln patents$  | the paper uses the number of green patent applications of listed companies to measure the green technology innovation of enterprises, and treats them logarithmically.             |
|                       | Enterprise R&D investment                             | $\ln rdsepn d$ | the amount of R&D investment of listed companies as the index of enterprise innovation investment, and treats the numerical value logarithmically.                                 |
| Explanatory variables | Whether it is affected by carbon trading pilot policy | DID            | Interaction item, affected by the carbon trading pilot policy is 1, otherwise 0. 1 before being affected, and 0 otherwise.                                                         |
| Intermediary variable | Financial constraint                                  | FC             | An indicator used to measure the degree of financing constraint of a company, which refers to the difficulties or restrictions that a company faces when obtaining external funds. |
| Control variables     | Firm size                                             | $\ln size$     | Natural logarithm of total company assets                                                                                                                                          |
|                       | debt-to-asset ratio                                   | Lev            | Gearing ratio = total liabilities/total assets                                                                                                                                     |
|                       | Ownership concentration                               | Topten         | Shares held by top ten shareholders/total share capital                                                                                                                            |
|                       | Market-to-book ratio                                  | PB             | Market price per share/book value per share                                                                                                                                        |
|                       | Separation of ownership and control ratio             | Separation     | (Control - cash flow rights) / cash flow rights                                                                                                                                    |
|                       | Big four accounting firms audit                       | Big4           | whether it is audited by a Big Four accounting firm                                                                                                                                |
|                       | Financial year                                        | $\ln age$      | the number of years of continuous operation since its establishment.                                                                                                               |

### 3.3. Model

This paper adopts a double-difference regression model, and selects the number of green patents ( $\ln patents_{i,t}$ ) and enterprise innovation investment ( $\ln rdsepn d_{i,t}$ ) as the explanatory variables, and selects whether it is affected by the carbon trading pilot policy ( $DID_{i,t}$ ) as the explanatory variables. The control variables include gearing ratio ( $Lev_{i,t}$ ), company size ( $Size_{i,t}$ ), equity concentration ( $Topten_{i,t}$ ), market-to-book ratio ( $PB_{i,t}$ ), two rights separation rate ( $Separation_{i,t}$ ), whether the four major audits ( $Big4_{i,t}$ ), and the company's operating year ( $Age_{i,t}$ ) to construct the model as follows:

$$\ln patents_{i,t}(\ln rdsepn d_{i,t}) = \alpha_i + \beta_1 DID_{i,t} + \beta_i Controls_{i,t} + Indu_i + Year_t + \varepsilon_{it} \quad (1)$$

where  $Controls_{i,t}$  is the control variable, Industry and Year represent industry and year fixed effects,  $i$  represents enterprise,  $t$  represents year, and  $\varepsilon$  represents the residual term.

In order to analyze the mechanism of carbon trading pilot policy on enterprise green technology innovation, this paper uses the corporate financing constraint (FC) mediating variable to check whether the two play a mediating effect between carbon trading pilot policy and enterprise green technology innovation. The causal step method is used to test the mediating effect, in which the causal step method testing process is as follows:

$$\text{Lnpatents}_{i,t}(\text{Lnrdsdpnd}_{i,t}) = \alpha_i + \beta_2 \text{DID}_{i,t} + \beta_i \text{Controls}_{i,t} + \text{Indu}_i + \text{Year}_t + \varepsilon_{it} \tag{2}$$

$$\text{FC}_{i,t} = \alpha_i + \beta_3 \text{DID}_{i,t} + \beta_i \text{Controls}_{i,t} + \text{Indu}_i + \text{Year}_t + \varepsilon_{it} \tag{3}$$

$$\text{Lnpatents}_{i,t}(\text{Lnrdsdpnd}_{i,t}) = \alpha_i + \beta_4 \text{DID}_{i,t} + \omega \text{FC}_{i,t} + \beta_i \text{Controls}_{i,t} + \text{Indu}_i + \text{Year}_t + \varepsilon_{it} \tag{4}$$

The test is carried out according to the above steps to determine whether there is a mediation effect based on the significance of the regression coefficients. Specific judgment criteria are: (1) If the regression coefficient  $\beta_2$  is significant, the next test is conducted, if it is not significant, it is considered that there is no mediation effect. (2) If  $\beta_3, \omega$  are both significant, then the existence of mediation effect. (3) If the regression coefficient  $\omega$  is not significant, it means that there is a full mediation effect (strong mediation effect); if the regression coefficient  $\beta_4$  is significant and  $|\beta_4| < |\beta_2|$ , the mediation effect is said to be partial mediation effect (weak mediation effect)

4. Empirical Results

4.1. Descriptive Statistics

Table 2 demonstrates the descriptive statistics of each variable. The maximum, minimum, mean, and standard deviation of the variables are statistically analyzed so as to avoid excessive data volatility and large polar deviations that can cause bias in the regression results. The standard deviation of all variables is less than the extreme deviation, indicating that there are some differences in the variables between different enterprises.

Table 2. Descriptive Statistics

| Variable   | Obs   | Mean   | Std. Dev. | Min    | Max    |
|------------|-------|--------|-----------|--------|--------|
| Lnpatents  | 30356 | 0.461  | 1.288     | 0      | 5.521  |
| Lnrdsdpnd  | 30356 | 13.032 | 8.128     | 0      | 25.025 |
| DID        | 30356 | 0.331  | 0.47      | 0      | 1      |
| FC         | 30356 | -0.436 | 0.274     | -0.997 | 0      |
| Lnsize     | 30356 | 22.435 | 1.336     | 19.831 | 26.428 |
| Lev        | 30356 | 0.459  | 0.202     | 0.067  | 0.915  |
| Topten     | 30356 | 57.669 | 15.659    | 22.53  | 90.9   |
| PB         | 30356 | 4.159  | 3.386     | 1.191  | 25.025 |
| Seperation | 30356 | 5.077  | 7.677     | 0      | 29.337 |
| Big4       | 30356 | 0.066  | 0.248     | 0      | 1      |
| lnage      | 30356 | 2.946  | 0.339     | 1.792  | 3.555  |

## 4.2. Matrix of Correlations

In this paper, the correlation test was analyzed between the selected variables two by two, and the results of the correlation analysis are shown in Table 3. According to the results, it can be seen that the correlation coefficient between the variables, most of the values are below 0.4, indicating that the degree of correlation between the variables selected in this paper is not high, and there is no serious multicollinearity.

**Table 3.** Matrix of correlations

| Variables      | (1)    | (2)    | (3)    | (4)    | (5)    | (6)    | (7)    | (8)   | (9)   | (10)  |
|----------------|--------|--------|--------|--------|--------|--------|--------|-------|-------|-------|
| (1) Lnpatents  | 1.000  |        |        |        |        |        |        |       |       |       |
| (2) Lnrdsdpnd  | 0.206  | 1.000  |        |        |        |        |        |       |       |       |
| (3) DID        | 0.015  | 0.071  | 1.000  |        |        |        |        |       |       |       |
| (4) Lnsize     | 0.074  | 0.086  | 0.123  | 1.000  |        |        |        |       |       |       |
| (5) Lev        | 0.003  | -0.109 | 0.015  | 0.434  | 1.000  |        |        |       |       |       |
| (6) Topten     | 0.004  | 0.075  | 0.069  | 0.228  | -0.066 | 1.000  |        |       |       |       |
| (7) PB         | -0.021 | -0.092 | -0.000 | -0.149 | 0.387  | -0.143 | 1.000  |       |       |       |
| (8) Seperation | 0.005  | -0.009 | -0.099 | 0.065  | 0.050  | 0.074  | 0.008  | 1.000 |       |       |
| (9) Big4       | 0.028  | 0.036  | 0.115  | 0.343  | 0.087  | 0.193  | -0.040 | 0.081 | 1.000 |       |
| (10) lnage     | -0.058 | -0.037 | 0.146  | 0.166  | 0.106  | -0.181 | 0.049  | 0.024 | 0.001 | 1.000 |

## 4.3. Benchmark Regression

The above table shows the results of the benchmark regression, in column (2) is the enterprise's green patent Lnpatents, column (4) is the enterprise's R&D investment Lnrdsdpnd, and the core explanatory variable is whether the enterprise is affected by the policy (DID) policy\*post interactive term.

From the regression results in column (2), it can be seen that the coefficient of DID is 0.0961 and the result is significant at the significance level of 1%, indicating that the carbon trading policy plays a significant role in the increase of enterprise green technology output. It has a significant improvement in promoting enterprise green technology innovation. Carbon trading policies through carbon allowances and carbon price mechanisms. The enterprises have economic incentives to reduce emissions, for example, enterprises can reduce emissions to save the cost of buying carbon allowances, emissions below the allowance enterprises can sell excess allowances to obtain profits. In order to save costs or increase profits, enterprises will pay more attention to the creation and purchase of green patents, and then improve their green technology innovation capabilities.

From the regression results in column (4), it can be seen that the coefficient of DID is 0.483 and the result is significant at the level of 1%, indicating that the carbon trading policy plays a significant role in the R&D investment of enterprises, that is, it improves the R&D investment of enterprises and promotes green innovation of enterprises. Carbon trading policies are often accompanied by strict emission regulations and policy pressures, forcing companies to innovate green, and at the same time promoting the development and application of related technologies. In order to cope with the cost of carbon emissions and achieve the long-term policy goal of gradually reducing carbon allowances, enterprises will choose to increase R&D investment in green technology and innovation, improve green innovation capabilities, and ensure long-term sustainable development.

In the regression results in column (2), it can be found that the coefficient of equity concentration topten is -0.00189 and is significant at the level of 1%, indicating that the

increase of equity concentration will reduce the number of green patents (green innovation output) of enterprises, that is, it will have a negative impact on the green technology innovation of enterprises, and high equity concentration means that the majority of the equity of enterprises is held by minority shareholders, who usually pay more attention to short-term financial returns and give priority to projects with quick profits, In order to meet short-term profit targets, companies may reduce the R&D and purchase of green technology patents.

**Table 4.** The Impact of Carbon Trading Policy Pilot on Green Technology Innovation

|                | (1)       | (2)         | (3)       | (4)        |
|----------------|-----------|-------------|-----------|------------|
|                | Lnpatents | Lnpatents   | Lnrdsdpnd | Lnrdsdpnd  |
| DID            | 0.109***  | 0.0961***   | 0.611***  | 0.483***   |
|                | (6.64)    | (5.84)      | (8.33)    | (6.74)     |
| Lnsize         |           | 0.142***    |           | 1.086***   |
|                |           | (18.83)     |           | (33.08)    |
| Lev            |           | -0.149***   |           | -1.314***  |
|                |           | (-2.99)     |           | (-6.08)    |
| Topten         |           | -0.00189*** |           | 0.0132***  |
|                |           | (-3.73)     |           | (6.01)     |
| PB             |           | 0.00119     |           | -0.0657*** |
|                |           | (0.46)      |           | (-5.85)    |
| Seperation     |           | -0.000180   |           | 0.00102    |
|                |           | (-0.19)     |           | (0.25)     |
| Big4           |           | -0.0444     |           | -0.361***  |
|                |           | (-1.41)     |           | (-2.63)    |
| Lnage          |           | -0.117***   |           | -2.211***  |
|                |           | (-4.39)     |           | (-18.98)   |
| Constant       | 0.186***  | -2.371***   | 3.868***  | -13.29***  |
|                | (2.69)    | (-13.25)    | (12.46)   | (-17.05)   |
| Obs            | 30356     | 30356       | 30356     | 30356      |
| R <sup>2</sup> | 0.0520    | 0.0666      | 0.5215    | 0.5557     |

Notes: t statistics in parentheses \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01.

#### 4.4. Mediating Effect Model Regression Results

In this paper, the FC index of financing constraint degree is selected as the mediating variable, and the larger the financing constraint FC index, the greater the financing constraint of the enterprise. From the regression results in column (1) of the above table, it can be seen that the

coefficient of policy impact DID is 0.483, and it is significant at the significant level of 1%, indicating that the carbon trading policy has a significant effect on the R&D investment (green technology innovation) of enterprises.

**Table 5.** The financing constraint mechanism test

|                | (1)        | (2)          | (3)        |
|----------------|------------|--------------|------------|
|                | Lnrdsdpnd  | FC           | Lnrdsdpnd  |
| DID            | 0.483***   | -0.00676***  | 0.473***   |
|                | (6.74)     | (-4.13)      | (6.60)     |
| FC             |            |              | -1.488***  |
|                |            |              | (-5.92)    |
| Lnsiz          | 1.086***   | 0.169***     | 1.337***   |
|                | (33.08)    | (225.95)     | (24.89)    |
| Lev            | -1.314***  | 0.219***     | -0.988***  |
|                | (-6.08)    | (44.38)      | (-4.43)    |
| Topten         | 0.0132***  | -0.000585*** | 0.0123***  |
|                | (6.01)     | (-11.65)     | (5.60)     |
| PB             | -0.0657*** | 0.0184***    | -0.0383*** |
|                | (-5.85)    | (71.84)      | (-3.15)    |
| Seperation     | 0.00102    | 0.000857***  | 0.00230    |
|                | (0.25)     | (9.07)       | (0.55)     |
| Big4           | -0.361***  | -0.0275***   | -0.402***  |
|                | (-2.63)    | (-8.77)      | (-2.93)    |
| Lnage          | -2.211***  | 0.0379***    | -2.154***  |
|                | (-18.98)   | (14.27)      | (-18.45)   |
| Constant       | -13.29***  | -4.431***    | -19.88***  |
|                | (-17.05)   | (-249.07)    | (-14.63)   |
| Obs            | 30356      | 30356        | 30356      |
| R <sup>2</sup> | 0.5557     | 0.7966       | 0.5562     |

Notes: t statistics in parentheses \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01.

The results in column (2) of the above table show that the coefficient of policy impact on DID is -0.00676, and it is significant at the significance level of 1%, indicating that carbon trading policies can effectively reduce the level of corporate financing constraints. After adding both the policy impact on DID and the degree of financing constraint FC in column (3), the coefficient of FC is -1.488, and it is significant at the significance level of 1%, and the coefficient of DID is from 0.483 to 0.473, and is still significant at the level of 1%. It shows that financing constraints

play a partial mediating role between carbon trading policy and enterprise innovation investment, and carbon trading policy can reduce financing constraints to a greater extent, and further promote enterprise green technology innovation through this approach.

Carbon trading policies provide companies with the opportunity to generate additional revenue by selling excess carbon allowances, encouraging companies to optimize their production processes and reduce carbon emissions by adopting green technologies to save costs. At the same time, the policy brings ESG investment attractiveness, when more and more investors pay attention to environmental, social and governance (ESG) factors, enterprises that actively participate in carbon trading are more likely to attract green investment; Some financial institutions may also improve their dedicated green finance products, such as green bonds and loans, to help companies finance green technology innovation.

## 4.5. Heterogeneity Analysis

### 4.5.1. Heterogeneity Analyses based on the Shareholding

**Table 6.** Based on firm ownership test

|                | (1)        | (2)         | (3)       | (4)        |
|----------------|------------|-------------|-----------|------------|
|                | Lnpatents  | Lnpatents   | Lnrdsdpnd | Lnrdsdpnd  |
| DID            | 0.132***   | 0.0754***   | 0.479***  | 0.447***   |
|                | (4.93)     | (3.63)      | (3.89)    | (5.35)     |
| Lnsize         | 0.110***   | 0.129***    | 1.132***  | 1.173***   |
|                | (9.17)     | (12.23)     | (20.59)   | (27.62)    |
| Lev            | -0.0458    | -0.241***   | -0.391    | -1.878***  |
|                | (-0.57)    | (-3.78)     | (-1.07)   | (-7.31)    |
| Topten         | -0.00126   | -0.00196*** | 0.00323   | 0.0168***  |
|                | (-1.47)    | (-3.14)     | (0.81)    | (6.67)     |
| PB             | -0.00771*  | 0.00470     | -0.00478  | -0.104***  |
|                | (-1.82)    | (1.45)      | (-0.25)   | (-7.93)    |
| Seperation     | -0.00349** | 0.00157     | 0.00584   | -0.0219*** |
|                | (-2.27)    | (1.27)      | (0.83)    | (-4.39)    |
| Big4           | -0.0251    | -0.0699     | 0.0400    | -0.677***  |
|                | (-0.59)    | (-1.41)     | (0.21)    | (-3.39)    |
| Lnage          | -0.267***  | -0.112***   | -1.618*** | -2.029***  |
|                | (-5.48)    | (-3.47)     | (-7.23)   | (-15.61)   |
| Constant       | -1.466***  | -2.004***   | -17.18*** | -13.83***  |
| Obs            | (-5.09)    | (-8.01)     | (-12.98)  | (-13.73)   |
| Obs            | 13415      | 16941       | 13415     | 16941      |
| R <sup>2</sup> | 0.0942     | 0.0507      | 0.5402    | 0.5737     |

Notes: t statistics in parentheses \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01

Based on the analysis of equity nature, in (1), (3) and (2) and (4) in the above table, the nature of the enterprise is divided into state-owned enterprises and non-state-owned enterprises for sub-sample regression, and the experimental results show that the coefficients of state-owned enterprises are 0.132 and 0.479, and both are significant at the level of 1%. The coefficients for non-state-owned enterprises were 0.0754 and 0.447, both significant at the 1% level. The results show that the carbon trading policy has a particularly obvious effect on both state-owned enterprises and non-state-owned enterprises, but the impact of the policy on state-owned enterprises is more significant.

On the one hand, state-owned enterprises (SOEs) tend to have access to more government support and resources, which gives them an advantage in dealing with carbon trading policies. The government may also provide technical support through research institutes or internal research departments of SOEs to help SOEs adopt advanced technologies more quickly. State-owned enterprises (SOEs) also generally have a more stable position in the market and better resource allocation, which makes them more flexible and adaptable in response to carbon trading policies, and their abundant resources and capital can flexibly adjust the allocation of resources and invest in green technology innovation and low-carbon projects.

On the other hand, non-state-owned enterprises pay more attention to market-oriented and short-term financial performance, and non-state-owned enterprises usually face greater short-term profit pressure, and the fierce competition in the market makes non-state-owned enterprises pay more attention to cost control and short-term market performance, and invest less in green projects with uncertainty of long-term investment returns. At the same time, the financial situation of non-state-owned enterprises is relatively unstable, and it is difficult to bear the high risks brought by technological innovation.

Therefore, the effect of carbon trading pilot policy on green technology innovation of state-owned enterprises is better.

#### **4.5.2. Based on the Analysis of Regional Development Level Heterogeneity**

Based on the analysis of regional differences, columns (1), (3) and (2) and (4) of the table divided the regional differences into the eastern region and the central and western regions for sub-sample regression. The empirical results show that in terms of green technology output, as shown in tables (1) and (2), the coefficient is 0.0810 in the eastern region and the results are significant at the 1% significance level, and the coefficient in the central and western regions is 0.0866. but the results are significant at the 10% significance level. In terms of green technology input, as shown in Table (3) and (4), the coefficient in the eastern region is -0.0871 and the results are not significant, while the coefficient in the central and western regions is 1.449 and significant at the 1% significant level. The results show that the number of green patent and green technology innovation investment, the central and western regions are more significantly affected by the policy. Due to the underdeveloped economy in the central and western regions, industries such as energy, chemicals, and manufacturing industries account for a relatively large proportion of the technical base, so the number of green technology innovation products is small, and the government also encourages more enterprises to increase investment in green technology research through policies to make up for the technology gap, so the carbon trading policy has a significant impact on investment.

Table 7. regional development level heterogeneity

|                | (1) East    | (2) midwest | (3) East   | (4) midwest |
|----------------|-------------|-------------|------------|-------------|
|                | Lnpatents   | Lnpatents   | Lnrdselpnd | Lnrdselpnd  |
| DID            | 0.0810***   | 0.0866*     | -0.0871    | 1.449***    |
|                | (3.93)      | (1.94)      | (-1.05)    | (6.57)      |
| Lnsize         | 0.169***    | 0.0925***   | 1.002***   | 1.235***    |
|                | (17.37)     | (7.68)      | (25.71)    | (20.73)     |
| Lev            | -0.176***   | -0.0404     | -0.692***  | -2.106***   |
|                | (-2.71)     | (-0.53)     | (-2.65)    | (-5.57)     |
| Topten         | -0.00308*** | -0.0000494  | 0.0120***  | 0.00764*    |
|                | (-4.73)     | (-0.06)     | (4.58)     | (1.91)      |
| PB             | 0.00686*    | -0.00716*   | -0.0782*** | -0.0275     |
|                | (1.93)      | (-1.94)     | (-5.47)    | (-1.51)     |
| Seperation     | 0.00215*    | -0.00329**  | 0.00429    | -0.00693    |
|                | (1.74)      | (-2.22)     | (0.86)     | (-0.95)     |
| Big4           | -0.0942**   | -0.0368     | -0.101     | -1.240***   |
|                | (-2.48)     | (-0.62)     | (-0.66)    | (-4.20)     |
| Lnage          | -0.0907***  | -0.154***   | -1.933***  | -2.582***   |
|                | (-2.79)     | (-3.20)     | (-14.78)   | (-10.84)    |
| Constant       | -2.735***   | -1.501***   | -12.62***  | -15.22***   |
|                | (-11.22)    | (-5.52)     | (-12.89)   | (-11.32)    |
| Obs            | 19590       | 10766       | 19590      | 10766       |
| R <sup>2</sup> | 0.0729      | 0.0638      | 0.5865     | 0.5174      |

Notes: t statistics in parentheses \* p < 0.1, \*\* p < 0.05, \*\*\* p < 0.01.

5. Conclusion

This paper examines the impact of carbon trading policies on corporate green technology innovation by analyzing data from listed companies in Shanghai and Shenzhen between 2009 and 2023. The study employs the Difference-in-Differences (DID) model and a mediating effect model to explore this relationship. The empirical results indicate that carbon trading policies significantly promote green technology innovation among enterprises. Specifically, the regression coefficient for the impact of carbon trading policies on green patents is 0.0961, and for R&D investment, it is 0.483, both of which are statistically significant at the 1% level. These findings suggest that carbon trading policies effectively enhance green technology innovation in enterprises.

The heterogeneity analysis reveals that the value enhancement effect of carbon trading policies is more pronounced for state-owned enterprises and companies located in the central and western regions. Specifically, the regression coefficient for state-owned enterprises is 0.132, which is notably higher than that for non-state-owned enterprises (0.0754). This indicates that carbon trading policies are more beneficial to the value of state-owned enterprises. Similarly, for companies in the central and western regions, the regression coefficient is 0.0866, significantly higher than that for enterprises in the eastern region (0.0810), suggesting that the value enhancement effect of carbon trading policies is more evident in the central and western regions.

The findings underscore the significant role that the pilot carbon trading policy has played in promoting green technology innovation among enterprises. This has been achieved by alleviating financing constraints, providing economic incentives, and enhancing the innovation capacity of companies, particularly state-owned enterprises and those in the central and western regions.

Based on these results, it is recommended that the government continue to deepen and expand the pilot carbon trading policy to further stimulate green technology innovation among enterprises. Special emphasis should be placed on supporting state-owned enterprises and companies in the central and western regions. This could be accomplished by optimizing the carbon trading market mechanism, increasing the flexibility of carbon allowances, and enhancing financial support for green R&D projects. Additionally, the government should promote green financial products, reduce financing costs for enterprises, and encourage broader participation in green technology innovation.

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