How Carbon Emission Trading Effects Enterprise Technological Innovation: A Quasi-Natural Experiment from China

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Abstract

As an important policy tool to realize the vision of "carbon peaking and carbon neutralization", the carbon emission trading system is considered to be useful for alleviating enterprise financing constraints and stimulating high-quality technological innovation. Based on the data of Chinese listed companies, this paper tests the above policy effects by setting a quasi-natural experiment. The conclusions are as follows: (1) The introduction of the market mechanism for carbon emission control can improve the quality of enterprise R & D, and the mitigation of financing constraints has a positive contribution to this improvement; (2) The innovation incentive effect of carbon emission trading system is significant in the sample of state-owned enterprises with government credit endorsement, but it shows the opposite statistical results in non-state-owned enterprises; (3) The incentive effect of carbon emission trading system on innovation quality is higher in heavy pollution industries than others. The above conclusions have important reference value for developing countries to achieve the dual goals of high-quality economic development.

1. Introduction

Economists have been concerned about the contradiction between greenhouse gas emissions and endogenous economic growth (innovation) for a long time and attempted to solve the incentive compatibility between them through the property rights trading mechanism (Hass and Dales, 1969; Porter, 1995). Since China joined the Kyoto Protocol in 1997, it has imposed strict controls on carbon dioxide emissions, among them, the credit lever with environmental protection conditions has become an important tool to achieve environmental goals. While such direct control and regulation has a good emission reduction effect in the short term, it has a profound impact on enterprises in the long term (Kneller and Manderson, 2012). To meet strict credit conditions, the enterprise had to give up R&D projects with longer cycles and higher risk, and focus on low-quality strategic innovations such as green appearance, green concept innovations, in order to exchange for numerical advantages and obtain the broader policy care and credit support. Thus, in the field of patent R&D, the effect of "bad money driving out good money" is produced, and the credit lever attached with "green" conditions has been criticized by the academic community. Therefore, after 2005, the Chinese government gradually tried to introduce an emission trading system (ETS) from Europe, the United States, and South Korea, hoping to increase asset liquidity and weaken the role of credit leverage through more compatible marketization means, thus providing a more suitable financing environment for enterprises to improve the quality of innovation. So, can the carbon emission trading system, which aims to neutralize the side effects of environmental regulation, really improve the financing environment and innovation environment of enterprises? And in the face of softer regulatory policies, what kind of research and development choice will enterprises make?

Carbon emission control internalized exogenous environmental costs, which had an impact on enterprises' production and operation (Stavins, 1996). A large number of credits with environmental protection requirements raises the cost of financing for enterprises, which cannot reserve more profits to absorb the risks of R&D. To solve this problem, Hass and Dales (1969) proposed that the market mechanism should be used to guide enterprises to neutralize external costs, that is, enterprises should be given emission rights and be allowed to trade them, so the operating environment of enterprises will be improved with the help of property rights mechanism and liquidity. A properly designed emission trading system will guide enterprises to continue technological research and development through market signals, and finally find a new equilibrium point between marginal revenue and marginal cost, which is verified in the research of Cui et al. (2018). Unfortunately, at present, Chinese enterprises still rely on financial leverage to carry out R&D activities (Pan and Jiang, 2020), but Cui et al. (2018) does not explain the intermediate transmission mechanism and ignore the decisive role of the financing environment on technology R&D. Therefore, this paper constructs a quasi-natural experiment based on the carbon emission trading pilot object of China's carbon emission trading in 2013. Through counterfactual analysis, this paper discusses whether the trading system can help improve financing constraints and thus encourage enterprises to improve the quality of R&D. Specifically, this paper intends to answer the following questions: Can carbon emission trading policy stimulate the substantive innovation of enterprises? In the pilots' cities, does the implementation of carbon emission trading policies ease financing constraints, thus leaving more profit space for enterprises to improve the quality of innovation? Are there differences in innovation incentive effects of carbon emission trading policies under different enterprise ownership and different industry types?

The marginal contribution of this paper is as follows: Firstly, by classifying and identifying the patent database, the patents of enterprises are divided into substantive innovation and strategic innovation according to their quality, and the influence of carbon emission trading system on the two kinds of innovation is verified through counterfactual analysis. In addition, in order to obtain the net effect of the innovation incentive of the carbon emission trading system in the pilot cities, this paper sets the data time window before 2017; Secondly, by introducing the variable of "financing constraint", the mediating effect model is constructed to measure the role of financing environment factors in the incentive effect of carbon emission trading policy innovation, thus improving the analysis chain of relevant mechanisms; Finally, the samples are classified and tested according to industry and ownership perspective, and the innovation incentive effect of carbon emission trading system is investigated vertical and horizontal perspectives. We try to tell different stories from Cui et al. (2018), Zhu et al. (2019), Wei and Ren (2021) through the analysis and evidence mining in the above links. The main findings of this study are as follows: the introduction of market mechanism in the field of carbon emission control can alleviate the financing pressure of enterprises, so as to reserve more space for improving the quality of R&D, and this incentive effect is significantly different between state-owned enterprises and non-enterprises, in the sample of heavily polluting industries, the incentive effect of substantive innovation of carbon emission trading system is more obvious.

The remaining structures of this paper are as follows: The second part is literature review; The third part is research hypothesis; The fourth part is empirical design, model setting and related variable description; The fifth part is empirical results, mediating effect test and related robustness test; The sixth part is the heterogeneity analysis, which empirically analyzes the heterogeneity of impact effects from the perspective of enterprise ownership and different industry types; The seventh part is the research conclusion and policy enlightenment; The last part is the research prospect.

2. Literature Review

The carbon emission trading system is a further expansion and extension of Coase's property rights hypothesis (Coase, 1960). Compared with the carbon tax, emission trading has the lowest emission reduction cost (Montgomery, 1972), higher effectiveness (Stern, 2007), and the strongest desirability (Zeng and Wan, 2010). However, the economists are more concerned about whether such environmental regulation policies based on market mechanisms can stimulate enterprise innovation and promote endogenous economic growth (Chen et al, 2021; Zhang et al, 2020; Lv and Bai, 2021). From the existing fuzzy causal identification, Cui et al. (2018), Zhu et al. (2019), Wei and Ren (2021) all agree that there is a positive relationship between carbon trading policy and enterprise innovation. In terms of mechanism analysis, they all believe that the price mechanism of the carbon market gives enterprises more flexible cost signals, so the enterprises have enough time to adjust the R&D strategy and strive for higher profit margins. Qi and Zhang (2019) are considered that the positive statistical relationship is due to the fact that carbon emission trading changes the profit function of enterprises, enabling them to find that quota trading can also achieve higher economic returns, thus greatly increasing their enthusiasm for technological innovation. Shi and Li (2020) also drew a similar conclusion in their research on emission trading.

However, the problem of the above studies is that the carbon emission trading system is an indirect rather than a direct motivation for enterprises to carry out technological R&D because the high risk and long cycles of innovation activities require enterprises to have a steady flow of capital investment (Brealey and Leland, 2012). Therefore, in the attribution analysis between the trading system and technology R&D, the ability of enterprises to obtain financial support is undoubtedly the first. But in the face of loans with environmental protection conditions, the enterprises of the traditional financing channel have been greatly limited, and the research of Yu and Li (2021) shows that there is a significant negative correlation between the intensity of environmental regulation and the financing ability of enterprises, and this constraint will gradually transfer to the R&D, producing a significant inhibitory effect. The introduction of property rights mechanism and trading mechanism bring more flexible financing methods for enterprises and makes innovation activities more fault-tolerant, which has been verified in the research of Lv and Bai (2021). However, Cui et al. (2018), and Zhu et al. (2019) still have some deficiencies in the logical chain of this point, which need to be further supplemented and improved. So, an important contribution of this paper is to combine the characteristics of the intermediary model and the differences-in-differences method and construct a counterfactual analysis framework of carbon emission trading, financing constraints, and enterprise innovation through the alternative use of the two paradigms, to obtain more accurate policy performance assessment.

Another marginal contribution of this paper lies in the classified discussion of innovation. Existing studies (Chen et al., 2021; Yu and Li, 2021) did not make a specific distinction in the definition of innovation, but generally took the R&D investment of the current year as the core explanatory variable, or simply classified the attributes into environmental protection patent and non-environmental protection patent according to the code (Shi and Li, 2020). However, Kamien and Schwartz (1978) and Tong et al. (2014) believe that there is serious information asymmetry in innovation activities. In order to obtain more external financial support, enterprises will deliberately choose low-risk and low-quality imitative innovation to release more positive signals to alleviate financing constraints. Therefore, evaluating enterprise R&D based on patent code and investment amount can lead to bias in research results. Therefore, on the basis of the above studies, Li and Zheng (2016) divided the motivation and quality of patent acquisition into substantive innovation and strategic innovation based on China's experience, expanded the research boundary of innovation quality, Tang and Xiao (2012) also conducted similar studies based on the above motivations. However, due to the literature writing mostly before 2015, the above research mainly focused on the impact of financing constraints and financing channels on substantial innovation. It is impossible to evaluate the financing effects and innovation incentive effect of carbon emission trading, and there is not enough time span to set up quasi-natural experiments, thus causing the lack of relevant practical evidence. In contrast, this paper uses the financial data of the listed companies from 2008 to 2017, combines the studies of Li and Zheng (2016), Cui et al. (2018), Lv and Bai (2021), and adopts more accurate quasi-natural experimental settings. To investigate whether environmental policies can affect the substantive innovation of enterprises through influencing the financing constraints of enterprises, which provides a reference for further improving the design of carbon emission trading policy system and promoting enterprise innovation.

3. Mechanism Analysis And Hypothesis

The incentive effect of the carbon emission trading system on enterprise innovation is mainly reflected in the flexible cost impact (Montgomery, 1972; Zeng and Wan, 2010; Cui et al., 2018). In essence, carbon emission rights are based on the property of environmental capacity resources, by allocating the emission reduction target of total amount control as a quota to each participant, and constructing the carbon trading market with corresponding trading rules and the price mechanism. The trading mechanism effectively increases the liquidity of emission rights, whether it is free or paid initial resource allocation, enterprises can obtain a continuous, equalization, and predictable marginal emission reduction cost signal, thus discovering potential profit growth points and improving the flexibility of enterprises to carry out practical technological innovation (Baumol and Oates, 1971). And from the price mechanism, the emission trading system is more flexible than other environmental control policies, and the price signal has also let enterprise has the possibility in the aspect of quantification, predicting the production and business operation risk, and can effectively respond to the risk of policy changes, enables enterprises to make more flexible and initiative in adjusting production and emission decisions, reduces the uncertainty brought by environmental regulation cost, which makes the risk cost of the enterprise's long period and high-risk substantive technology research and development under control. The innovation incentive mechanism of carbon emission rights is shown in Fig. 1 below:

Therefore, under the combined effect of the above two paths, the quantity and quality of enterprise innovation will also be improved. Accordingly, the first hypothesis of this paper is proposed:

H1: The establishment of the carbon emission trading mechanism has positive marginal contribution to the improvement of enterprise innovation quality.

The carbon emission trading mechanisms are innovative by alleviating financing constraints. The introduction of a market mechanism allows enterprises to decrease significantly on bank credit, and the structure has an obvious offset. Benz and Truck (2009) found that the establishment of the carbon emission trading system had a significant impact on the source of cash flow of enterprises. Purchase, sale, and pledge of emission rights had become an important way for enterprises to obtain funds, Yu and Li (2021) also drew a similar conclusion in their research on the Chinese market. The main reason is that the

carbon transaction system gives the asset higher fluidity, which makes the original curing environmental rights and interests have price attributes. The transaction cost of financing activities through the equity market will be significantly lower than the bank credit, so as to make the enterprises have more funds to invest in a longer cycle of technology innovation activities. On the other hand, for enterprises with advanced emissions, emission reduction technology can be obtained by selling excess carbon emissions to obtain additional benefits, and the enterprises have motivated technology R&D, and further competitive profit advantages, and the strategic innovation squeeze of too much cash flow, so the priority of decision-making will be significantly reduced. Another important reason that can not be ignored is the acceptable capacity of the carbon emission trading system. Each investment agency is also willing to finance more environmentally friendly assets, and political acceptability also plays an important role in reducing the financing threshold of enterprises. The mediating effect mechanism of financing constraints is shown in Fig. 2 below:

Therefore, on the whole, the introduction of the carbon emission trading system has played a role in improving the financing structures, optimizing financing channels, and reducing the financing thresholds. Whether subjective motivation or objective fact, it has created a favorable capital environment for the enterprises' R&D. Accordingly, the second research hypothesis of this paper is proposed:

H2: The carbon emission trading policy has stimulated substantive innovation by easing financing constraints.

However, the incentive effect of the relaxation of financing constraints on enterprise innovation is affected by enterprise ownership (Han and Ma, 2013). In China, state-owned enterprises are far better than other types of enterprises in obtaining financing. Whether in government subsidies, bank credit, or equity financing, state-owned enterprises have significantly better financing advantages than other enterprises. This effect also applies to the carbon emission right market. The public capital and franchise make the state-owned enterprises obtain unique credit endorsement. Therefore, when using carbon emission right for financing and pledge, the state-owned enterprises' assets with stronger stability and lower risk are more favored by investors. From another perspective, the utility function of state-owned enterprises includes other social responsibilities besides economic benefits. The establishment at the beginning of the carbon trading market, the participation of state-owned enterprises is much higher than that of other ownership enterprises. In the early stage of the carbon trading market, the state-owned enterprises face a lower degree of financing constraints and are better than other enterprises in undertaking R&D risks, so the state-owned enterprises show stronger marginal utility than other enterprises. On contrary, other ownership systems, especially private enterprises, whereas other ownership itself on a smaller scale and participate in carbon trading late, the possibility of obtaining financing through the carbon market is greatly reduced, and the derivation income of its carbon emissions can be far less than state-owned enterprises. Therefore, the strategic innovation, which has the lowest risk, sends positive signals to the market and becomes the second-best choice for non-state-owned enterprises under the constraints of environmental regulation, thus the carbon emission trading system has a negative effect on its substantive innovation. The incentive utility difference mechanism of enterprises of different ownership is shown in Fig. 3 below:

Based on the above, this paper further proposed research hypothesis 3:

H3: The carbon emission trading policy can stimulate the substantive innovation of state-owned enterprises, but it has a crowding-out effect on the substantive innovation of non-state-owned enterprises.

In addition to ownership factors, the incentive effects of different pollution types of enterprises have greatly different. From the perspective of the first batch of enterprises to participate in carbon emission trading, more than 80% of the enterprises are power generation, metal smelting and casting, steel processing, and other heavy polluting enterprises (such as Shanghai BaoGang Group), why are the heavy polluting enterprises more enthusiastic to participate in the carbon market? Apart from social responsibility, enterprises in the heavy pollution industries themselves face stricter environmental control and supervision, so they are more active in a soft emission trading system. In addition, the initial quota of carbon discharge will refer to historical emissions, so it is relatively advantageous for enterprises in heavy pollution industries with a higher base, and the motivation to increase profit margin is relatively strong. But for enterprises in non-heavy pollution industries, the level of emissions of themselves is not high, while the technology innovation investment with higher cost and larger risk, so even under the constraints of carbon emissions, the enterprises in non-heavy pollution industries have relatively weak urgency and the profit motive to carry out substantive innovation, and strategic technological improvement with low risk and less capital consumption is more in line with their practical needs.

Therefore, this paper proposed the fourth hypothesis to be tested:

H4: The substantial innovation incentive effect of carbon emission right trading policy has a stronger marginal effect in enterprises in heavy pollution industries.

4. Sample Selection And Empirical Design

4.1 Variables definition and data description

In this paper, we select A-share listed companies in China's Shanghai and Shenzhen stock markets from 2008 to 2017 as the research samples, referring to the sample data selection method of Tong et al. (2014), excluding the financial enterprises, ST enterprises, and enterprises with missing financial data, and finally obtain 7070 observations. Among them, the patent data of listed companies is derived from the state intellectual property office of the official website of the People's Republic of China[1], and the financial data of listed companies come from the CSMAR Database and the annual report of listed companies published on Cninf Website[2].

The main explanatory variables of this paper are substantive innovation and strategic innovation, referring to the practices of Li and Zheng (2016), and Tong et al. (2014), according to the quality and motivation, the patents filed by enterprises are divided into two categories: substantive innovation (code: patenti) and strategic innovation (code: patentud). According to the notes of scholars such as Li and Zheng (2016), substantial innovation mainly refers to those

invention patents that have technological progress effect and can bring technological evolution, mainly including products or improved technical solutions for products, these kind invention patents often require a large amount of capital investment, and the R&D cycle is long, and the risk is high (there is a direct classification of this kind of invention patent in the China Intellectual Property Network), so the quality and value of the patent is higher. Strategic innovation mainly refers to utility models and appearance patents. Due to the lack of substantial technological progress effect, this kind of patent is often used for marketing and other purposes, belonging to the strategic category of enterprises, and the actual value is low. Therefore, existing studies (Li and Zheng, 2016) strictly distinguish enterprises' innovation behaviors according to the above criteria. In addition, it should be noted that, in order to more intuitively observe the behavior of enterprises, the number of patent applications is used as the main regression, and other factors may be involved in the process of patent approval, so the batch of patents will be used as a robustness test.

The grouping variable in this paper is the carbon emission right pilot (CET). According to the Notice on The Pilot Work of Carbon Emission Right Trading issued by the Chinese government, seven provinces and cities including Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen are approved to carry out the pilot work of carbon emission right trading. Based on this, the value of the region where the company is located in the above seven provinces and cities is assigned as 1, otherwise, it is 0. In addition, it should be noted that although the Chinese government announced the pilot carbon trading in 2011, it only carried out relevant preparatory and demonstration work at that time, and did not carry out substantive trading activities. Moreover, the biggest feature of carbon transaction system is to compliance punishment mechanism and transaction mechanism (Cui et al., 2018; Zhu et al., 2019), therefore, 2013 should be taken as the time point according to the actual year of the carbon market, which meets the requirements of the quasi-natural experiment.

The choice of control variables is to solve the endogeneity problem, that is, to reduce the association between carbon trading incentives and other random disturbance terms. Therefore, other variables that may affect the R&D decision-making of enterprises need to be screened out in variable selection. The R&D decision of enterprises are mainly influenced by the operating status and decision-making of enterprises. The variables of the operating status of enterprises mainly include: Tobin Q value (lnTobinQ), which is the ratio of enterprise's market value to the capital replacement cost, is used to measure the performance and growth of the company, processed by logarithm; Debt (Indebts), calculated as the ratio of enterprise debts to total assets in the current year, processed by logarithm; Return on total assets (Roa), expressed by the ratio of the net profit and total assets of the enterprise. The variables in the corporate decision-making mainly include the capital intensity (cap_inten), which is measured by the ratio of total assets to the operating income of enterprises in this paper. In addition, existing studies believe that the degree of shareholding dispersion of shareholders and board diversification of enterprises (An et al., 2021) will have an impact on enterprises' R&D decisions, so this paper uses the shareholding ratio of the largest shareholder (Top1) and the proportion of independent directors (independent) to measure the influence of the above two aspects.

Another important point that needs to be emphasized in this paper is the intermediary variable of financing constraint (FC). According to the notes of Kaplan and Luigi (1997), the financing constraint refers to the difference between the internal and external financing costs of the enterprise due to incomplete information. However, in the practice of modern enterprise management theory, it can usually be defined as the difficulty that the enterprises face in the process of external financing. In order to quantify this constraint, Hadlock and Pierce (2010) constructed the SA index through the enterprise financial indicators, the specific calculation method is shown in formula (1) below, where $size_{it}$ represents the natural logarithm of the enterprise size (unit: million yuan); age_{it} represents the length of time the enterprise was established.

$$SA_{it} = -0.737 * size_{it} + 0.043 * size_{it}^2 - 0.040 * age_{it} \quad (1)$$

The maximum advantage of the above indicators is to portray and describe the enterprise's financing constraint characteristics from a long-term aspect, at the same time, since they do not include financial leverage indicators, they can avoid the interference of endogenous problems on measurement results to a large extent, so they are adopted by most researches, such as Lu and Chen (2017). In the calculation method of financing constraints, it is not essentially different from Hadlock and Pierce (2010), but considers the stability of the econometric model, this paper, based on the above quantitative analysis, the SA index, processed by logarithm and taken the absolute value, ultimately forming the variable of financing constraints (abbreviation: FC). In the context of this paper, the greater the FC value, the greater the financing constraint.

All of the above specific variable definitions will be given in Table 1 below:

Table 1
Definitions of main variables.

Variables	Variable meaning
patenti	Number of invention patent applications (unit: hundreds)
patentud	Number of patent applications for utility models and designs (unit: hundreds)
CET	Dummy variable of carbon emission trading policy
InTobinQ	The ratio of the market value and the capital replacement cost of the company
Indebts	Liabilities of enterprises
Roa	The return on total assets of the enterprise
cap_inten	The capital intensity of the enterprise
Top1	The shareholding ratio of the largest shareholder
independent	The proportion of independent directors
FC	Financing constraint

The descriptive statistics of the main variables are shown in Table 2 below. Among them, the mean value of substantive innovation (patenti) is 0.286, the standard deviation is 2.547, the minimum value is 0, and the maximum value is 72.150; the mean value of strategic innovation (patentud) is 0.204, the standard deviation is 1.121, the minimum is 0, and the maximum is 31.390. Therefore, from the statistical level, substantial innovation and strategic innovation among enterprises also have great differences. The mean value of financing constraints (FC) is 1.329, the standard deviation is 0.068, the minimum value is 0.770, and the maximum value is 1.560, so the differences of the financing constraints faced between enterprises are not large.

Table 2

Descriptive statistics.

Variables	N	Mean	Std	Min	Max
patenti	7070	0.286	2.547	0	72.150
patentud	7070	0.204	1.121	0	31.390
CET	7070	0.158	0.365	0	1
InTobinQ	7070	0.262	0.850	-2.493	3.319
Indebts	7070	-0.808	0.532	-4.950	1.182
Roa	7070	0.035	0.080	-1.375	2.301
cap_inten	7070	2.397	7.190	0.171	357.290
Top1	7070	35.705	15.227	0.286	89.986
independent	7033	0.368	0.053	0.143	0.714
FC	7070	1.329	0.068	0.770	1.560

4.2 Model setting

The differences-in-differences method can effectively avoid the endogenous problems caused by policy impact, so it is widely used in policy evaluation by domestic and foreign research and analysis. After the Hausman Test, we choose to use the fixed-effect model for estimation. Referring to the model setting method of emission rights trading in Shi and Li (2020), this paper designs and constructs the following model:

$$\text{patenti}_{it}(\text{patentud}_{it}) = \alpha_0 \text{CET}_{it} + \alpha_1 \text{Control}_{it} + u_i + \varepsilon_{it} \quad (2)$$

In model (2), i and t represent enterprises and years respectively; patenti_{it} and patentud_{it} are the numbers of applications for substantive innovation (invention patent applications) and strategic innovation (utility model and appearance) respectively; the explanatory variable CET_{it} is the dummy variable of carbon emission trading policy; Control_{it} is the relevant control variables at the enterprises level; u_i is an individual heterogeneous disturbance that does not change with time; ε_{it} is the disturbance term that varies with individual and time.

5. Empirical Test And Results Analysis

5.1 Parallel trend test

The differences-in-differences model requires the treatment group and the control group to meet the parallel trend assumption, that is, before the implementation of the policy, the variation trend of the explained variables in the treatment group and the control group should remain relatively stable. Therefore, before baseline regression, it is necessary to test whether the treatment group and the control group meet the parallel trend hypothesis. This paper adopts the event analysis method of Jacobson (2013) for estimation. Specifically, by constructing the time trend chart of the mean value of substantive innovation (patenti) and strategic innovation (patentud) of enterprises in pilot areas and non-pilot areas from 2008 to 2017, we analyzed whether the variation trend of explained variables of enterprises in pilot areas and non-pilot areas is consistent. The time trend charts are shown in Fig. 4 below:

In Fig. 4, the solid lines represent enterprises in pilot areas, and the dotted lines represent enterprises in non-pilot areas. Fig. 4 (left) shows that before 2013, substantive innovation (patenti) of enterprises in the pilot areas and non-pilot areas showed the same changing trend. However, after the pilot implementation of carbon emission trading policy in 2013, the substantive innovation (patenti) of the enterprises in pilot suffered obvious exogenous impact and the slope changed significantly, while the substantive innovation (patenti) of enterprises in non-pilot areas remained unchanged, so it can be intuitively judged from the figure that the policy has an obvious incentive effect on substantive innovation of enterprises. Fig. 4 (right) also show a similar trend, but the difference is that the incentive effect of policy on strategic innovation (patentud) is not stable, and shows drastic fluctuation. Therefore, the fixed-effect model is needed to further control the time effect. However, in general, before and after the implementation of the policy, there is an obvious parallel trend between enterprises in pilot areas and enterprises in non-pilot areas, thus meeting the prerequisites conditions for the use of differences-in-differences.

5.2 Baseline regression results

In order to verify the hypothesis H1, that is, the establishment of carbon emission trading mechanism, which effectively promotes the enthusiasm of enterprises to carry out substantive innovation, and to comprehensively estimate the impact effect, this paper uses the fixed effect model, combining the differences-in-differences method, conducting regression analysis on the model (2) respectively. We mainly examine the size of the dummy variable of the carbon emission trading policy (CET) and its positive and negativeness, the CET coefficient estimate reflects the policy effect under the differences-in-differences method. The results of the baseline regression are shown in Table 3 below:

Table 3

Summary of the baseline regression results.

Variables	(1) patenti	(2) patenti	(3) patentud	(4) patentud
CET	0.380*** (0.070)	0.380*** (0.070)	0.202*** (0.032)	0.205*** (0.032)
cons	0.119** (0.051)	0.113 (0.214)	0.097*** (0.024)	-0.006 (0.099)
Control	NO	YES	NO	YES
Year	YES	YES	YES	YES
N	7070	7033	7070	7033
R2	0.013	0.015	0.017	0.019
Notes: In parentheses is the value of the standard error, “*” “**” “***” represent significance levels of 10%, 5%, and 1% respectively.				

It can be seen from Table 3(1) and (3) that the implementation of the carbon emission trading policy effectively promotes the increase of enterprises’ invention patent applications, and it is significant at the level of 1%. Moreover, after controlling for the time effect and adding control variables, the positive causality between the policy and enterprises does not change, which verifies the correctness of hypothesis H1, that is, the introduction of the market mechanism in the field of environmental regulation has a positive incentive effect on enterprises’ technological invention. In order to verify the hypothesis, the enterprises’ strategic innovation has also been regressed, and the specific method is consistent with the above. As can be seen in columns (3) and (4) of Table 3, under the exogenous intervention of the carbon emission trading policy, the overall strategic innovation (utility model and appearance) of the enterprise is also impacted, showing an obvious positive relationship, and the significance level remains at 1% level, but the estimated coefficient is significantly lower than columns (1) and (2). Therefore, on the basis of verifying the hypothesis H1, the inference of this paper can be drawn:

Inference: The introduction of the carbon emission trading system has a positive incentive effect on the R&D innovation of enterprises, but it has a stronger incentive effect on the substantive innovation of enterprises.

5.3 Mediation effect

In order to further explore the mechanism through which carbon emission trading policy affects enterprise innovation behavior, we consider adding intermediary variable financing constraints to the analysis. In the mechanism analysis above, it is believed that the carbon trading system endows assets with higher liquidity, which increases enterprises’ cash flow and allows more funds to invest in technological innovation activities with a longer cycle. To verify whether the carbon emission trading policy affects different types of innovation of enterprises through financing constraints, based on the fixed-effect model, combining the differences-in-differences method, the mediation effect model of financing constraints is further constructed, the design model is as follows:

$$\varepsilon_{it} \quad FC_{it} = \beta_0 CET_{it} + \beta_1 Control_{it} + u_i + \quad (3)$$

$$patenti_{it}(patentud_{it}) = \alpha_0 CET_{it} + \alpha_1 FC_{it} + \beta_0 Control_{it} + u_i + \varepsilon_{it} \quad (4)$$

The regression results of Model (3) and Model (4) are shown in Table 4 below:

Table 4

Carbon emission trading policy, financing constraints, and enterprise innovation.

Variables	(1) FC	(2) patenti	(3) patentud
CET	-0.003*** (0.001)	0.335*** (0.069)	0.183*** (0.032)
FC		-16.452*** (1.082)	-8.033*** (0.498)
cons	1.275*** (0.002)	21.095*** (1.396)	10.239*** (0.643)
Control	YES	YES	YES
Year	YES	YES	YES
N	7033	7033	7033
R2	0.822	0.049	0.058
Notes: In parentheses is the value of the standard error, “*” “**” “***” represent significance levels of 10%, 5%, and 1% respectively.			

As can be seen from column (1) of Table 4, carbon emission trading policy significantly reduces financing constraints of enterprises at the level of 1%, showing a significant negative correlation between them. It can be seen from column (2) to column (3) of Table 4, the coefficient of corporate substantive innovation (patenti) and carbon emission trading policy (CET) is positive, but the coefficient of financial constraints (FC) is negative, and both are significant at the level of 1%. According to the design mechanism of the integrated mediation effect, there is reason to believe that the transaction policy, it is reasonable to think that the logical chain between transaction policy, financing constraint, and firm innovation is established. From the perspective of economic significance, the statistical results show that the implementation of carbon emission trading policy reduces the financing constraints of enterprises in the pilot areas, thus creating a better financial environment for technological R&D, the hypothesis H2 is established, and from the coefficient, carbon emission trading policy promotes the increase of invention patents through reducing financing constraints more than utility model and design patents. Therefore, carbon emission trading policy effectively promotes substantive and strategic innovation of enterprises by reducing financing constraints, thus, the hypothesis that “emission trading policy plays an incentive role in enterprises’ substantive innovation by reducing financing constraints” is verified. However, similar to the results in Table 3, the coefficient estimate of the strategic patent (patentud) is still significantly lower than that of substantive innovation, so the inference still holds.

5.4 Robustness test

5.4.1 Placebo test

In addition to the parallel trend test, before using the differences-in-differences method, it is also necessary to make a placebo test for the treatment group and control group after the time point of policy intervention, that is, to test whether the changes are interfered by other policies or random factors. This paper refers to the method of Ren et al. (2019) and uses the method of fictitious treatment group for placebo test. To be specific, this paper conduct 1000 samples in 707 listed companies, randomly selected virtual treatment group and control group, regressing the explained variables patenti and patentud respectively, by extracting the T value and draws the kernel density distribution figure, to observe whether the regression results are interfered by other factors. The kernel density distribution is shown in Fig. 5 below:

As can be seen from Fig. 5, the sampling estimation results of patenti and patentud show that the absolute value of most t is within 2, and most p values are greater than 0.1, presenting a normal distribution, that is, the regression results of the randomly generated fictitious treatment group estimators are not significant. In other words, we conduct 1000 times random sampling, excluding the influence of other policies or random factors on the regression results during the same period. Therefore, the conclusions obtained in this paper pass the placebo test.

5.4.2 Eliminate the interference of exogenous policies at the same time

Although strict parallel trend and placebo test have demonstrated the externality of carbon trading policy, Wang et al. (2020) believe that the implementation of the New Environmental Protection Law also has an exogenous policy impact on enterprises’ innovation behaviors. In order to further verify the robustness

of the research conclusions in this paper, and eliminate the interference of the implementation of the New Environmental Protection Law on enterprises' innovation behavior, samples from 2015 to 2017 are deleted in this paper, a new sub-samples are generated and regress the Model (2) again. As can be seen from Table 5, after replacing the samples as sub-samples, regardless of whether control variables are added, carbon emission trading policy is significant at 1% level, and the hypothesis H1 and inference are still valid.

Table 5

Regression results after sampling replacement.

Variables	(1) patenti	(2) patenti	(3) patentud	(4) patentud
CET	0.206*** (0.062)	0.207*** (0.063)	0.143*** (0.035)	0.149*** (0.035)
cons	0.119*** (0.035)	0.209 (0.199)	0.097*** (0.019)	0.097 (0.111)
Control	NO	YES	NO	YES
Year	YES	YES	YES	YES
N	4949	4913	4949	4913
R2	0.010	0.011	0.017	0.019
Notes: In parentheses is the value of the standard error, "*" "***" "****" represent significance levels of 10%, 5%, and 1% respectively.				

5.4.3 Replacement indicator

Although the number of patent fillings can be used as the explained variable to more intuitively measure the innovation motivation of enterprises and intuitively examine the policy effect, it can not reflect the final innovation quality. Therefore, this paper replaces *patenti* and *patentud* with substantive innovation patent acquisition number (*Invjg*) and strategic patent acquisition number (*umjg*), while this approach will include other endogenous factors in the process of patent approval, it can show the net effect of the conclusion from the side, the data source is still from China Intellectual Property Network. Regressing Model (2), the regression results are shown in columns (1) - (4) of Table 6:

Table 6

Regression results of replacement indicator.

Variables	(1) Invjg	(2) Invjg	(3) umjg	(4) umjg
CET	0.142*** (0.026)	0.144*** (0.026)	0.135*** (0.016)	0.137*** (0.016)
cons	0.008 (0.019)	-0.045 (0.079)	0.005 (0.012)	-0.030 (0.050)
Control	NO	YES	NO	YES
Year	YES	YES	YES	YES
N	7069	7069	7069	7069
R2	0.009	0.010	0.018	0.020
Notes: In parentheses is the value of the standard error, "*" "***" "****" represent significance levels of 10%, 5%, and 1% respectively.				

The regression results of each column in Table 6 show that the incentive effect of carbon emission trading system is still significantly positive, and its incentive effect on substantive innovation is still higher than that on strategic innovation, but the estimated value of the coefficient is different from that in Table 3 because the number of patents granted will be greatly adjusted compared with the number of patents applied. According to the Annual Report of The State Intellectual Property Office of China, in the past ten years, China's patent application approval rate (authorized) is between 40% and 50%, therefore, there is a gap between the estimated results of the coefficients in Table 3 and Table 6, but it does not affect the robustness of the statistical results.

5.4.4 PSM-DID method

In order to reduce the bias of counterfactual estimation results caused by individual differences between the treatment group and the control group, we refer to the approach of Heckman et al. (1998), combining the differences-in-differences (DID) and propensity score matching (PSM), using PSM-DID method to

screen the samples of the treatment group and the control group. In terms of matching mode, this paper selects two methods of nearest neighbor matching and radius matching, and the matching results are shown in Fig. 6 below:

As can be seen from Fig. 6, after 1 to 1 nearest neighbor matching and radius caplier matching, the standard deviation of data after matching is significantly reduced, and the errors of all control variables are within 10%. It is considered that the matching results balance the data structure well and meet the basic premise of propensity score matching. The common values of 1 to 1 nearest neighbor matching and radius matching variables before and after matching are shown in Fig. 7 below:

According to the above matching results, after the samples beyond the matching range are removed, regression analysis is conducted on enterprises within the scope of the common value range, and the regression results are shown in Table 7 below:

Table 7

Regression results of PSM-DID.

Variables	1to1		Cal(0.01)	
	(1)	(2)	(3)	(4)
	patenti	patenti	patentud	patentud
CET	0.380*** (0.070)	0.380*** (0.070)	0.205*** (0.032)	0.205*** (0.032)
cons	0.127 (0.215)	0.139 (0.216)	-0.004 (0.099)	-0.001 (0.100)
Control	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	7023	7014	7023	7014
R2	0.015	0.015	0.019	0.019
Notes: In parentheses is the value of the standard error, “*” “**” “***” represent significance levels of 10%, 5%, and 1% respectively.				

As shown in Table 7 above, the regression results are still supported. Table 7 (3) and (4) respectively show the effect of carbon emission trading policy on substantive innovation and strategic innovation after radius matching. It can be seen that no matter using the nearest neighbor matching method (1 to 1) or the radius matching method (cal 0.01), the regression results maintain the significance of 1% and the coefficient estimation value is positive, which passes the robustness test.

6. Heterogeneity Analysis

6.1 Enterprise ownership

The introduction of the market mechanism produces different marginal utilities for enterprises of different ownership, which is also applicable in the field of environmental control. The above mechanism analysis believes that state-owned enterprises have relatively strict management and strong motivation of carbon transactions, so put forward “The carbon emission trading policy can stimulate the substantive innovation of state-owned enterprises, but it has a crowding-out effect on the substantive innovation of non-state-owned enterprises”, to test and verify the correctness of the above conjecture, based on the Model (2) and Model (3), we design the following empirical tests. Firstly, the samples are divided into two groups according to whether the enterprises are state-owned enterprises or not, the two sub-samples are generated according to the ownership form disclosed in the company’s annual report. Secondly, according to the requirements of the differences-in-differences method, setting a quasi-natural experiment, and conducting the regression analysis in different samples respectively. The explained variable is still substantial innovation, and strategic innovation is listed synchronously as a contrast, the results are shown in Table 8 below:

Table 8

Analysis of the heterogeneity of enterprise ownership.

Variables	State-owned enterprises		Non-state-owned enterprises	
	(1)	(2)	(3)	(4)
	patenti	patentud	patenti	patentud
CET	0.751*** (0.111)	0.349*** (0.051)	-0.184*** (0.054)	0.002 (0.028)
cons	0.138 (0.348)	0.077 (0.159)	0.218 (0.160)	-0.146* (0.083)
Control	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	4343	4343	2690	2690
R2	0.029	0.033	0.007	0.012

Notes: In parentheses is the value of the standard error, *** ** * represent significance levels of 10%, 5%, and 1% respectively.

Table 8(1)-(2) show the regression results of emission trading policy on different types of innovation in state-owned enterprises. Statistically speaking, the carbon emission trading policy has effectively promoted the increase of the number of two types of patent applications, and the regression result is significant at the 1% level. However, the regression analysis of non-state-owned enterprises has the opposite conclusion. Column (3) shows that the transaction system has a significant restraining effect on substantive innovation in the sample of non-state-owned enterprises, but has no significant incentive effect on strategic innovation. The test results of the mediation effect are shown in Table 9:

Table 9
Mediation effect of enterprise ownership heterogeneity.

Variables	State-owned enterprises			Non-state-owned enterprises		
	(1)	(2)	(3)	(4)	(5)	(6)
	FC	patenti	patentud	FC	patenti	patentud
CET	-0.007*** (0.001)	0.522*** (0.108)	0.238*** (0.049)	0.005*** (0.001)	-0.183*** (0.054)	0.003 (0.028)
FC		-30.880*** (1.929)	-14.879*** (0.877)		-0.088 (0.819)	-0.143 (0.422)
cons	1.284*** (0.003)	39.793*** (2.500)	19.184*** (1.136)	1.267*** (0.004)	0.329 (1.049)	0.036 (0.541)
Control	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
N	4343	4343	4343	2690	2690	2690
R2	0.834	0.089	0.100	0.842	0.007	0.012

Notes: Since the FC coefficients in columns (5) and (6) are not significant, the bootstrap method is used for the test. The results show that the confidence interval does not include 0, so the mediation effect exists. In parentheses is the value of the standard error, *** ** * represent significance levels of 10%, 5%, and 1% respectively.

The reason can still be attributed to two points: Firstly, as the carbon emission trading policy in the pilot stage is not mandatory for non-state-owned enterprises, the enthusiasm of participation is generally universal. Secondly, the non-state-owned enterprises lack trust in government endorsement, so even if the financing relaxes utility is generated by the carbon market, still can not have much effect on improving the funding environment of enterprises, and their abilities of R&D risks bearing are still weak, in the face of the amount of carbon emission constraints, non-state-owned enterprises can only continue the operating through the way of purchasing emission rights, investing a lot of money in high-risk substantive innovation is clearly not optimal choose.

6.2 Industry types

The heterogeneity of incentive effect of carbon emission trading system is not only reflected in ownership, but also exists in the industry level. The environmental cost of the heavy pollution industry is much higher than other industries, so the marginal effect of introducing carbon markets should be stronger in the heavy pollution industry. This paper is based on the Guidance on Industry Classification of Listed Companies revised by China Securities Regulatory Commission in 2012 and The Management Directory of Environmental Protection Verification Industry Classification of Listed Companies formulated by The Ministry of Environmental Protection in 2008 (HBH [2008] No.373), further dividing the samples into the enterprises in heavy pollution industries and the enterprises in other industries, regressing the two sub-samples based on Model (2) respectively. The regression results are shown in Table 10 below:

Table 10

Industry heterogeneity analysis.

Variables	Heavy pollution industries		Non-heavy pollution industries	
	(1)	(2)	(3)	(4)
	patenti	patentud	patenti	patentud
CET	0.371*** (0.059)	0.198*** (0.031)	0.365*** (0.137)	0.205*** (0.061)
cons	-0.176 (0.168)	0.002 (0.089)	0.476 (0.435)	-0.021 (0.193)
Control	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	3981	3981	3082	3082
R2	0.026	0.026	0.017	0.021

Notes: In parentheses is the value of the standard error, “*” “**” “***” represent significance levels of 10%, 5%, and 1% respectively.

Columns (1)-(2) in Table 10 respectively show innovation incentive effects in heavy pollution industries, while columns (3)-(4) show innovation incentive effects in non-heavy pollution industries. From the perspective of significance, there is not much difference between them. However, from the estimation of the coefficient, the substantial innovation incentive effect of carbon emission trading policy in heavy pollution industries is slightly higher than in other industries, while the strategic innovation is slightly lower than that in other industries. This conclusion is basically consistent with the preceding conjecture, that is, the greater the pressure to reduce emissions, the greater the marginal utility that trading systems can produce, and the intermediary effect inspection of Table 11 also draws similar conclusions, common to verify the hypothesis H4: The substantial innovation incentive effect of carbon emission right trading policy has stronger marginal effect in enterprises in heavy pollution industries.

Table 11

Mediation effect test of industry heterogeneity.

Variables	Heavy pollution industries			Non-heavy pollution industries		
	(1) FC	(2) patenti	(3) patentud	(4) FC	(5) patenti	(6) patentud
CET	-0.005*** (0.001)	0.327*** (0.059)	0.172*** (0.031)	-0.002** (0.001)	0.300** (0.133)	0.176*** (0.059)
FC		-8.166*** (0.877)	-4.943*** (0.463)		-27.415*** (2.153)	-12.277*** (0.954)
cons	1.267*** (0.003)	10.166*** (1.123)	6.262*** (0.592)	1.284*** (0.004)	35.670*** (2.796)	15.740*** (1.240)
Control	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
N	3981	3981	3981	3082	3082	3082
R2	0.821	0.049	0.057	0.830	0.072	0.076

Notes: In parentheses is the value of the standard error, “*” “**” “***” represent significance levels of 10%, 5%, and 1% respectively.

7. Research Conclusions And Policy Implications

How to create a more favorable financing environment for enterprises has always been an important goal of the government, but the high environmental cost restricts the further development of enterprises, and the carbon emission trading system, with its incentive compatibility characteristics, has become the most likely tool to achieve both endogenous growth and environmental protection. In this paper, the innovation incentive effect of carbon emission trading system is evaluated theoretically and empirically by quasi-natural experiment method, and the conclusion is that the establishment of carbon emission trading system not only effectively promotes the enthusiasm of enterprises to carry out technological innovation, but also has a positive incentive effect on the quality of enterprise innovation. Further analysis, the mechanism of carbon emission trading system on the improvement of enterprise's financing environment, innovation incentive effect on an important role in transmission, but this effect is not indifference, the state-owned enterprises, which have higher participation and country credit endorsement, and the enterprises of heavy pollution industries, which under the most pressure to reducing emission, are obviously stronger, but less obvious for the non-state-owned enterprises and the enterprises of non-heavy pollution industries with lower participation. The above experience has special reference significance for the promotion of the carbon emission trading system worldwide.

The results of this study may have the following policy implications: (1) As an incentive environmental control tool, the carbon emissions trading system has positive value for the realization of the “green economy”. Therefore, gradually promoting the carbon emission trading system on a global scale is conducive to alleviating the contradiction between energy conservation and emission reduction, and economic development. However, based on China's pilot experience, in the process of designing the carbon transaction system, should highlight its financial attributes, attaches great importance to the causal relationship between the trading system and the financing environment of the region, putting the corporate funding environment improvement and the liquidity of equity assets increase at the first place of the trading rules design, lowering the threshold of carbon emission rights pledge, option, and other businesses, developing the direct consideration trading system between technology and “carbon assets”, allowing enterprises to use carbon assets for patent acquisition and other activities, and enhancing the technology innovation incentive function of the carbon market; (2) In the analysis of China's experience, it is found that government credit endorsement and public trust lead to different innovation incentive effects of carbon emission trading system on enterprises of different

ownership enterprises. Therefore, China and other developing countries should increase the trust of public investors in the emission right assets of non-state-owned enterprises, in the form of government guarantee, and the financing projects of non-stat-owned enterprises for technological R&D should be provided with corresponding credit by the national financial stability fund pool, and provided the special financing subsidies if necessary, so as to enhance the innovation incentive effect of the transaction on non-state-owned enterprises; (3) The design of the carbon emission system should pay attention to the attributes of the industry and carry out the gradient and differentiated development, such as establishing exchanges by industry or entering in batches according to industry. For example, at the beginning of the construction of the carbon market, only the power generation, coal, smelting, and other heavy pollution industries are included in the transaction range, and then gradually cover these industries. On the one hand, this way ensures the price validity and consistency of "carbon assets" during the period, on the other hand, it also provides a credible quantitative reference for subsequent financing pledge and derivative finance.

8. Research Prospect

Based on the counterfactual framework and mediating effect model, this paper measures the causal relationship between carbon emissions trading system and enterprise innovation quality, the whole mechanism construction focuses on the enterprise behavior and is logically developed from the micro-level. But this is one of the biggest limitations of this article's logical chain, carbon trading system belongs to the economic regulation tools, so in addition to the enterprise micro-level of incentive effect, equity market to foreign investment, exchange rate, and economic growth, the industrial structure also has the direct relationship. In the "carbon peak", "carbon neutral" overall policy background, research on the carbon market, foreign investment, industrial structure, and other topics may be more meaningful. Thus, we hope that on the basis of this paper, the above topics can be expanded, and scholars in related fields can jointly excavate the above research.

Declarations

Ethical Approval and Consent to Participant

Not applicable.

Consent to Publish

The Authors agree to publication in the Journal indicated below and also to publication of the article in English by Springer in Springer's corresponding English-language journal.

Availability of data and materials

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Author Contributions

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Figures

Figure 1

Innovative incentive mechanism of carbon emission right.

Figure 2

Mediation effect of financing constraints.

Figure 3

Ownership differences in incentive utility.

Figure 4

The time trend chart of the average value of substantive innovation (patenti) and strategic innovation (patentud).

Figure 5
 Kernel density distribution (left: patenti, right: patentud).

Figure 6
 Matching deviation of 1 to 1 nearest neighbor matching (left) and radius caliper matching (right).

Figure 7

The common value range of 1 to 1 nearest neighbor matching (left) and radius caliper matching (right).