Using green technology for a better tomorrow: How enterprises and government utilize the carbon trading system and incentive policies

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ABSTRACT

This unique study focuses on how the carbon trading system (CTS), stakeholder concerns and innovation incentive policies all combine to effect enterprises' green technology innovation. Using a three-dimension system, this study includes green output level, green output proportion and green total factor productivity. Utilizing a DID model of an unbalanced panel, we investigate how government and enterprise work together better to achieve carbon emission targets. The main findings are as follows: (1) Enterprises are displaying a high level of concern with environmental information disclosure and therefore their CTS will have a more significant impact on green technology output and the proportion of this green output. In contrast, government concerns about decarbonization with CTS have uncertain effects on the three dimensions of green technology innovation. (2) CTS Fiscal subsidies and R&D funding are strong ways to improve enterprises' green technology output. However, the best way to improve green technology output, green output proportion and green total factor productivity is with tax returns. When tax returns increase 1%, the green output level increases 1.5% under the CTS. (3) This study, utilizing data from the impact of different implementation modes of innovations incentive policies, shows that inclusive innovation policies make CTS's combined effects more significant than differentiated policies.

1. Introduction

With the rapid economic development of the past 40 years, China has borne great resource consumption and carbon dioxide emissions (Dong, Dong, Jiang, & Zhao, 2021; Ma, Ma, Cai, & Cai, 2020; Zhao, Dong, Dong, & Jiang, 2020). China's carbon dioxide emissions reached 982.58 million tons in 2019. This is seven times >141.85 million tons in 1978 (BP, 2020; Zhao, Jiang, Dong, Dong, & Jiang, 2022). As the world's largest greenhouse gas emitter, extensive and effective green transformation is necessary (Du, Cheng, & Yao, 2021). The promotion of green technology innovation is the fundamental way to achieve both economic development and carbon dioxide reduction in China (Shan, Genç, Kamran, & Dinca, 2021).

While enterprise development is still important, China must find a way to balance economic concerns with environmental protections (Adams, Jeanrenaud, Bessant, Denyer, & Overy, 2016; Dechezleprêtre, Glachant, Hascic, Johnstone, & Ménière, 2011; Johnstone et al., 2017). Green technology innovation helps enterprises to reduce emissions while enhancing their social reputation at the same time (Lv, Shao, & Lee, 2021; Varadarajan, 2017). Though this may seem like a win-win situation, green technology innovation requires enormous capital and patience for a long investment cycle. These factors often result in enterprises losing the motivation to forge through with their green technology innovations. Therefore, more incentives are needed to promote enterprise green technology innovation (Du et al., 2021; Jin, Peng, & Song, 2019).

Institutional innovation based on incentives can stimulate the innovation potential of enterprises (Edler & Fagerberg, 2017; Janssen, Torrens, Wesseling, & Wanzenböck, 2021). Most scholars believe that environmental regulation can promote enterprises' green technology innovation. Reasonable environmental regulation can enhance enterprises' innovation ability by creating a compensation effect. Pareto improvement occurs with both environmental and economic effects (Acemoglu, Aghion, Bursztyn, & Hemous, 2012; Kneller & Manderson, 2012).

One such incentive policy is the carbon trading system (CTS). This is a new policy in China. Carbon trading has been transferred from pilot areas to the whole country. With this focus on environmental concerns, more studies have been focused on the impact of China's CTS on enterprises' green technology innovation. Some of these studies argue convincingly that CTS can promote green technology innovation. A recent quasi-natural experiment shows that when enterprises control their emissions levels, they display a low-carbon innovation level increase of 5%–10%. We are also seeing a historical growth in green patents in uncontrolled companies due to CTS (Zhu, Fan, Deng, & Xue, 2019). When the carbon trading market is more active, the CTS plays a more significant role in promoting enterprises' green technology innovation (Hu & Huang, 2020). Because of the complexity of China's emissions reduction system, coordination difficulties exist in different government departments and enterprises. Therefore, CTS is difficult to form an innovation compensation effect (Duan, Tian, Zhao, & Li, 2017). The "signal-expectation" mechanism of the CTS for green technology innovation exists. However, the policy effects in each pilot area are different (Wang, Wang, & Lu, 2020).

Due to the difficulty of data acquisition and the limitations of methods, it is hard to extract the net impact of CTS. Therefore, there are few studies on the interactions between CTS, stakeholder concerns of decarbonization and innovation incentive policies. For the first time, this study investigates the combined effects of CTS, stakeholder concerns and innovation incentive policies on enterprises' green technology innovation.

CTS rarely works alone. The opinions and attitudes of stakeholders toward environmental issues could influence the impact of CTS on an enterprise's green technology innovation. Government sectors and enterprises are the two main stakeholders. In order to represent government concerns, this study counts the words related to carbon in the annual government reports. Using text mining, this study calculates the word frequency of carbon. Also, we calculate carbon emission cost per unit of industrial added value to represent the intensity of the government concerns. Environmental Information Disclosure (EID) is used to represent enterprise concerns. Paralleled to stakeholder concerns, innovation policies are universally used in concert with the CTS. Stakeholder concerns about the environment and policies' implementation should be both efficient and equitable to enterprises' green technology innovation. How should the stakeholder concerns and innovation incentive policies cooperate with the CTS to better stimulate the green technology innovation of enterprises? To answer this critical question, we research the optimization of the different concerns and mixed policies under China's carbon trading.

Three main findings of the study are as follows: First, the primary thing this study will do is investigate a three-dimensional system of green technology innovation (green output level, green output proportion and green total factor productivity). It clarifies the "black box" of green innovation of enterprises under the CTS. The impacts of carbon trading are various for different dimensions of green technology innovation.

Second, this study further investigates the combined effects of CTS and stakeholder concerns. It suggests that different government concerns of decarbonization with CTS have uncertain impacts on the green technology innovation output, green output proportion and green total factor productivity. However, enterprises' high-level concerns with CTS have positive effects on green technology output and the proportion of green innovation output.

Third, we find that when the three innovation incentive policies are combined with CTS, there is a positive effect on the enterprises' green technology innovation. Tax return works better than fiscal subsidy and R&D funding. Fiscal subsidy and R&D funding mainly improve enterprises' green technology output, while tax return, a post-tax incentive policy, positively affects all three dimensions of green technology innovation. This study further discusses the influence of different implementation modes of innovation incentive policies. It finds that inclusive policies are more conducive to the combined effects with CTS than differentiated policies.

The illuminating contributions of this study are as follows: First, few studies comprehensively examine the impacts of different types of policies on enterprises' green innovation, and a lot of studies only study one or two policies. This study makes a comprehensive evaluation of existing innovation incentive policies in China. Second, some literature reviews the effects of CTS together with stakeholder concerns and innovation policies. This study more completely investigates the government and enterprise concerns (word frequency of decarbonization, carbon emission cost per unit of industrial added value and enterprises' environmental information disclosure) and, in addition, also analyzes three incentive innovation policies (fiscal subsidy, tax return and R&D funding). It specifically analyzes the effects of the different combinations and reveals the optimal solution. Finally, the study reveals, for the first time, the impacts of two types of innovation policy implementation modes on green technology innovation.

The rest of this study is arranged as follows: The second section presents the literature review. The third section includes data and empirical methods. Empirical results and analysis will follow in the fourth section. The fifth section is the robustness test and the last section concludes the article.

2. Literature review

2.1. Enterprises' green technology innovation and how it relates to carbon trading

Green technology innovation is a driving force behind low-carbon development, and the definition of green technology innovation will vary according to the source material (Du et al., 2021; Hottenrott, Rexhäuser, & Veugelers, 2016; Lv et al., 2021). However, the essence of green technology innovation remains consistent. The core of green technology innovation is to improve the efficiency of resource and energy utilization, reduce pollution emissions and improve environmental benefits. There are challenges to measuring the direct effects of green technology innovation. Academia mainly measures the ability and efficiency of green technology innovation in enterprises or regions by constructing an evaluation system and selecting quantitative indicators (Hall & Helmers, 2013; Johnstone et.al, 2017; Tang, Xu, Hao, Wu, & Xue, 2021). Therefore, the corresponding proxy variables are constructed from the following perspectives: First, the output level indicator and green output proportion indicator of enterprises' green technology innovation are constructed based on the number of green patents and all kinds of patents of listed enterprises. Second, the efficiency of green technology innovation of enterprises is comprehensively evaluated by constructing an evaluation system consisting of various indicators.

Scholars have different views on the impact of the CTS on the green technology innovation of enterprises. Some studies on the EU CTS indicated that there existed no obvious effect of the CTS on technological innovation, and the irrational allocation of carbon emission quotas would have an inhibiting effect on green technology innovation (Borghesi, Cainelli, & Mazzanti, 2015; Neuhoff, Martinez, & Sato, 2006). Calel and Dechezleprêtre (2016) found that regardless of whether businesses were involved in carbon trading or not, the EU CTS had contributed to a significant increase in the number of green and low-carbon technology patents for enterprises in the host country. Some scholars also point out that whether green technology innovative effects existed was irrelevant to how the carbon emission rights are allocated (Requate, 2005).

This study reveals complex patterns used in China as CTS affects the green technology. The innovation effect of the CTS could be changed according to the design and implementation, the characteristics, and the external environment of enterprises. Liu and Wang (2017) concluded that carbon trading can promote innovation in the long term, although the short-term effect of carbon trading on innovation is negative. Zhang, Cao, Tang, He, & Li, 2019, Zhang, Duan, and Li (2019) held the view that China's emissions trading has a positive correlation with green innovation, and market competition weakens this positive correlation. Hu and Huang (2020) found that the more liquid the carbon market was, the more obvious the effect of the market was in promoting the technological innovation of enterprises. However, they also found that with the increasing pass-through cost of the enterprises, the positive impact of the liquid carbon market would be weakened. In addition, some scholars believed that due to the short history of China's carbon trading pilot, there are differences in the implementation of the regulations in pilot areas and the complex policy system for energy conservation and emission reduction (Duan et al., 2017). Pointless formalities have made it difficult for carbon trading to exert a potential compensatory effect on innovation. Wang et al. (2020) provided evidence for the view that carbon trading affects low-carbon technology innovation through the "signal-expectation" mechanism, but there were differences in the policy response effects among pilots. With the continuous improvement of China's CTS, the potential institutional effect has emerged. However, it is difficult to extract the "net impact" of the CTS because of the difficulty of collecting relevant data. There is no solution yet as to how to accurately assess the innovative effect of China's CTS, a market-incentive regulatory policy. This remains to be explored.

2.2. How stakeholder concerns affect innovation incentive policies and enterprises' green technology innovation

As with market-incentive regulatory policies, CTS works differently with different stakeholders. The government (CTS policy maker) and enterprises (CTS' main participants) are both concerned about the environment. Another key factor is decarbonization which can also influence enterprises' green technology innovation. Environmental concerns differ among stakeholders due to different environmental agendas and political interests (Lam, Cheung, Wang, & Li, 2019). There are several studies on how stakeholder concerns affect the green technology innovation of enterprises.

When we look at the governmental angle, the government's concerns are commonly through two kinds of tactics – punitive tactics (e.g. regulatory inspections and sanctions) and supportive tactics (e.g. technical assistance, recommendations, and follow-ups) (Dhanorkar, Siemsen, & Linderman, 2018). Since the 1980s, making environmental policy in some areas of China has been dominated significantly by the top-down command-and-control approach and regulatory policy measures (Liu, Mao, Tu, & Jaccard, 2014). There are several studies on government concerns by different measurements. For example, Zhang, Cao, et al., 2019, Zhang, Duan, and Li (2019) analyzed the impacts of various policies on enterprises' green and low-carbon technology innovation efforts. It showed that command-control energy-saving policies could inhibit low-carbon technology innovation of enterprises. Hille and Möbius (2019) differentiated the intensity of various environmental regulations according to diversified renewable energy support policies. They proved that the impact of such policies on innovation would increase significantly over time. Turken, Carrillo, and Verter (2020) discussed how different types of environmental regulations influenced green technologies and emission reduction decisions. The results showed that if environmental regulations were implemented, companies usually focus on investing in green emission reduction technologies. Huang, Ding, and Failler (2022) directly use the government work reports to represent the government's environmental concerns, which can more truly reflect the local government's subjective willingness to regulate the environment.

For the enterprise, the Attention Based View (ABV) of the firm (Ocasio, 1997) offers a behavioral perspective of why firms might not implement such changes. In the ABV, human attention to issues is viewed as a scarce resource within the firm. What gets done in a firm depends on what particular issues and solutions managers pay attention to (Ocasio, 1997). Brunnermeier and Cohen (2003)

indicated that increasing spending on pollution reduction would lead to more environmental innovation, and internationally competitive industries could be more likely to have environmental innovation capabilities. Miao et al. (2019) found that the enterprises' voluntary environmental concerns have a positive effect on the total factor productivity growth and thus conform to the Porter hypothesis in China. Bu, Zhang, Shi, and Wang (2022) suggested that environmental information disclosure would foster innovation among Chinese companies. Peneder, Arvanitis, Rammer, Stucki, and Wörter (2022) study the self-reported impacts of the adoption of "green" energy saving and related technologies (GETs). Their specific interest is in how different policy instruments are associated with energy efficiency, the reduction of CO2 emissions, and competitiveness at the firm level.

The innovation incentive policies can also influence the green technology innovation of enterprises. The literature shows that to improve companies' environmental governance initiatives, besides the rational environmental regulations, it is necessary to provide incentive measures. Green technology innovation has a positive knowledge spillover effect, resulting in a lack of innovation motivation for enterprises. Popp (2002) used U.S. patent data to prove that there is a correlation between government R&D and enterprises' innovation behavior. They found that behavior changed from substitution effects to complementation effects. In the process of green technology R&D, refining the policy mix consists of policies to encourage enterprises' green technology innovation and can ease the first-mover disadvantages, as well as insufficient incentives for investing in green technology R&D (Constantatos & Herrmann, 2011). Eichner and Pethig (2014) studied green technology subsidies and found significant differences between small and big countries. Big countries tend to provide green technology subsidies which could be effective, while small countries could hardly afford green technology subsidies. Nicolli and Vona (2016) indicated that lowering the entry barriers was an important driver for green technology innovation, but its impact varies from technology to technology. Hu, Wang, and Wang (2021) found that green credit policies could stimulate green innovation in emerging economies by imposing credit constraints, further contributing to the green technological transformation.

2.3. The effects of mixing policies on green technology innovation

Policies related to green innovation involve environmental regulations and scientific and technological innovation policies. China's scientific and technological innovation policies and environmental protection policies are implemented by different departments, and therefore this is a difference in the tendency of the departments. It is necessary to strengthen the coordination between environmental regulations and innovation policies to achieve effective policy mix incentives for enterprises' green technology innovation.

Policy mix first appeared in the economic policy literature in the 1960s. Many current studies have proposed a policy mix to achieve low-carbon development, but most of them focus on theoretical analysis. There is some rare research that has empirically analyzed the differences in the results of a diversified policy mix (Cao, Ho, Jorgenson, & Nielsen, 2019; Costantini, Crespi, & Palma, 2017; Kern, Rogge, & Howlett, 2019).

Policy mixes may play a crucial role in redirecting and accelerating innovation toward low-carbon solutions, thus addressing a key societal challenge (Rogge & Schleich, 2018). For green development, Acemoglu et al. (2012) believed that the optimum environment could not be achieved by environmental regulation alone. Only by combining environmental regulations with government subsidy policies can green technology innovation be effectively promoted. Veugelers (2012) found the combination of government R&D funding and carbon tax can have a positive impact on the green innovation activities of enterprises. This is another way to highlight the importance of policy mix. Liu and Wang (2017) argued that climate policies have played a greater role in promoting the adoption of managerial energy-saving activities in respondent companies, while comparatively their influences on the adoption of technology upgrading activities are relatively weak. Hepburn (2021) suggests that a mix of policies may best lead to deep decarbonization at an accelerated pace. Rosenbloom, Markard, Geels, and Fuenfschilling (2020) proposed that to achieve the goal of sustainable development, efforts should be made from the two dimensions of emission reduction policy and innovation policy. Du et al. (2021) held the view that different environmental regulations should be made based on the economic development levels of different regions. However, the study did not include an empirical test on the effects of the different policy mixes.

2.4. Research gaps

In sum, there are still a few gaps in the literature. Most studies only investigate the impact of the CTS, stakeholder concerns and innovation incentives policies separately on green technology innovation. Few studies have examined the interaction of CTS with stakeholder concerns and innovation incentives policies on enterprises' green innovation. It is essential to notice that CTS policy, government concerns, enterprise concerns and innovation incentive policies can interrelate with each other. That might influence CTS's effect on enterprises' green innovation.

Given the research gaps in the literature, this study, for the first time, empirically examines the combined effects of China's CTS and stakeholder concerns on enterprises' green technology innovation. It also examines the combined effects of the CTS and innovation incentive policies for the first time. We also study how the combined effects of the above mixed policies with policies' implement modes affect the green technology innovation of enterprises.

3. Data and research methods

3.1. Sample selection and data

This study focuses on carbon trading. To accurately identify the sphere of influence of this market-based environmental regulation,

we select the industries covered by the carbon emissions trading pilot (manufacturing, power and heat production and supply industry) as the sample (Cao et al., 2019).

In terms of the period, since we take the establishment of seven carbon emissions trading markets in China in 2013 as the quasi-natural experiment to build a difference-in-difference (DID) model, the year 2017 is identified as the end of the pilot period for carbon trading. The period of data we use to consider the impact of economic fluctuations caused by the financial crisis on business decisions is 2008–2017.

The data comes from the following databases: The financial data and basic information of the listed companies come from CSMAR database, iFIND database, and China Research Data Services Platform (CNRDS). The patent data comes from the CSMAR database, CNRDS database, and the State Intellectual Property Office (SIPO) database. The macro and industry data come from Economy Prediction System (EPS) data analysis platform, China's economic and social big data research platform, and China Economic Information database. Data related to innovation policies come from the CSMAR database and the CNRDS data platform.

Referring to the data processing method in the literature, we have done the data processing as follows: (1) Eliminate the listed companies that have been delisted during the sample period; (2) Eliminate ST and *ST companies, which are being warned of delisting risks; (3) Eliminate companies of the financial industry; eliminate companies with missing key variables; eliminate samples with negative or 0 values of assets and owners' equity and use interpolation method to make up for the missing values of the control variables; (4) To eliminate the interference of outliers, the continuous variables are winsorized at the top and bottom 1% of their distributions. Eventually, this study obtains the unbalanced panel data of 13,705 enterprise-year observations.

3.2. Variable selection and definition

3.2.1. Enterprises' green technology innovation

The dependent variable in this study is enterprises' green technology innovation, and we measure enterprises' green technology innovation from three aspects: innovation output, green output proportion and green total factor productivity.

Based on the IPC Green Inventory of the World Intellectual Property Organization, the output of enterprises' green technology innovation is evaluated by the number of green patents each year, which is obtained through screening and matching patents. The number of green patents from the innovation category can be further divided into the number of green invention patents and the number of green utility model patents in China. Since it is less difficult to authorize green utility model patents, as opposed to green invention patents, there exist differences between the two kinds of patents in terms of the technology-intensive degree and the difficulty of R&D. Therefore, the number of these two kinds of patents can be used as indicators to evaluate the quality difference of enterprises' green technology innovation.

The proportion of green patents among all the patents is also important (Hall & Helmers, 2019; Schiermeier, 2010). This proportion shows the green technology transformation and influences the green productivity of enterprises. For example, Hao, Chen, and Chen (2022) find that for every 1% increase in the proportion of the number of enterprises' green patent applications, the enterprise value (Tobin's Q) will increase by 0.023. Corresponding to the three classifications of green patents, green invention patents and green utility model patents, we use three proportions to quantify the green output proportion of enterprises' green technology innovation. They are the proportion of green patent applications of enterprises to all patent applications of the year (GAratio), the proportion of green invention patent applications to all invention patent applications of the year (GIAratio), and the proportion of green utility model applications to all utility model applications of the year (GUAratio). These three proportions are used to evaluate the overall technology innovation of enterprises and the trend of green transformation of different types of technology innovations. The higher the proportion is, the more prominent the green environmental factors are in enterprises' innovation decision-making, and the more significant the green transformation effect will be.

This study also considers green total factor productivity. Incorporating the impact on the environment and energy into the total factor productivity of enterprises, this study replaced the comprehensive efficiency of enterprises' green technology innovation with green total factor productivity. Referring to Lee and Lee (2022) and Wu and Wang (2022), we construct the green total factor productivity of the listed enterprises as follows:

$$Gtfp_{jit} = green_{jt} \times tfp_{jit}$$

$Gtfp_{jit}$ represents the green total factor productivity of enterprise i in industry j during the period of t. $green_{jt}$ means the green coefficient of industry j during the period of t.

The calculation procedure of the green coefficient is as follows. First, calculate the economic output of unit CO_2 emission:

$$q_{jt} = \frac{y_{jt}}{p_{jt}}$$

where y_{jt} is the total industrial output value of industry j in period t; p_{jt} is CO_2 pollution discharged by industry j in period t; j = 1, 2... 37, represent 37 industrial sectors. The larger q_{jt} is, the higher the economic output per CO_2 is. Second, calculate the green coefficient of the industry. It calculates the relative level of unit environmental energy cost and economic output of j industry.

$$green_{jt} = \frac{q_{jt}}{\sum_{j=1}^{37} q_{jt}}$$

If $green_{jt}$ is larger, the higher the economic output of unit pollutants in j industry is in all industries, which means the higher environmental economic efficiency.

The green coefficient indicates the economic benefits of the industry to the environment. It also reflects the green development level of the industry. tfp_{jit} represents the total factor productivity of listed companies. For the calculation of the total factor productivity of enterprises, there are two main semi-parametric calculation methods which are OP and LP. Since the OP method requires that the real investment of the enterprises must be >0, it has resulted in the loss of many samples in the estimation process. In practice, it is difficult to estimate the actual investment of enterprises, and once the monotonicity condition between investment and productivity is not met, the OP estimate will not meet the consistency condition (Zhang & Zhang, 2016). As a result, the estimation results are biased. The LP method uses intermediate inputs as the proxy for productivity shock, which eases the problem of negative investment variables and better solves the problem of sample losses. Therefore, this study chooses the LP method to measure the total factor productivity of listed enterprises. Fig. 1 shows the evaluation system for enterprises' green technology innovation.

3.2.2. Explanatory variables

DID: The treatment group is identified as the sample data of listed enterprises in eight provinces and metropolises including Beijing, Tianjin, Shanghai, Chongqing, Hubei, Shenzhen, Guangdong and Fujian. The data of three enterprises in Fujian Province have been eliminated because the Fujian carbon emissions trading pilot began at the end of 2016, which only covers a short period. As a result, seven provinces and metropolises have been included in the sample data, which means the treated variable for these regions is assigned a value of 1. Likewise, the sample data of listed enterprises of the remaining non-pilot provinces and metropolises is defined as the control group, and the treated variable for the control group is 0. In terms of time, the pre-2013 period is set as a non-pilot period, and 2013 and later period is set as the pilot period. Therefore, the time variable for the pre-pilot period (2008–2012) is assigned a value of 0 and the time variable for the pilot period (2013–2017) is 1. The explanatory variable DID is then constructed according to the treated and time.

Government concerns: Using text mining, we select the number of words related to decarbonization and their proportion in the provincial government work report during the study period as one proxy variable for government concerns. By screening the 2008–2017 government work reports of 31 provinces and metropolises, counting the frequency of environmental-related words in government work reports, the ecoword has been obtained (Chen, Kahn, Liu, & Wang, 2018). The government's concerns have also been measured from another perspective. The implementation intensity of government concerns in each region can be measured by carbon emission cost per unit of industrial added value, which is recorded as ER (Dou & Han, 2019).

Enterprise concerns: Enterprise concerns are usually not mandatory, so enterprises can make their policy and behavior choices. This study adopts the method (Cormier, Magnan, & Van Velthoven, 2005) to get the data for evaluating the quality of EID of Shanghai and Shenzhen A-shares listed enterprises. According to the annual report, social responsibility report and environmental report of listed enterprises, we divide the environmental information of enterprises into ten categories to judge the quality of EID. By constructing an interaction term between the logarithm of EID and the CTS, the combined effects of enterprise concerns and CTS can be tested.

Government innovation incentive policy: Innovation incentive policies can be divided into the fiscal subsidy, tax refunds and R&D funding. The fiscal subsidy is represented by the logarithm of the financial subsidy received by the enterprise in the year (fisaid); the tax refund is measured by the logarithm of the tax refund received by the enterprise in the year (tax). By collecting data on funding related to the R&D and innovation activities of enterprises, a proxy variable for R&D funding can be obtained. The scale of R&D funding is recorded as rdsub , rdsub=ln(The amount of government R&D funding +1).

Implementation of government innovation incentive policy: Inclusive implementation methods mean market-based allocation of government innovation resources to enterprises in the industry; whereas differentiated implementation methods indicate selective allocation of government innovation resources to selected enterprises. The combined effects of the CTS and the innovation incentive policies is investigated under these two ways of policy implementation. In order to measure the implementation of the innovation policies (Aghion, Dechezleprêtre, Hémous, Martin, & Van Reenen, 2016), we construct the following indicator to measure whether the implementation is inclusive or differentiated. It represents the dispersion of policies:
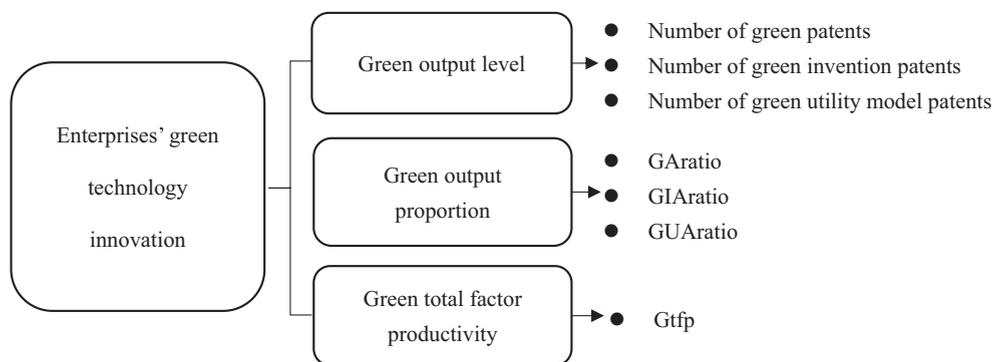

Fig. 1. The evaluation system for enterprises' green technology innovation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

$$Dispersion\_Policy_{jkt} = 1 - \sum_{i \in j} \left(\frac{Policy_{ijkt}}{sum\_Policy_{jkt}} \right)^2$$

In the equation, $Policy_{ijnt}$ means the share of government innovation resources obtained by i enterprise in j industry in k region during the t period. According to the previous analysis, it includes three parts: financial subsidy (fisaid), tax refund (tax) and R&D funding (rdsub). sum_Policy_{jkt} refers to the total amount of a certain kind of innovation support received by all enterprises in j industry in k region. $Dispersion\_Policy_{jkt}$ measures the dispersion of government innovation resources among enterprises in the same industry and same region, and is regarded as the proxy for the differences in the implementation methods of government innovation policies. The larger the $Dispersion\_Policy_{jkt}$ is, the more balanced the distribution of government innovation resources among enterprises should be.

3.2.3. Control variables

To study the impact of the CTS comprehensively on the green technology innovation of enterprises and ease the problems of bias and missing variables, we introduce control variables. Referring to Hu and Huang (2020), the following control variables have been taken into consideration: enterprise scale, enterprise age, asset-liability ratio, enterprise growth, fixed asset ratio, profitability, and Tobin's q ratio. Table 1 shows the variables with their description.

3.3. Descriptive statistics

Table 2 shows the descriptive statistics of the green patents and the green total factor productivity of the sample enterprises. As analyzed above, this study mainly measures the enterprises' green technology innovation from three dimensions: output, proportion and green productivity. Judging from the descriptive statistics of the sample, the average number of applications for green patents, green invention patents and green utility model patents of the sample enterprises are 1.752, 1.0222 and 0.7290 respectively. The average number of green invention patent applications is higher than that of green utility model patent applications. Compared with the overall average number of patent applications, the number of green patent applications is low. No matter whether it is a green invention patent or a green utility model patent, the number of it is far lower than that of invention patent applications and utility

Table 1
Variable and description.

	Variable		Variable description and calculation method
Dependent variable	Green output level		The number of green patent applications in a certain year: 1. The total number of green patent applications 2. The number of green invention patent applications 3. The number of green utility model patent applications
	Green output proportion		The proportion of enterprises' green patent applications in a certain year: 1. The proportion of green patent applications to all patent applications (GAratio) 2. The proportion of green invention patent applications to all patent applications (GIAratio) 3. The proportion of green utility model patent applications to all patent applications (GUAratio)
	Green total factor productivity		Enterprise green total factor productivity (gtfp), gtfp = green coefficient (green) ×enterprises' total factor productivity (tfp)
Explanatory variable	DID	Variables for the CTS	Whether the enterprise is in the carbon trading market pilot area, if so, the treated variable is 1; otherwise it is 0
		Time variables	Whether the carbon trading market pilots have been established (time), the time variable after establishment (2013–2017) is 1; before the establishment (2008–2012) is 0
	Concerns	Government concerns	Ecoword: The frequency of carbon-related words in government reports ER: Carbon emission cost per unit of industrial added value
		Enterprise concerns	Quality of environmental information disclosure (EID) of Shanghai and Shenzhen A-shares listed enterprises
	Policy	Innovation incentive policy	Fiscal subsidy: The logarithm of the fiscal subsidy received by the enterprise in a certain year (fisaid) Tax refunds: Denoted as the logarithm of the tax refunds received by enterprises in a certain year (tax) R&D funding: Recorded as rdsub, rdsub=ln(The amount of government R&D funding+1)
		Implementation methods of innovation incentive policies	Indicator for policy dispersion $Dispersion\_Policy_{jkt}$
Control variable	Enterprise scale (Scale)		The logarithm of total assets (size) and the total number of employees (labor) of the enterprise is used to represent the scale of the enterprises
	Enterprise age (Age)		Sample year - year of establishment +1
	Asset-liability ratio (LEV)		Total enterprise liabilities / Total enterprise assets
	Enterprise growth (Growth)		(Current main business income - main business income in last year) / main business income in the last year
	Fixed asset ratio (FAR)		Net fixed assets / total assets at the end of the year
	Profitability (ROA)		Net profit for the current year / total assets at the end of the year
	Tobin's q ratio (Tobin's q)		Market value / total assets at the end of the year

Table 2
Descriptive statistics of explanatory variables in full sample and subsamples.

Variable	Full sample			Treatment group			Control group		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
Number of green patent applications	13,705	1.75	8.79	4505	1.87	11.35	9200	0.65	3.23
Number of green invention patent applications	13,705	1.02	6.15	4505	1.15	7.07	9200	0.59	2.58
Number of green utility model patent applications	13,705	0.73	3.53	4505	1.00	5.95	9200	0.36	2.06
Number of patent applications	13,705	37.16	185.00	4505	61.24	346.20	9200	26.52	82.55
Number of invention patent applications	13,705	17.36	127.32	4505	32.10	233.00	9200	10.53	37.74
Number of utility model patent applications	13,705	15.09	64.64	4505	21.61	109.80	9200	12.09	39.57
Number of design patent applications	13,705	4.73	23.33	4505	6.51	30.84	9200	3.84	18.26
GAratio	13,705	0.04	0.13	4505	0.05	0.14	9200	0.04	0.12
GIAratio	13,705	0.04	0.15	4505	0.05	0.17	9200	0.04	0.14
GUAratio	13,705	0.04	0.13	4505	0.04	0.14	9200	0.03	0.13
Gtfp	13,705	0.46	0.74	4505	0.49	0.76	9200	0.38	0.63

model patent applications. According to the green output proportion variables GAratio, GIAratio and GUAratio, the proportion of green technology innovations in the R&D activities of the sample enterprises is quite low. Hence, green innovations have not got as much attention as they deserved.

The descriptive statistics of the main control variables in the full and subsamples refer to the enterprises involved in the treatment group and the control group (see Table 3). Based on the mean and standard deviation, the difference between enterprises from the treatment group and the control group during the sample period is not that huge, indicating that the DID model can be well applied to the study.

4. Empirical analysis

4.1. CTS single policy estimation

This study investigates the impact of the carbon trading system (CTS) on green technology innovation by using a DID model of an unbalanced short panel. We control for both time and individual effects and the DID model is as follows:

$$y_{it} = \alpha_0 + \alpha_1 treated_i + \alpha_2 time_t + \alpha_3 treated_i \times time_t + \alpha_4 \sum control_{it} + \varepsilon_{it}$$

y_{it} is the variable of green technology innovation, including the green output level, green output proportion and green total factor productivity. $treated_{it}$ is the policy variable of CTS in this study: $treated_i=1$ means the treatment group, representing the enterprises affected by CTS; $treated_i=0$ indicates the enterprise group is not affected by CTS. $time_t$ is the time variable of policy implementation, 2013 is the starting year of the carbon trading pilot. $time_i=1$ or 0 represent after and before policy implementation, respectively. $DID_{it} = treated_i \times time_t$, the focus of this study, measures the real policy effect of CTS on enterprise green technology innovation. $control_{it}$ is the control variable; ε_{it} is the random term; α_1 captures the group effect of the treatment group; α_2 controls the inherent time trend before and after the treatment period. Interaction coefficient α_3 represents the net true effect of the treatment group. Table 4 shows the results of the impact of CTS on the green output level, green output proportion and green total factor productivity.

The impact of CTS on enterprises' green output level (Columns 1 to 3) shows that CTS plays a role in promoting the output level of green patents. Under the robust clustering standard error of the prefecture-level cities, it passes the significance level test of 1%. The green patent includes the green invention patent and green utility model. The empirical results show that CTS has a positive impact on green invention patents at 1% significance level. However, the influence of CTS on the green utility model is not significant. This means that CTS affects two types of patents differently. CTS can promote the green invention patent (with higher technology) but does not affect the green utility model (with lower technology). In other words, CTS significantly promotes the quality of enterprises' green technology innovation. Under carbon trading, a long-term and market-based environmental regulation, rational enterprises would carry out high-tech green technology innovation activities to reduce the cost of emission reduction.

For the green output proportion (Columns 4 to 6), the impact of CTS on GAratio is significantly positive, indicating that it promotes the green transformation of enterprises and leads to a green-biased technological innovation effect. CTS also has a positive impact on GIAratio which is significant at the 1% level, and the estimated coefficient is larger than that of all green patents. Consistent with the above finding on the impact of green output level, the empirical results also show that CTS can promote green transformation, especially high-tech green transformation of enterprises.

For the green total factor productivity (Column 7), CTS has a significant promotion effect on the green total factor productivity of enterprises, with an impact coefficient of 0.08. Under the CTS, more enterprises with high energy consumption and emissions are incentivized to make better use of green technology and higher productivity.

4.2. Combined effects of CTS- stakeholder concerns

To estimate the impact of the combined effects of CTS and stakeholder concerns, this study puts a concerning indicator and an interaction indicator of DID and concerns to the model. The model is as follows:

Table 3
Descriptive statistics of control variables in full sample and subsamples.

Variable	Full sample			Treatment group			Control group		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
Size	13,704	21.87	1.23	4505	21.91	1.34	9199	21.86	1.16
Labor	13,704	7.68	1.19	4504	7.64	1.31	9200	7.70	1.13
Age	13,705	15.88	5.48	4505	16.11	6.18	9200	15.77	5.10
Lev	13,705	0.42	0.97	4505	0.39	0.30	9200	0.44	1.16
Growth	13,491	5.90	514.40	4428	1.33	29.91	9063	8.14	627.30
FAR	13,704	0.26	0.16	4505	0.22	0.16	9199	0.27	0.16
ROA	13,705	0.04	0.22	4505	0.05	0.07	9200	0.04	0.26
Tobin's q	13,697	2.17	1.78	4503	2.24	1.47	9194	2.14	1.91

Table 4
The impact of CTS on green technology innovation.

	Green output level			Green output proportion			Green total factor productivity
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	Green patent	Green invention patent	Green utility model patent	GAratio	GIAratio	GUAratio	Gtfp
DID	1.199***	0.782***	0.417	0.011**	0.022***	−0.002	0.084***
	(3.836)	(4.196)	(0.249)	(2.244)	(3.81)	(−0.213)	(4.421)
Constant	−17.87***	−11.20***	−6.665***	−0.092	−0.107	−0.067	−0.543***
	(−3.465)	(−2.895)	(−4.249)	(−1.561)	(−1.519)	(−1.213)	(−3.803)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	13,482	13,482	13,482	13,482	13,482	13,482	13,482
Adj.R²	0.193	0.174	0.111	0.145	0.103	0.116	0.332

Notes: The t statistics are in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

$$y_{it} = \alpha_0 + \alpha_1 DID_{it} \times Policy_{it} + \alpha_2 DID_{it} + \alpha_3 Concern_{it} + \sum control_{it} + \mu_i + \lambda_t + \varepsilon_{it}\#$$

$Concern_{it}$ is a concern variable investigated in this study. The coefficient α_1 of interaction term $DID_{it} \times Concern_{it}$ reflects the influence of combination. μ_i represents individual fixed effects and λ_t represents time fixed effect. Apart from those control variables defined in the previous section, the control variables here include all the other stakeholder concerns discussed in this study that may affect green technology innovation of enterprises to extract the net influence of a certain combination based on CTS. The stakeholder of CTS mainly includes government and enterprises. This study investigates the combined effects of them and CTS. We use environmental words' frequency in government reports (ecoword) and carbon emission cost per unit of industrial added value (ER) as proxies of government concerns. The former represents the top-down regulations, while the latter represents the result of policy implementation.

First, we analyze the interaction between CTS and government concerns represented by government environmental words' frequency. Table 5 shows that the mixed policies have different impacts on the green technology output, green output proportion and green total factor productivity. Table 5 shows that the combination has a significant positive impact on green output level and green total factor productivity but a negative impact on green output proportion. With the help of CTS, when the proportion of

Table 5
Combined effects of CTS and government concerns (ecoword).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	Green patent	Green invention patent	Green utility model patent	GAratio	GIAratio	GUAratio	Gtfp
DIDecoword	0.034**	0.098	0.038***	−0.001**	−0.001**	−0.001**	0.112***
	(2.384)	(1.032)	(4.938)	(−2.028)	(−1.993)	(−2.329)	(4.392)
DID	−0.838	0.072	−0.728**	0.052***	0.089***	0.023**	−0.008
	(−0.789)	(0.071)	(−2.319)	(2.751)	(4.128)	(2.942)	(−0.108)
Ecoword	−0.017	−0.019	0.001	0.001	−0.002	0.001	−0.001***
	(−0.010)	(−1.033)	(0.179)	(0.343)	(−0.983)	(1.481)	(−3.418)
Constant	−14.518***	−9.876***	−9.822***	−0.1589*	−0.203	−0.991	−1.845***
	(−4.254)	(−4.937)	(−5.928)	(−1.713)	(−1.075)	(−0.0892)	(−4.818)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	12,685	12,685	12,685	12,685	12,685	12,685	12,685
Adj.R²	0.172	0.159	0.221	0.204	0.199	0.170	0.391

Notes: The t statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

environmental words in government reports increases 1%, the green patent increases 0.034% and green total productivity increases 0.112%. However, the proportion of enterprises' green patent applications slightly declines 0.001%.

The market-based single policy (CTS) has a positive effect on the green output proportion of green technologies. It becomes a negative effect when government concerns are taken into consideration. This is because the three dimensions of green technology have different responses to government concerns. The formation of the green technological innovation structure should take a long time, so the proportion of green patents changes slower. The government report reflects the intensity of government environmental supervision and law enforcement as a government work plan formulated at the beginning of the year. It is likely to crowd out investment in green technology innovation and offset the incentive effect of CTS on green transformation.

ER is the carbon emission cost per unit of industrial added value. Compared with the environmental word frequency in the government report, ER is the real input-output ratio of enterprises to deal with carbon emissions and can better reflect the actual management strength of the government. ER is the government concern represented by command-control environmental regulations. Command-control environmental regulations mainly force enterprises to comply with regulatory standards and punish polluters. They aim to control pollution and have limited incentives for enterprise green technology innovation. In order to achieve the standard of pollution emission, enterprises must expand green investment, which has a crowding out effect on enterprises' green technology innovation.

Table 6 illustrates that the positive effect of CTS on innovation is small and the negative effect of the government's rigid concerns on innovation is more obvious. Under CTS, 1% increase of ER declines 3.447% of green patents under the significance of 1%. In terms of the proportion of enterprises' green patent applications, 1% increase of ER declines 0.817% of the proportion. This combination cannot significantly influence green total productivity. The combination of CTS and the government's concerns fail to promote innovation. However, this combination can achieve complementary advantages. To ensure that the government's environmental protection will truly stimulate enterprise green transformation, Chinese environmental regulation system reform should use more market-based incentive tools.

Next, we examine the combined effects of CTS and enterprise concerns. According to Cormier et al. (2005), this study uses the environmental information disclosure (EID) of Shanghai and Shenzhen A-shares listed enterprises. Based on the annual report, social responsibility report and environmental report of listed enterprises, the data includes ten categories[2] of enterprises' environmental information to reflect the quality of environmental information disclosure.

As can be seen from Table 7, except for green total factor productivity, the estimated coefficients of the interaction terms between enterprise information disclosure and CTS are positive. The green invention patent and GIAratio are significantly positive at 5%. Improving the quality of information disclosure can significantly promote the green technology output and enterprises' green technology transition. The establishment of the CTS also provides a platform for enterprises to further improve the disclosure of environmental protection information. However, the influence coefficient on the green total factor productivity is −0.015, which is significant at the 5% level. The possible reason could be the cost of environmental information disclosure. For example, too much enterprises' internal business information is disclosed, which is not conducive to optimizing resource allocation and consolidating market competitive advantages.

4.3. CTS-innovation incentive policy combined effects

Besides environmental regulations, innovation incentive policies can also affect the green development of enterprises. We examine the effects of different innovation incentive policies under the CTS from the perspectives of fiscal subsidy, tax return, R&D funding and policy implementation modes.

Table 8 shows the incentive effect of the CTS and fiscal subsidy combination on innovation. The interaction coefficient of the green technology output is positive. With the fiscal subsidy, CTS has a greater incentive effect on improving the quantity and quality of green technology innovation output. For the green output level, the coefficient of DID and fiscal subsidy is 1.938 under the significance of 1%. However, CTS itself may aggravate the financing constraint of enterprise innovation. The appropriate fiscal subsidy can alleviate the financing constraint of enterprises' innovation and encourage enterprises to improve their green technology output.

For the green output proportion, the combination of CTS and fiscal subsidy has a positive effect. The estimated coefficient 0.004 is significantly positive at the level of 5%, but the main contribution is from the utility model patent. For green total factor productivity, the combination makes a negative effect, which is not significant. It indicates that in the competitive market, more financial subsidies cannot be conducive to improving green total factor productivity.

Table 9 shows the combined effects of CTS and tax returns. Except for GUAratio, interaction term coefficients are significantly positive at 5%. When tax returns increase 1%, the green output level increases about 1.5% under the influence of CTS. Therefore, under the CTS, the tax return can alleviate the financing constraints of enterprises and strengthen the innovation incentive effect of CTS on enterprises. The combined effects of CTS and tax return improve the level of enterprises' innovation output, lead to green technology

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[2] The subcategories of environmental information disclosure quality of listed enterprises are as follows: Information regarding ISO certification of environmental management system; measures to improve ecological environment; the objectives of environmental protection in enterprises; corporate environmental investment and environmental technology development; government funding, fiscal subsidy and tax return related to environmental protection; emission and emission reduction of corporate pollutants; impact of government environmental policy on enterprises; loans on environmental protection; lawsuits, compensation, penalty and rewards related to environmental protection; enterprises' other income and expenditure items related to environment.

Table 6
Combined effects of CTS and government concerns (ER).

Variable	(1) Green patent	(2) Green invention patent	(3) Green utility model patent	(4) GAratio	(5) GIAratio	(6) GUAratio	(7) Gtfp
DIDER	−3.447***	−2.423***	−0.817 ***	−0.018***	−0.0281*	−0.016**	−0.064
	(−6.836)	(−5.972)	(−3.883)	(−4.918)	(−2.059)	(−2.338)	(−0.194)
DID	4.0.290***	3.0297***	2.393***	0.049***	0.048***	0.027**	0.108
	(5.801)	(7.283)	(3.328)	(4.292)	(3.975)	(2.318)	(0.217)
ER	−68.937	−173.383*	−21.852	−3.923***	−4.788*	−1.169	−22.332***
	(−0.027)	(−1.977)	(−0.003)	(−5.301)	(−1.837)	(−0.083)	(−4.290)
Constant	−9.263***	−8.3982***	−6.010***	−0.052	−0.183	−1.002	−0.684***
	(−10.297)	(−3.290)	(−9.372)	(−0.028)	(−1.086)	(−0.202)	(−4.2927)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	13,431	13,431	13,431	13,431	13,431	13,431	13,431
Adj.R^2	0.231	0.232	0.132	0.187	0.128	0.164	0.392

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

Table 7
Combined effects of CTS and enterprise concerns (EID).

Variable	(1) Green patent	(2) Green invention patent	(3) Green utility model patent	(4) GAratio	(5) GIAratio	(6) GUAratio	(7) Gtfp
DIDEID	0.585**	0.639***	0.428	0.002	0.003***	0.005**	−0.115***
	(1.997)	(4.197)	(0.022)	(0.092)	(3.739)	(2.974)	(−3.972)
DID	0.836	1.298	0.183	0.001	0.002	−0.004	0.019***
	(1.028)	(1.483)	(0.098)	(0.092)	(0.088)	(−0.018)	(4.985)
EID	−0.093**	−0.023*	−0.083	−0.001	0.002	−0.002	−0.011**
	(−2.068)	(−1.990)	(−0.986)	(−0.738)	(0.983)	(−1.172)	(−1.987)
Constant	−8.286***	−8.915***	−3.949***	−0.286**	−0.986	0.034	−0.573**
	(−4.972)	(−5.927)	(−3.928)	(−4.703)	(−0.270)	(0.386)	(−2.913)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	11,319	11,319	11,319	11,319	11,319	11,319	11,319
Adj.R^2	0.183	0.174	0.105	0.105	0.097	0.109	0.334

Notes: The t statistics are in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Table 8
Combined effects of CTS and fiscal subsidy.

Variable	(1) Green patent	(2) Green invention patent	(3) Green utility model patent	(4) GAratio	(5) GIAratio	(6) GUAratio	(7) Gtfp
DIDfisaid	1.938 ***	1.082***	0.403**	0.004**	0.004	0.002**	−0.012
	(4.938)	(3.097)	(2.564)	(2.132)	(0.208)	(2.183)	(−0.382)
DID	−9.397***	−8.873***	−4.291***	−0.073***	−0.032	−0.065**	1.189**
	(−8.387)	(−4.972)	(−4.987)	(−4.409)	(−1.092)	(−2.276)	(2.017)
Fisaid	−1.093**	−1.087*	−0.103	−0.001	−0.001	−0.001	0.002
	(−1.987)	(−1.932)	(−0.308)	(−1.002)	(−0.388)	(−0.948)	(0.029)
Constant	−11.298***	−7.982**	−4.297***	−1.293**	−0.293***	−0.324**	−0.765***
	(−3.981)	(−5.382)	(−4.957)	(−2.432)	(−3.875)	(−0.191)	(−2.976)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	12,590	12,590	12,590	12,590	12,590	12,590	12,590
Adj.R^2	0.283	0.294	0.144	0.132	0.123	0.117	0.298

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

transformation, and promote the green total factor productivity.

Next, we empirically estimate the combined effects of CTS and R&D funding. According to the estimation results in Table 10, the interaction term between CTS and R&D funding has a positive impact on the green output level, which is significant at the level of 1%. 1% percent increase of the combination increases 0.329% of green patent. Among green patents, the estimated coefficient of the green invention patent is higher than that of the green utility model patent. However, the green invention patent has less significance. As for

Table 9
Combined effects of CTS and tax return.

Variable	(1) Green patent	(2) Green invention patent	(3) Green utility model patent	(4) GAratio	(5) GIAratio	(6) GUAratio	(7) Gtfp
DIDtax	1.873***	1.9282***	0.319**	0.002***	0.003***	0.001*	0.104***
	(3.918)	(4.918)	(2.038)	(3.197)	(4.092)	(1.934)	(5.193)
DID	−0.293 ***	−0.298***	−0.098	−0.012***	−0.032	−0.002	−0.106***
	(−5.082)	(−3.298)	(−0.901)	(−3.402)	(−0.983)	(−0.109)	(−4.098)
Tax	−0.041*	−0.028**	−0.013	0.000	−0.001*	−0.000	−0.001*
	(−1.943)	(−1.993)	(−1.002)	(0.009)	(−1.832)	(−0.098)	(−1.906)
Constant	−10.928***	−12.384***	−3.092***	−1.028	−1.082	−0.073	−1.287***
	(−4.209)	(−3.049)	(−4.394)	(−0.093)	(−1.09)	(−1.193)	(−4.398)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	13,482	13,482	13,482	13,482	13,482	13,482	13,482
Adj.R^2	0.223	0.226	0.123	0.147	0.113	0.107	0.339

Notes: The t statistics are in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

the green output proportion, the policy combination has a significant positive effect on GAratio and GIAratio, while the positive effect on GUAratio is very small. For green total factor productivity, the combined effects are low, and R&D funding plays a limited role in policy combination. Overall, R&D funding has a positive impact on green technology innovation, but R&D funding has less significance than fiscal subsidy and tax returns.

We compare the three policies above and find that the scope of fiscal subsidies and tax returns is larger, and R&D funding is more targeted. In general, both fiscal subsidy and tax return can alleviate the financing constraints and strengthen the incentive of CTS to enterprises' green technology innovation. In terms of the value of the estimated coefficient, the incentive effect of the fiscal subsidy on the quantity and quality improvement of green innovation is better than that of the government's post-tax compensation (tax return). Under the constraint of carbon emissions, the fiscal subsidy can encourage enterprises to choose high-quality innovation behavior. However, post-tax compensation can stimulate enterprises to improve the green total factor productivity and accelerate the green transformation of technology innovation. If a reasonable tax return is adopted, enterprises can be inspired to improve their image and implement green technology innovation throughout the whole production process. R&D funding also has a positive impact on green technology innovation but compared to fiscal subsidy and tax returns it has less significance. The effect of R&D funding on green utility models is greater than that of fiscal subsidy and tax return. In order to obtain continued funding, enterprises must apply for relatively low-technology green utility model patents to meet the requirements of green R&D funding. However, this is not conducive to real green technology innovation.

It can be found that the combined effects of the CTS and innovation incentives policy are significantly higher than that of the single policy CTS. Innovation incentive policy inhibits the negative impact of CTS. However, the optimal innovation policy mix is not fixed and may be in dynamic change due to the differences in policy implementation.

Furthermore, this study investigates the different policy implementation ways. Some policies are implemented on a specific object while others are equal to every participant.

Table 11 shows the results of inclusive and differentiated fiscal subsidies. In each estimation, we fixed the industries to eliminate the impact of industries' different characteristics. The estimated results are generally consistent with the previous full-sample estimation. The combination of inclusive fiscal subsidies and CTS can play a significant role in increasing the quantity and quality of

Table 10
Combined effects of CTS and R&D funding.

Variable	(1) Green patent	(2) Green invention patent	(3) Green utility model patent	(4) GAratio	(5) GIAratio	(6) GUAratio	(7) Gtfp
DIDrdsub	0.329***	0.277**	0.123***	0.001	0.002**	0.001	−0.021
	(4.028)	(1.983)	(4.309)	(0.097)	(2.1212)	(0.876)	(−0.097)
DID	−0.422***	−0.944***	−0.383***	−0.002	−0.012	−0.009	0.112***
	(−4.982)	(−2.993)	(−4.391)	(−0.098)	(−0.864)	(−0.344)	(4.089)
Rdsub	0.010	0.010	−0.000	0.001*	0.001*	−0.000	−0.000
	(0.245)	(0.325)	(−0.255)	(1.974)	(1.845)	(−0.566)	(−0.234)
Constant	−20.091**	−10.394**	−11.293***	−1.234*	−2.456***	−1.244	−1.394**
	(−2.344)	(−2.742)	(−4.204)	(−2.304)	(−4.39)	(−0.203)	(−2.213)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	6416	6416	6416	6416	6416	6416	6416
Adj.R^2	0.254	0.189	0.219	0.195	0.163	0.170	0.386

Notes: The t statistics are in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

enterprises' technological innovation output, the coefficient on green patent is 1.928. It has no significant effect on enterprises' green transformation. It is significant at 10% level on enterprises' green total factor productivity.

The interaction between CTS and differentiated fiscal subsidies has a significant impact on green invention patents, with an influence coefficient of 1.253 and being significant at the level of 1%. However, it has no significant impact on the overall green patents and green utility model patents. For the coefficients, the incentive effect of the differentiated fiscal subsidy is much smaller than that of the inclusive fiscal subsidy. It can be considered that the combined effects of CTS and fiscal subsidy have a more significant effect in the case of inclusive subsidy implementation. The inclusive subsidy can better promote industry competition, stimulate enterprise innovation vitality, and reduce unreasonable interference in competition or resource allocation.

Table 12 reflects the estimated incentive effects of policy combinations under the inclusive and differentiated tax returns. It has 1% significant level on green output level, green patent proportion and green total factor productivity. While implementing an incentive tax return policy, 1% increase in tax returns can enhance the coefficient by 1.937%. In each estimation, we fixed the industries to eliminate the impact of industries' different characteristics. The estimation in Table 12 is consistent with the full-sample estimate, and the coefficient under the inclusive tax return has a higher significance than the full-sample estimate. Compared with the whole, the inclusive tax return policy has a significant positive impact on the output level, green output proportion and green total factor productivity. Under the differentiated tax return, the mixed policies only have a significant impact on green invention patents and GIAratio, which is significantly different from the full sample. The coefficient of green invention patents is 1.092 and the coefficient of GIAratio is 0.002. For the coefficient, the incentive effect of differentiated tax returns is much smaller than that of the inclusive tax return. This indicates that the greater the coverage of the tax return, the more CTS can encourage enterprises to carry out green technology innovation. Compared with fiscal subsidies, it can be found that tax return has a more comprehensive incentive effect on enterprises' green technology innovation, which has a significant incentive effect on all dimensions. Hence, the tax return works better than the fiscal subsidy.

Table 13 shows the combined effects of R&D funding under different implementation modes. In each estimation, we fixed the industries to eliminate the impact of industries' different characteristics. The estimation results under the inclusive R&D funding are generally consistent with the full-sample estimation. The coefficient is 0.137 for green patent and is 0.002 for GAratio. Inclusive R&D funding and CTS can play an incentive role in improving the output level of green technology innovation. Market-based inclusive R&D subsidies can improve the innovation vitality of enterprises. It also has an incentive effect on the output proportion of green technology innovation. With differentiated R&D funding, the incentive effect no longer exists. All the estimation cannot pass the significance test. Due to information asymmetry, differentiated R&D funding will inevitably lead to distorted resource allocation. R&D resources do not flow to enterprises that truly carry out green technology innovation. At the same time, no matter which implementation mode is adopted, R&D funding has no significant impact on the green total factor productivity.

5. Robustness test

In order to eliminate the interference of other factors and clarify the causal relationship, this study applies several robustness tests, including the parallel trend test, placebo test and endogeneity test. As for the stakeholder concerns/other innovation incentive policies,

Table 11
Different ways of implementing fiscal subsidy.

Variable	(1) Green patent	(2) Green invention patent	(3) Green utility model patent	(4) GAratio	(5) GIAratio	(6) GUAratio	(7) Gtfp
Inclusive fiscal subsidy							
DIDfisaid	1.938***	1.021***	0.409**	0.003	0.004	−0.001	−0.009*
	(3.998)	(3.918)	(2.093)	(1.093)	(0.352)	(−0.145)	(−1.948)
DID	−0.286***	−0.382**	−1.843**	−0.038	−0.098	0.042	0.2532**
	(−3.873)	(−2.273)	(−2.642)	(−0.535)	(−0.488)	(0.948)	(2.873)
Fisaid	−1.398*	−0.837	−0.245	0.001	0.002	−0.002	−0.003
	(−1.924)	(−1.452)	(−1.873)	(0.246)	(0.948)	(−0.838)	(−0.948)
N	4156	4156	4156	4156	4156	4156	4156
Adj.R²	0.042	0.058	0.029	0.932	0.014	0.021	0.302
Differentiated fiscal subsidy							
DIDfisaid	1.189	1.253***	0.38	0.001	−0.002	−0.002	−0.010
	(1.025)	(4.294)	(0.186)	(0.651)	(−0.351)	(−1.413)	(−0.563)
DID	−2.873	−2.983***	−0.971	−0.014	0.025	0.038	0.002
	(−0.283)	(−4.392)	(−0.425)	(−0.724)	(0.242)	(1.093)	(0.134)
Fisaid	0.103	0.084	0.245	0.002	0.004***	0.001*	0.002
	(0.264)	(0.124)	(1.093)	(0.278)	(4.832)	(0.189)	(0.836)
N	4219	4219	4219	4219	4219	4219	4219
Adj.R²	0.213	0.297	0.172	0.201	0.132	0.127	0.324

Notes: The t statistics are in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1. We add a special variable—different characteristics of the industries (the industrial sectors) here into this study's control variables (including enterprise scale, enterprise age, asset-liability ratio, enterprise growth, fixed asset ratio, profitability, and Tobin's q ratio). It is used to eliminate the impact of industries' different characteristics.

Table 12

Different ways of implementing tax return.

Variable	(1) Green patent	(2) Green invention patent	(3) Green utility model patent	(4) GAratio	(5) GIAratio	(6) GUAratio	(7) Gtfp
Inclusive tax return							
DIDtax	1.937***	1.387***	0.397***	0.002***	0.003***	−0.000	0.021***
	(5.029)	(3.298)	(4.082)	(4.001)	(3.013)	(−0.892)	(5.292)
DID	−0.283 ***	−0.322***	−0.197*	−0.093***	−0.047	−0.014	−0.123***
	(−5.082)	(−3.298)	(−1.901)	(−3.402)	(−0.183)	(−0.356)	(−5.872)
Tax	−0.053**	−0.026***	−0.023*	0.000	−0.001**	−0.001	−0.002***
	(−2.093)	(−3.983)	(−1.921)	(0.353)	(−1.992)	(−0.455)	(−3.786)
N	4439	4439	4439	4439	4439	4439	4439
Adj.R^2	0.033	0.047	0.021	0.023	0.016	0.018	0.317
Differentiated tax return							
DIDtax	1.092*	1.098**	0.002	0.001	0.002**	−0.001	−0.001
	(1.902)	(2.102)	(0.467)	(0.168)	(2.235)	(−0.725)	(−0.356)
DID	−1.097***	−0.865**	−0.101	0.004	−0.019	0.007	−0.337**
	(−3.927)	(−1.992)	(−1.093)	(0.245)	(−1.546)	(0.243)	(−2.37)
Tax	−0.026*	−0.011**	−0.006*	−0.002	−0.001	−0.001	0.000
	(−1.821)	(−2.341)	(−1.903)	(−0.524)	(−0.454)	(−0.654)	(0456)
N	4531	4531	4531	4531	4531	4531	4531
Adj.R^2	0.201	0.198	0.177	0.102	0.145	0.112	0.2337

Notes: The t statistics are in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. We add a special variable—different characteristics of the industries (the industrial sectors) here into this study's control variables (including enterprise scale, enterprise age, asset-liability ratio, enterprise growth, fixed asset ratio, profitability, and Tobin's q ratio). It is used to eliminate the impact of industries' different characteristics.

Table 13

Different ways of implementing R&D funding.

Variables	(1) Green patent	(2) Green invention patent	(3) Green utility model patent	(4) GAratio	(5) GIAratio	(6) GUAratio	(7) Gtfp
Inclusive R&D funding							
DIDrdsub	0.137***	0.091***	0.298**	0.002***	0.001	−0.000	−0.002
	(4.891)	(4.981)	(2.314)	(3.924)	(0.532)	(−0.245)	(−0.411)
DID	−1.481**	−0.872*	−0.293**	0.009	−0.041	0.005	0.460***
	(−1.987)	(−1.876)	(−1.982)	(0.415)	(−0.060)	(0.413)	(3.492)
Rdsub	−0.324	−0.145	−0.086*	0.002***	0.002***	0.002*	0.001
	(−0.374)	(−1.314)	(−1.945)	(3.941)	(4.931)	(1.934)	(1.005)
N	1350	1350	1350	1350	1350	1350	1350
Adj.R^2	0.041	0.073	0.032	0.015	0.034	0.063	0.323
Differentiated R&D funding							
DIDrdsub	0.124	0.031	0.32	0.003	−0.001	−0.003	−0.001
	(0.415)	(0.835)	(0.352)	(0.425)	(−0.623)	(−0.145)	(−0.513)
DID	−1.342	−0.414	−0.983	−0.031	0.008	0.031	−0.023
	(−0.534)	(−0.442)	(−0.624)	(−0.526)	(0.525)	(0.624)	(−0.624)
Rdsub	0.042	0.007	0.023	0.001	0.001**	−0.001	0.001
	(1.092)	(0.314)	(1.352)	(0.3742)	(2.351)	(−1.034)	(0.425)
N	2433	2433	2433	2433	2433	2433	2433
Adj.R^2	0.172	0.182	0.281	0.211	0.118	0.193	0.302

Notes: The t statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. We add a special variable—different characteristics of the industries (the industrial sectors) here into this study's control variables (including enterprise scale, enterprise age, asset-liability ratio, enterprise growth, fixed asset ratio, profitability, and Tobin's q ratio). It is used to eliminate the impact of industries' different characteristics.

it is necessary to conduct a DDD test on each combination. However, these policy variables are generated earlier than all the sample periods, which means that all the enterprises are in the post-disposal period. This means there is no difference before and after the policy implementation. Similarly, the concerns (proxied by the word frequency/carbon emission cost per unit of industrial added value and enterprise environmental information disclosure extent) also exist earlier than 2008. Therefore, we conduct a series of robustness checks to validate the robustness that whether CTS does have a causal relation with green technology innovation.

5.1. Parallel trend test

The parallel trend chart is first used for preliminary judgment, presenting the dynamic effect of CTS in different years. Fig. 2 shows

parallel trends of green patents and green invention patents. The estimation coefficients of green patents and green invention patents are not significantly different from 0 before the policy. After the implementation of the policy, the estimated coefficients of DID are significantly positive, which means that the treatment group and the control group can be compared to these two variables.

Fig. 3 shows that the estimated coefficients of GIAratio are not significantly different from 0 before the policy. The treatment and control groups have the same trend before the policy implementation. After the policy implementation time, the estimated coefficients of GIAratio are different from 0, so the policy effect is obvious. It also illustrates the parallel trend of the green total factor productivity. Before the carbon trading pilot, gtfp is not significantly different from 0. After the carbon trading pilot, the estimated coefficient is significantly positive, which satisfies the hypothesis of the parallel trend.

5.2. Placebo test

1. Policy time placebo test. To exclude the possibility that policies before the establishment of the CTS cause the same results, we set forward the establishment time of the carbon trading market 2–4 years for the time placebo test. If the interaction coefficient of the treatment group is still significant, it indicates that the variables related to green technology innovation are affected by other policies or interference factors. In this study, the carbon trading time is put forward to 2010, 2011 and 2012. $Did2010 = time2010 \times treated$ ($time2010$=1 means the time after 2010; $time2010$=0 means the time before 2010), $did2011 = time2011 \times treated$, and $did2012 = time2012 \times treated$.

Columns (1) and (2) are the estimated results controlling the potential policy factors in 2010. The estimated coefficients of DID2010 do not pass the significance test, and the estimated coefficients of DID concerned in this paper are still significant. China's regional CTS pilots were announced in 2011 and launched in 2013, so we also choose 2011 and 2012 as placebo times. After controlling the potential policy impact in 2011, the dummy variable DID2011 has no significant effect on the green total factor productivity. Similarly, in columns (5) and (6), the dummy variable DID2012 also has no significant effect on the green total factor productivity. In summary, after controlling the potential policy impact in other years, the CTS still has a promoting effect on green technology innovation of the sample enterprises in the treatment group, which passes the time placebo test (See Table 14).

2. Treatment group placebo test. In this test, we aim to exclude the influence of the selecting pilot provinces and ensure that the conclusions of this study are indeed caused by the CTS. According to Cai, Lu, Wu, and Yu (2016), six provinces were randomly selected from 31 Chinese provinces, assuming that the six provinces are the CTS pilot and using a regression model to estimate green technology innovation variables.

In this study, 500 random samples were taken to avoid the influence of accidental events. Figs. 4 and 5 respectively take green patent, green invention patent, GAratio and green total factor productivity as the estimated coefficients of the explained variables. Using t-value kernel density distribution, the horizontal axis represents the t-value of the estimated coefficients from 500 random samples of treated×post, and the vertical axis represents the corresponding *P*-value. The curve represents the t-value distribution of the kernel density estimate. As can be seen from the kernel density distribution, the absolute value of t of the estimated coefficients of most random sampling is 1.96, and the *P* value is above 0.05. It can be inferred that the influence of CTS on the variable of green technology innovation has no significant effect in the 500 random sampling treatment group. There is no significant difference between the effects of carbon trading on the fictitious treatment group and the control group. The above baseline estimate (true value) was a significant outlier (>1.96) on the placebo test.

The conclusion of this paper can be tested by placebo, and shows there is no causal relationship between the influence of CTS on enterprise green technology innovation and other unknown policies.
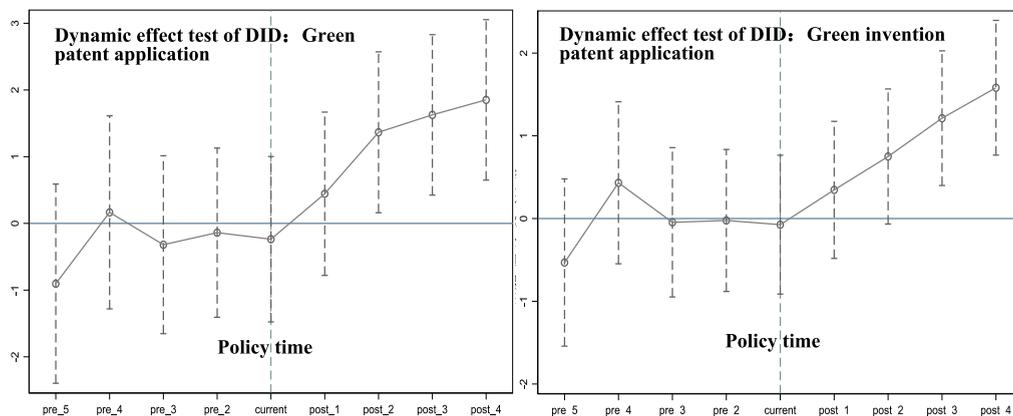

Fig. 2. Parallel trend of green patent and green invention patent. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
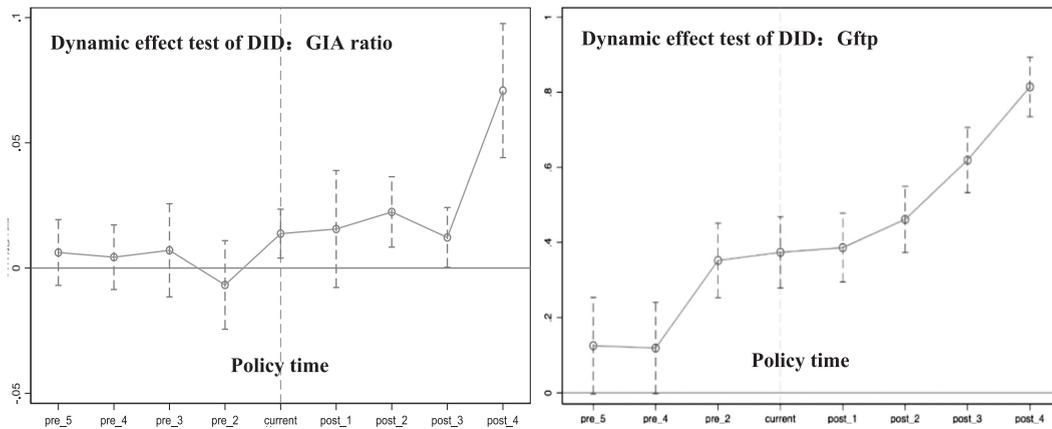
Fig. 3. Parallel trend of GIAratio and Gtfp.

Table 14
Policy time placebo test.

Variable	(1) Green patent	(2) Gtfp	(3) Green patent	(4) Gtfp	(5) Green patent	(6) Gtfp
DID	1.144***	0.622***	1.072**	0.073***	1.282***	0.764***
	(3.826)	(4.172)	(1.977)	(4.192)	(5.193)	(4.189)
Did2010	0.198	0.019				
	(0.796)	(1.330)				
Did2011			0.265	−0.010		
			(0.819)	(−0.894)		
Did2012					0.321	−0.018
					(0.201)	(−0.491)
Constant	−17.851***	−0.861***	−17.877***	−0.707***	−18.283***	−0.982***
	(−3.470)	(−2.865)	(−3.470)	(−2.859)	(−3.928)	(−4.112)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
N	13,482	13,482	13,482	13,482	13,482	13,482
Adj.R^2	0.193	0.385	0.192	0.398	0.208	0.367

Notes: The t statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
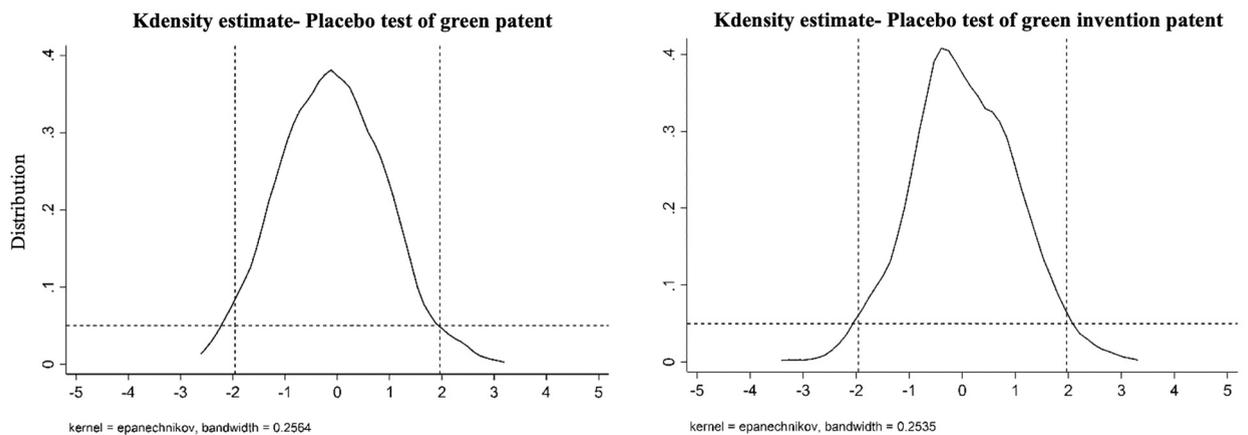
Fig. 4. Green patent and green invention patent: Fixed effect estimation.
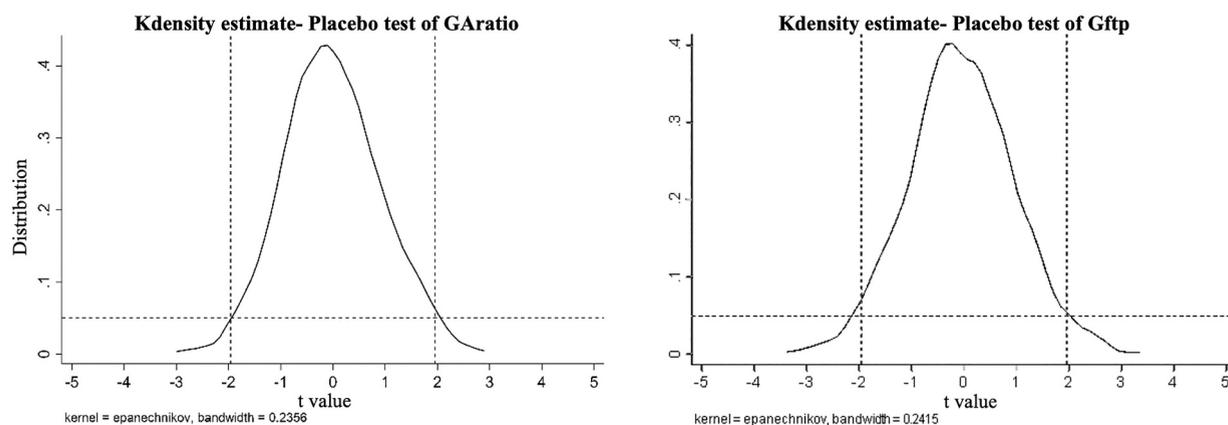
Fig. 5. GAratio and Gtfp: Fixed effect estimation.

5.3. Endogenous test

The selection of instrumental variables needs to meet two requirements: one is highly correlated with endogenous variables, and the other is not correlated with random perturbation terms. Carbon emission reduction is closely related to curbing excessive emissions of greenhouse gases and reducing the greenhouse effect. The establishment and implementation of CTS are closely related to temperature change. Under the condition of certain other factors (like the same latitude), the stronger the regional greenhouse effect and the higher the average temperature, the higher the probability of being included in the pilot area. At the same time, air temperature mainly depends on geographical location and climate characteristics. This paper chooses the average air temperature of the province as the instrumental variable.

The present study selects the regional annual average temperature (Celsius) from 2008 to 2010 before the pilot carbon trading as an instrumental variable (Godzinski & Suarez Castillo, 2021). The annual average temperature of a region is calculated from the annual average temperature of the prefecture-level cities under its jurisdiction. After calculating the annual average data of each province in 2008, 2009 and 2010, the annual average temperature of these three years is calculated as the instrumental variable of the CTS, and the interaction term of Temp0810 and time is written as Temp0810 × time.

The test results in Table 15 show that the first stage Temp0810 × time has a positive effect on the CTS. This indicates that there is a significant positive correlation between regional average temperature and carbon trading pilot selection. In the second stage, treated×time has a significant impact on all three dimensions of green technology innovation, but GAratio estimation coefficient based on bidirectional fixed effect does not pass the significance test.

As for the validity test of instrumental variables, the K-PRK LM statistic is 1402.568 at the significance level of 0.00000, and the C—D Wald F statistic is 2656.538, rejecting the unrecognized test (rejecting the null hypothesis, which is under-recognized) and weak instrumental variable test (rejecting the null hypothesis, the null hypothesis is the existence of weak instrumental variables), indicating that the selected instrumental variables meet the requirements of endogeneity test.

6. Conclusions

This study focuses on the combined effects of CTS, stakeholder concerns and innovation incentive policies on green technology innovation. For the first time, this study deconstructs green technology innovation into three dimensions (green output level, green output proportion and green total factor productivity). We also establish a data set including stakeholder concerns (government and enterprise concerns), three innovation incentive policies (fiscal subsidy, tax return and R&D funding) and two policy implementation methods (inclusive and differentiated policies). The main findings are as follows:

First, this study constructs a three-dimension system of green technology. Green output level includes the quantity and quality of green patents; green output proportion is the tendency of enterprises' green innovation structure and green transformation; and green total factor productivity measures the efficiency of enterprises to transform green technology input into economic benefits. The empirical study finds that carbon trading has a significant positive influence on enterprise green patent output. The influence of carbon trading on green invention patents is significantly higher than on green utility model patents. This indicates that CTS can motivate enterprises to carry out higher-quality green technology innovations. In terms of innovation structure, CTS has a significant positive impact on the proportion variables, indicating that CTS promotes the green technology innovation of enterprises. CTS also has a significant positive impact on green total factor productivity, indicating that CTS promotes green transformation and the application of green technology innovations.

Second, this study examines the effective combination of CTS and stakeholder concerns. CTS and government concerns have significant combined effects, but the influences are uncertain. With government concerns, CTS has a significant negative impact on the output proportion of green technologies. Government concerns weaken the positive effect of CTS. There is heterogeneity in the

Table 15
The impact of carbon trading on green technology innovation: The estimate of instrumental variable.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Stage 1		Stage 2									
	DID	DID	Green patent	Green patent	Green invention patent	Green invention patent	GAratio	GAratio	GIAratio	GIAratio	Gtfp	Gtfp
Temp0810 × time	0.046***	0.045***					0.014*	0.006	0.027**	0.021*	0.138***	0.208***
	(52.444)	(47.949)					(1.863)	(0.447)	(2.398)	(1.905)	(6.930)	(7.43)
DID			2.347***	2.177***	0.931**	1.061**	−0.248***	−0.094	−0.310***	−0.108	−0.713***	−0.987***
			(3.605)	(2.864)	(2.442)	(2.064)	(−5.172)	(−1.210)	(−5.211)	(−1.525)	(−13.150)	(−8.937)
Constant	0.486***	0.403***	−52.012***	−17.407***	−31.005***	−11.073***	Yes	Yes	Yes	Yes	Yes	Yes
	(9.597)	(3.437)	(−3.023)	(−4.108)	(−2.868)	(−3.862)	Yes	Yes	Yes	Yes	Yes	Yes
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
Ind FE	Yes	No	Yes	No	Yes	No	No	Yes	No	Yes	No	Yes
Area FE	Yes	No	Yes	No	Yes	No	13,482	13,482	13,482	13,482	13,482	13,482
Firm FE	No	Yes	No	Yes	No	Yes	0.045	0.013	0.037	0.011	0.956	0.198
N	13,482	13,482	13,482	13,482	13,482	13,482	13,482	13,482	13,482	13,482	13,482	13,482
Adj.R^2	0.730	0.442	0.194	0.171	0.187	0.173	0.245	0.113	0.137	0.111	0.756	0.231

Notes: The t statistics in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

influence of the other two dimensions of green technology innovation. Enterprise concerns have significant combined effects on green technology innovation. These factors help CTS play a positive role in improving the green technology output and the proportion of green output.

Third, this study investigates the combined effects of CTS and various innovation incentive policies. It further examines the effects of different policy implementation modes. Results show that for the combined effects of CTS and innovation incentive policies, the incentive effect of the fiscal subsidy on the green technology output's quantity and quality is significant. With the CTS, government subsidies, given in advance, encourage enterprises to make high-quality innovations. Besides green technology output, tax return also promotes enterprises' green total factor productivity and accelerates the green transformation in technology. R&D funding also has positive combined effects, but it has less significance. Therefore, in the long term, tax return works better than fiscal subsidy and R&D funding. Furthermore, the different ways of implementing incentive policies lead to different outcomes. Compared with differentiated innovation policy implementation, the inclusive innovation policy implementation mode could more equitably promote green technology development. The inclusive innovation policy could also more effectively realize the combined effects of CTS and innovation incentive policies.

Finally, based on the above conclusions, we make the following suggestions to the government and enterprises. First, compared with stricter government concerns, market-oriented government concerns (initiatives) can better promote the effectiveness of CTS and thereby better motivating enterprises to innovate green technologies. Second, we compare the three innovation incentive policies of tax returns, financial subsidies, and R&D funding, and find that they can generally help CTS to exert their effect, but the effect of tax returns is greater. Under the CTS, when tax returns increase 1%, the green output level increases about 1.5%. Therefore, the government should give more consideration to the tax return system. Third, the government should choose inclusive innovation incentive policies instead of partial incentives. Finally, for enterprises, paying more attention to the environment and disclosing their environmental governance is conducive to better technological innovation. This will fundamentally help solve the problem of carbon emissions. The government and enterprises should cooperate better for the aim of carbon neutrality.

Data availability

Data will be made available on request.

Acknowledgements

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