Journal of Asian Economics 86 (2023) 101597

Contents lists available at ScienceDirect

Journal of Asian Economics

journal homepage: www.elsevier.com/locate/asieco

Does carbon emission trading system induce enterprises' green innovation?

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ARTICLE INFO

Keywords:
Carbon emission trading system
Green innovation of enterprise
Difference-in-differences

ABSTRACT

To control total carbon emissions and achieve the emission reduction target, the Chinese government has implemented the carbon emission trading system (CETS), which has been applied in two provinces and five cities since 2013. This study uses the environmental regulation policy of the pilot CETS as a quasi-experiment to investigate whether the implementation of this environmental policy induces green innovation among enterprises. This study employs a difference-in-differences model to conduct an empirical test using green patent data of A-share listed enterprises from 2002 to 2018. The results indicate that the CETS pilot-policy-induced green invention innovation in enterprises. Notably, compared with non-state-owned enterprises, the pilot policy is more conducive to promoting green innovation in state-owned enterprises.

1. Introduction

The 19th National Congress of the Communist Party of China clearly proposed "accelerating the reform of the ecological civilization system" and "building a green technology innovation system" to meet the people's growing needs for a better life. Therefore, to better assume domestic and international responsibilities and adhere to the concept of a "community with a shared future for mankind," China has actively promoted the implementation of energy conservation and emission reduction in economic development and has made significant contributions to the world's emission reduction. In September 2020, at the 75th United Nations General Assembly, President Xi promised that China would spare no effort to reach the peak of carbon dioxide emission by 2030 and accomplish the goal of carbon neutralization by 2060. Around this blueprint for environmental protection, China's major work in the fields of "carbon neutralization" and "carbon emissions" has been steadily promoted, and system exploration and technological innovation in relevant areas have gradually developed and matured (Chen & Lin, 2021).

Following the concept of "emission trading" proposed by economists in the last century, China has gradually implemented the carbon emission trading system (CETS) since 2011. In October of that year, the National Development and Reform Commission (NDRC) issued a *Notice on Carrying Out the Pilot Work of Carbon Emission Trading,* which approved several regions to carry out the pilot work. Based on the National 12th Five-Year Plan, the pilot CETS comprehensively started in 2013, covering two provinces and five cities: Beijing, Chongqing, Hubei, Shanghai, Tianjin, Guangdong, and Shenzhen (Jiang et al., 2014; Munnings et al., 2016; Wu et al., 2014). By 2020, the intensity of carbon emissions in China had decreased by 48.4% compared to 2005, which exceeded the target of a 40–45% reduction promised to the international community (Sun & Zhan, 2022). Moreover, China has reduced its carbon emissions by

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https://doi.org/10.1016/j.asieco.2023.101597
Received 23 April 2022; Received in revised form 15 February 2023; Accepted 2 March 2023
Available online 4 March 2023

approximately 5.8 billion in more than a decade, reversing the rapid growth of carbon emissions. Existing empirical studies show that, through the implementation of CETS, market players' enthusiasm in policy pilot areas to reduce carbon emissions has been significantly stimulated, the green efficiency of enterprises has effectively improved, and environmental performance has improved (Li et al., 2021; Liu & Li, 2022; Shao et al., 2022; Zhang et al., 2022; Zhao et al., 2022).

CETS encourages enterprises with low technological transformation costs to sell their carbon emissions quotas by determining their carbon emissions quotas, creating a carbon trading market, and decreasing enterprise carbon emissions by relying on technological innovation in the green field. This is meant to drive the entire market trading body to optimize the allocation of carbon emission quotas and attain the emission reduction goal at the lowest cost. The core of the policy lies in enterprises' green innovation ability. Entrepreneurs make full use of their pioneering innovative spirit, transforming knowledge and insight into production output, and driving the recombination of production factors. This can then generate excess profits and significantly improve the development efficiency of relevant fields (Schumpeter & Backhaus, 2003; Shen et al., 2023; Song et al., 2023a,b; Sone et al., 2013b). Studies have proven that by marketizing carbon emission rights, enterprises can decrease the demand intensity for emission quotas through the intermediary role of green innovation and technological advancement to realize a win-win situation between enterprise and green benefits (Chen et al., 2020; Yan et al., 2020; Zhou et al., 2020). In this process, the regulatory policy instrument can expand the total factor productivity of enterprises by encouraging technical innovation and optimizing resource allocation (Ren et al., 2019), indicating that enterprises with higher technological innovation ability can occupy a dominant position in carbon emission trading (CET). Consequently, the operation of CETS has the potential to promote enterprise green innovation.

Compared with the green utility model (GUM), the technological innovation form of green invention (GI) is a more effective way to reduce enterprise carbon emissions and the demand for carbon quotas. Therefore, the promotion of CETS to different types and degrees of enterprise innovation will be heterogeneous. Simultaneously, in terms of enterprise ownership, different types of enterprises respond differently to environmental regulation (ER). Thus, the impact of CETS will also be heterogeneous at the enterprise level.

Therefore, this study aims to investigate the impact of the CETS on enterprise green technology, the heterogeneous impact on different types of green technology, and the impact of the CETS across different ownership types. This study's results could offer theoretical guidance and policy proposals for the further implementation and promotion of CETS, augmenting the important role of market-oriented policies and promoting enterprise green technological innovation.

The remainder of this paper is organized as follows. Section 2 presents the literature on the impact of ER on enterprises' green innovation and CETS. Section 3 presents the theoretical conceptual framework and hypotheses. Section 4 presents the research design. Sections 5 and 6 present the results of the empirical analysis and the conclusion and policy implications, respectively.

2. Literature review

This section summarizes the literature on the influence of ER on green innovation and CETS. A large body of literature adheres to the "Porter Hypothesis"[1] of ER and concludes that reasonable ER can promote technological innovation (Peng et al., 2021; Porter, 1991; Porter & van der Linde, 1995; Zhang et al., 2018). For example, Qi et al. (2018) employ green patent (GP) data of listed companies (LC) in the Shanghai and Shenzhen stock markets and the difference-in-differences (DID) method to support the Porter Hypothesis. Tao et al. (2021) constructed indicators to define green innovation activities using the DID method and found that ER plays a significant role in encouraging the expansion of GP applications for enterprises. Using the LC data of A-share heavy pollution industries as a sample, Li and Xiao (2020) found that effective ER "forced" the advance of companies' green innovation capability. However, from the perspective of technological innovation costs, many scholars have found that ER has a strong blocking effect on technological innovation. Using provincial panel data, Jiang and Lu (2011) proved that ER has no significant positive influence on China's technological innovation. Based on LC data from 31 provinces in China from 1990 to 2018, Chen et al. (2021) find that ER leads to a decline in the number of enterprises' GP, failing to promote innovation. Zhang et al. (2011) built a mathematical model between the intensity of ER and the advancement of enterprise manufacturing technology and indicated that there is a "U" relationship between the two. This suggests that a weak ER intensity reduces enterprises' production technology progress rates. Using national and regional data, Shen and Liu (2012) reveal that only when the intensity of ER crosses a threshold can it have a positive impact on enterprise technological invention.

CETS research was conducted from two perspectives. Some scholars have evaluated the policy impact of the CETS from the perspective of the emissions decrease effect. Employing the DID model, researchers have found that CETS can effectively decrease carbon emissions (Hu et al., 2020b; Hu et al., 2020c; Ma et al., 2022; Shen et al., 2017; Wang et al., 2019; Xuan et al., 2020). Dong et al. (2019) used the DID model and an improved data envelopment analysis model and indicated that CETS can realize the Porter Hypothesis in the long run. Zhang et al. (2021) employed a synthetic control method to estimate the reduction effect of carbon emissions and found that CETS played a substantial role in restraining the growth of carbon emissions in the pilot area. Using China's provincial panel data, Yang et al. (2022) find that CETS can effectively promote emissions reduction and that there are regional spillover effects in its promotion effect. Many scholars have explored the CETS mechanism and analyzed the influence of relevant policies on enterprise innovation. Lyu et al. (2020) and Liu and Sun (2021) find that the number of low-carbon technological innovations increased significantly under the CETS. Wei and Ren (2021) and Lv and Bai (2021) concluded that the CETS could promote enterprises' technological innovation in the green field from the viewpoint of carbon prices. By constructing a mathematical model and using LC patent

[1] The "Porter Hypothesis" suggests that appropriate environmental regulation will lead to more innovative activities in enterprises, which will increase their productivity and profitability, thereby offsetting the costs of environmental protection.

data, Song et al. (2021) and Hu et al. (2020a) found that CETS has a strong incentive influence on enterprise green innovation. Nevertheless, several scholars have found that enterprises considering cost-benefit will turn to decreasing production rather than promoting green innovation to attain a decrease in release, suggesting that government policy is not helpful for green innovation (Chen et al., 2021; Zhang et al., 2019).

Previous research has analyzed the policy impact of CETS from multiple perspectives. However, these studies have several limitations. First, there is a large amount of literature on the connection between ER and enterprise technological innovation in green fields in terms of policy evaluation. However, the number of studies analyzing the implementation of CETS in recent years is still relatively limited. Second, although some studies use policy effect assessments to test the effect of CETS, most use macro data to examine the emission-lessening impact. In contrast, the number of studies based on a micro perspective and analyzing the policy's impact on enterprise innovation remains small. Third, in studies on the impact of the CETS on enterprise green innovation, only a few analyze the heterogeneous impact on enterprise innovation by innovation type and enterprise ownership.

Given the limitations of previous studies, this study makes two major contributions to existing literature. First, it examines the effect of CETS on enterprises' green technological innovation, which could provide valuable empirical evidence of the influence of relevant policies. Second, this study distinguishes the categories of green innovation and enterprise ownership and explores the impact of CETS as well as the heterogeneous impact across state-owned enterprises (SOEs) and non-state-owned enterprises (NSOEs).

3. Theoretical analysis and hypothesis proposal

3.1. CETS and enterprise green innovation

To promote the construction of a beautiful China and fulfill domestic and international commitments, exploring institutional incentives to assume primary responsibility and effectively stimulate the enthusiasm of central microbodies for emission reduction is essential for the formulation of relevant policies. As a public matter, serious market failures will occur if environmental governance is addressed only by the main body of market enterprises. If the government intervenes to assist in management and control, it will also lead to low governance efficiency, owing to the lack of comprehensive information on enterprise emission reduction costs. Therefore, by creating a CET market, taking the carbon emissions market price as the signal, and making the emissions reduction cost information of enterprises transparent, we can promote a market mechanism to regulate the carbon emissions behavior of enterprises (Fu et al., 2022; Zhang et al., 2015; Zhu et al., 2022). When the technological innovation cost of reducing carbon emissions is high and an enterprise cannot achieve technical emission reduction at a low cost in a short time, it will choose purchase ratios to meet the emission demand. By contrast, enterprises with higher emission reduction technologies can effectively use technological advantages to reduce emission demand, sell excess carbon emission quotas, and maximize the development of enterprise benefits (Zhou & Wang, 2022). Enterprises with higher emissions reduction technology costs are faced with an urgent need to buy more quotas, which results in a significant increase in production costs. The minute the marginal income gradually approaches the marginal cost, they will consider halting production, relocating, or local green innovation. For enterprises in the market, choosing to stop production or relocate means that a specific investment, based on a previous enterprise strategy, becomes invalid and a sunk cost (Liu et al., 2022). Therefore, based on cost-benefit considerations, most enterprises are reluctant to give up their original production base because of path dependence. Under such pressure, enterprises are forced into a path of green innovation (Du et al., 2021). Simultaneously, enterprises with a lower cost of emission-reduction technology have dividends in transferring quotas owing to the emergence of the quota-trading market, which provides more incentives to continue developing and innovating green technologies and impedes the virtuous circle of green carbon reduction in the region (Zhu et al., 2019). Based on this analysis, this study suggests the following:

H_1: Pilot CETS have a significant influence on enterprise technological innovation in the green field.

3.2. The CETS and green innovation

The green technological innovation capability of companies is mainly represented by GI and GUM patents (Liu et al., 2021b). Invention patents indicate new technical resolutions for products, approaches, or advances, whereas utility model patents refer to a new pragmatic technical scheme for the figure, construction, or blending of products (Cui et al., 2022; Liu et al., 2021a). From the perspective of creativity and technicality, invention patents have a higher degree of innovation and greater value, whereas utility model patents focus more on practicality and have relatively weak technological requirements (Liu et al., 2021a). Regarding the demand for enterprises to reduce carbon emissions, innovation in related technology fields will have a better emission reduction effect, which is an urgent and innovative way to resolve the issue of carbon release and reduce the demand for quotas. Therefore, the influence of the CETS on green technological innovation is principally reflected in invention patents with higher innovation values (Ren et al., 2020). Therefore, this study proposes the following hypothesis:

H_2: The influence of CETS on enterprise innovation in the green field is primarily reflected in invention patents with a higher degree of innovation and value.

3.3. Different types of enterprise ownership and enterprise green innovation

The type of enterprise ownership has different effects on innovation incentives (Fang et al., 2021). SOEs are relatively large and bear essential economic and social responsibilities in economic operations. Therefore, the incentive effect of emissions reduction under the CETS will be more significant (Pan et al., 2021). However, SOEs usually enjoy support from national finance, taxation, financing, and other areas (Hu et al., 2021). Thus, they have a solid foundation for exploring green technological innovations (Mbanyele & Wang, 2022). By contrast, the scale effect of private enterprises is comparatively small. In addition, the economic foundation of enterprises' technological inventions is relatively weak. Therefore, under the CETS, the incentive to purchase excess quota is relatively strong under relatively stable costs. Accordingly, this study suggests the following hypothesis:

H_3: Compared with NSOEs, pilot CETS is more favorable for giving impetus to the green innovation of SOEs.

4. Research design

4.1. Data description

The A-share LC in the Shanghai and Shenzhen stock markets from 2002 to 2018 are taken as the research object in this study. We exclude samples with return on assets (ROA) of less than 0 and greater than 1, abnormal transactions, and serious missing values. In addition, given that green technological innovation is mainly from the manufacturing industry, this study excludes financial and insurance LC in the industry screening process and only retains LC in the industrial sector. The data sources used in this study were primarily comprised of two parts. First, the enterprise innovation data were obtained from the State Intellectual Property Office. Second, corporate characteristic data are collected from the China Stock Market & Accounting Research. After matching the data, 7171 observations were obtained. We winsorized the main continuous variables by 1% to eliminate the impact of outliers.

When screening the innovation data of the LC, the GP data were extracted based on the "International Patent Classification Green Inventory" launched by the World Intellectual Property Organization (WIPO) in 2010, which follows the United Nations Framework Convention on Climate Change, dividing the GP into seven categories. These include transportation, waste management, energy conservation, alternative energy production, administrative regulations or design aspects, agriculture or forestry, and nuclear power generation. To identify the degree of innovation and value levels of diverse types of GP, GP patents were divided into GI and GUM patents. It is commonly assumed that the degree of innovation in GI patents is higher than that in GUM patents (Qi et al., 2018).

In 2011, the NDRC issued an *Announcement on the Pilot Work of the CET*, and seven provinces and cities were permitted to conduct the pilot project. Since then, under the guidance and support of the central and local governments, all regions have actively promoted and conducted research and practice in relevant aspects, completing work on scheme design, data verification, quota allocation, organization construction, and other aspects of CETS. They gradually implemented and expanded the development of green exploration in relevant fields, and successively launched the CET market in 2013. Given that there is a particular exploration cycle between the approval of the pilot program and the start of trading, this study takes the launch of the CET market in each pilot area in 2013 as the time node for the operation of the policy to examine the inducing influence of the CETS on the green technology innovation of LC.

4.2. Index construction

This study considered the number of GP applications of LC as an explanatory variable. On the one hand, the GP application data of LC can directly reflect their innovation output in the preservation of environmental aspects, consistent with the idea of studying the innovation incentives of the CETS. Simultaneously, patent application data differ according to the quantity of research and development (R&D) investment. It can be classified according to the classification standard of the WIPO, and it is helpful to divide the innovation level of LC to facilitate a more in-depth analysis. However, given that the patent application process takes a long time, if the granted patent data are used as an indicator to measure the enterprise innovation level, there will inevitably be a certain lag, which is also inconvenient for examining the timely influence of the pilot policy on enterprises' green innovation activities.

This study divides the index of the number of GP applications of enterprises, which is the explanatory variable, into logGreen, logGreeninvention, and logGreenutilitymodel, to investigate the impact of CETS on the green innovation of enterprises with diverse degrees of innovation and value levels. Moreover, this study used logarithmic processing for the GP application data of the LC. To avoid the impact of the zero value, this study adopted the method of adding one to the number of GP applications and then taking the logarithm. The number of GUM patents is dealt with in the same manner as the number of GI patents.

Enterprise characteristics were selected as control variables. The first is the enterprise size (logCompanySize). Research shows that enterprise size may significantly influence innovation (Bu et al., 2020; Li & Zheng, 2016). In enterprise development, the division of labor is becoming increasingly refined, the degree of specialization is gradually improving, and the size of the enterprise is expanding. Sustainable development requires that larger enterprises make strategic choices. To ensure the sustainability of their development, enterprises make more stable investments in R&D to ensure that their technology is always at a high level in the industry. We log the sizes of the LC and use these figures to capture enterprise size. The second category is enterprise liabilities (logDebts). Previous research shows that the quantity of enterprises' bank loans can be used to measure market investors' credit evaluations (Meuleman & De Maeseneire, 2012; Wang et al., 2017). Moderate debt management is positively significant for enterprises to compensate for a lack of funds, make better use of funds, improve technical levels, and implement innovation. Accordingly, this study uses the logarithm of the total liabilities of the LC to measure the enterprises' liabilities. The next most important factor is ROA. Enterprise business performance directly impacts R&D inputs and outputs. Enterprises with better business performance have sufficient technology investment funds and relatively stable innovation environments (Xu & Cui, 2020). The ROA rate is captured as the proportion of net profit to total assets. The next is enterprise capital intensity (logCap_inten). In general, capital-intensive enterprises adopt more advanced technology and equipment in the production process and invest more time and energy in training employees, which means that enterprises with higher capital intensity can attract a concentration of highly skilled workers, resulting in a stronger foundation for R&D. We used the logarithmic form of the ratio of total assets to operating income to measure enterprises' capital intensity. The fifth is the enterprise's wealth creation ability (log TobinQ). If the value created by an enterprise for society is greater than its input costs, it is generally considered to have a strong sense of innovation. Therefore, we take the logarithmic form of TobinQ of LC as the control variable to estimate corporations' social wealth-creation capabilities.

Table 1 presents the descriptive statistics for the main variables. This shows that the logarithm of the number of GP applications of corporations is 0.318, and the standard deviation is 0.702, which means that significant variances exist in the number of GP applications among the sample LC, which is also reflected in the number of applications for GI and GUM patents of LC. Moreover, compared with the number of GI and GUM patents, the average number of GI patents is 0.202, whereas the average number of GUM patent applications is 0.196, which indicates that there are more invention patent applications with a higher innovation degree and value level.

4.3. Econometric model

This study tests whether CETS can induce green technological innovation in enterprises. In a natural experimental scenario, this pilot policy could effectively overcome endogeneity. This study uses the DID model to examine the impact of the policy, taking seven provinces and cities that successively launched the CETS in 2013 as the treatment group and other cities that have not implemented CETS, such as Henan, Hebei, Shandong, Shanxi, and other provinces and cities, as the control group, to conduct an empirical evaluation of the policy effect of the CETS. The model is as follows:

$$\log Green_{it} = \beta_0 + \beta_1 treat_r \times time_t + \rho X_{it} + \mu_{jt} + \varepsilon_{ijrt}$$

In the model, $logGreen_{it}$ is the dependent variable, which refers to the green technology innovation of LC i in year t, and is measured by the logarithm of the number of GP applications. $treat_r$ indicates a dummy variable of the pilot area of CETS. If the province was the pilot area of CETS in 2013, the value of $treat_r$ is 1 or the value is 0. $time_t$ is the dummy variable before and after the policy pilot. If it is in the pilot period of CETS, that is, 2013 or after 2013, the value is 1 or 0. X_{it} is the control variable matrix of the economic characteristics of LC, including logCompanySize, logDebts, ROA, and logTobinQ. The model lists the entire number of GP applications of LC. To examine the impact of government environmental policy on the technological innovation of enterprises with different levels of innovation and value, we also investigate the GI and the GUM patent, respectively. In the benchmark regression, the coefficient β_1 of $treat_r \times time_t$ is this study's focus, which reflects the influence of this policy on the number of GP applications of LC after DID between the pilot and non-pilot areas before and after the implementation. If β_1 is significantly positive, it suggests that the pilot of CETS will help promote the green technology innovation of LC in relevant regions. In addition, to obtain more robust regression results, the regional time effect is also controlled in the model. In the model, ε_{ijrt} is a random error term.

5. Results

5.1. Results of the impact of the CETS on green technology innovation in China

Table 2 lists the results of the benchmark regression model. The dependent variables in Columns (1) and (2) are the total number of applied GP; those in Columns (3) and (4) are the number of applied GI patents; and those in Columns (5) and (6) correspond to the number of applied GUM patents. In all columns, the time-fixed effects are controlled. Columns (1), (3), and (5) add the control variables, whereas Columns (2), (4), and (6) do not.

The regression results show that the coefficients of DID are positive at the 1% significance level, demonstrating that the application of the CETS promotes green technological innovation in listed enterprises. In particular, in Columns (1) and (2), the coefficient of $treat_r \times time_t$ is 0.159, suggesting that after the implementation of CETS, the total number of GP applications for LC increased by nearly 16%. This means that the CETS has given impetus to the green technological innovation of the LC.

The results are consistent with the conclusions of Hu et al. (2020b) and Hu et al. (2020c). The former finds that CETS can give impetus to the increase in innovation and the improvement of innovation quality. The latter shows that the ER systems reduced carbon release in the pilot areas by approximately 15.5% compared with the non-pilot areas. Moreover, the results indicated that policy influence is primarily achieved by enhancing technical efficiency. Thus far, $\mathbf{H_1}$ has been supported.

The results in Columns (3)–(6) indicate that the coefficients of $treat_r \times time_t$ are significantly positive. However, for GI patents, after controlling for the fixed effects of region, time, and other factors, the coefficient is 0.112, whereas, for utility model patents, the

Table 1
Summary Statistics.

VarName	Obs	Mean	SD	Min	Median	Max
logGreen	7171	0.318	0.702	0.000	0.000	6.026
logGreeninvention	7171	0.202	0.536	0.000	0.000	5.464
logGreenutilitymodel	7171	0.196	0.520	0.000	0.000	5.347
logCompanySize	7171	21.327	1.084	19.228	21.205	26.438
ROA	7171	0.057	0.039	0.000	0.050	0.188
logDebts	7171	20.298	1.440	17.366	20.242	26.204
logCap_inten	7171	0.604	0.520	-0.794	0.596	3.577
logTobinQ	7171	0.618	0.422	-0.078	0.537	1.962

Table 2
Impact of the CETS on enterprises' applied green patents.

VARIABLES	(1) logGreen	(2) logGreen	(3) logGreeninvention	(4) logGreeninvention	(5) logGreenutilitymodel	(6) logGreenutilitymodel
did	0.159 * **	0.159 ***	0.113 * **	0.112 * **	0.099 * **	0.099 ***
	(6.09)	(6.28)	(5.52)	(5.66)	(5.06)	(5.18)
logCompanySize		0.061 ***		0.069 ***		0.014
		(3.34)		(4.76)		(1.00)
logDebts		0.082 ***		0.045 ***		0.071 ***
		(6.55)		(4.67)		(7.84)
ROA		0.717 ***		0.598 ***		0.431 **
		(2.89)		(3.03)		(2.41)
logCap_inten		-0.000		0.003		0.009
		(−0.01)		(0.21)		(0.77)
logTobinQ		0.020		0.030		-0.007
		(0.80)		(1.62)		(−0.38)
Constant	0.284 ***	-2.722 ***	0.178 ***	-2.262 ***	0.176 ***	-1.578 ***
	(31.83)	(−10.97)	(26.48)	(−11.13)	(26.67)	(−7.92)
Observations	7171	7171	7171	7171	7171	7171
R-squared	0.024	0.081	0.020	0.075	0.018	0.063

Note: t-statistics in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ (the same below).

coefficient is 0.099. This illustrates that the CETS pilot policy has a greater influence on GI patent applications than on GUM patent applications. This view was verified using a robustness test.

This study selected control variables, including enterprise scale, enterprise liabilities, ROA, and enterprise social wealth creation ability, to control for the impact of relevant economic factors on enterprise technological innovation. The regression results indicate that enterprise size, debt, and ROA have more positive impacts on green technological innovation, which is in line with the aforementioned theoretical expectations. The other control variables did not have a significant impact on enterprises' green innovation.

5.2. Parallel trend test of the impact of the CETS on green technology innovation of the LC

We also conducted a parallel trend test to ensure unbiased estimation results. Theoretically, there should be no systematic difference between the treatment and control groups before CETS. Therefore, the time trends in the two groups were consistent. After the implementation of the CETS, the trends of the two groups were broken, and many changes in the trend of green technological innovation appeared. The parallel trend results, which reflect the dynamic effect of CETS on the number of green technology innovations in the LC, are shown in Fig. 1. The horizontal axis represents the year, where zero is the starting year when the policy was implemented, namely 2013, whereas the vertical axis represents the estimated value of the treatment effect coefficient.

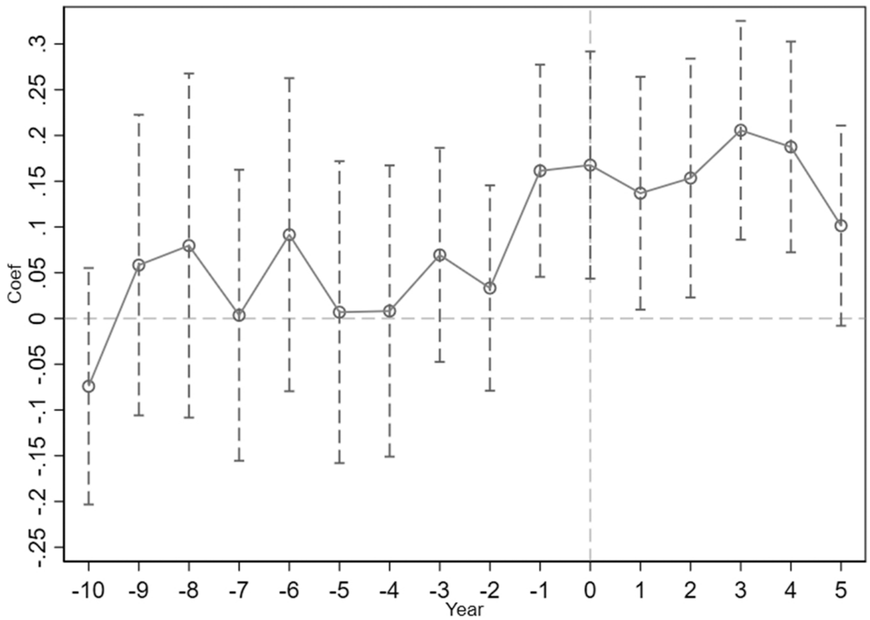

Fig. 1. Parallel trend test of the impact of the CETS on green innovation of enterprises.

Fig. 1 illustrates that the estimated coefficients of β_1 for the nine years before the pilot operation in 2013 were not significant, whereas the estimated coefficient of β_1 for 2012 was significant. A possible reason is that because of the issuance of the pilot notice in 2011, seven provinces and cities were approved to implement the pilot CETS, which had a certain influence on the strategy adjustment of enterprises in R&D. LC in the relevant regions immediately changed their green technology innovation strategies and strengthened R&D investment. Thus, the number of green technology patent applications increased to a certain extent in the second year (2012). Therefore, it can be concluded that the parallel trend assumption of DID estimation can be satisfied. After the pilot function of the CETS in 2013, the number of GP applications for LC in the pilot provinces and cities showed an apparent increasing trend. Specifically, after the pilot policy, the cross-coefficient was positive, whereas it was not before the pilot policy. The above results illustrate that CETS has induced green technological innovation in the LC, and the test results correspond to the benchmark regression results.

5.3. Robustness check of the impact of the CETS on green technology innovation

Given that other unobservable factors may induce an increase in the number of GP applications, which may interfere with the regression results, this study replaces the explained variables in the robustness test. The number of enterprise patent applications was used to measure green technological innovation, and the effect of CETS on green technological innovation was retested through panel regression. Simultaneously, because the sample data focus on the number of GP applications of enterprises, overdispersion can easily occur. Consequently, to guarantee the robustness of the results, we use a panel negative binomial regression. The regression results are presented in Table 3. Columns (1), (3), and (5) list the panel regression results and Columns (2), (4), and (6) list the negative binomial regression results.

For the entire number of GP applications, after using negative binomial regression, the coefficient of $treat_r \times time_t$ is positive at the significance level of 1%. For GI patents of enterprises, the coefficients of $treat_r \times time_t$ are significantly positive at the level of 5%, which demonstrates that after considering the focus of the number of enterprise patent applications, the pilot policy of CETS still has a strong inducing effect on the increase of the total number of GP applications and GI patent applications of LC. However, in the robustness test, the regression results of GI patents of enterprises are not significant, and the significance is lower than the benchmark regression, which proves the heterogeneity analysis in the regression results above. It also indicates that the induced influence of the pilot policy on corporation green technology innovation mainly acts on invention patents with a higher innovation degree and value level and has no significant effect on the increase of GUM patent applications. Thus far, $\mathbf{H_2}$ has been verified.

5.4. Placebo test

The increase in the level of enterprises' green innovation could result from sources other than CETS. To clarify the true effectiveness of this ER policy, a placebo test should be conducted, using a dummy policy as a placebo, and if enterprises' green technology innovation still improves after applying the placebo, it indicates that it is not the CETS that promotes enterprises' technology innovation. Using 2008 as the virtual time for policy implementation, provincial and municipal areas that did not implement CETS between 2008 and 2011 were used as the experimental group. In this way, we obtain a dummy DID variable, which is a placebo, and run regressions using the dummy DID data. The principle is to take the virtual policy as a "placebo" and conduct experiments to determine

Table 3
Robustness test.

VARIABLES	(1) Green	(2) Green	(3) Green invention	(4) Green invention	(5) Green utility model	(6) Green utility model
did	0.560 *	0.318 * **	0.468 * *	0.314 * *	0.092	0.118
	(1.79)	(2.72)	(2.49)	(2.23)	(0.58)	(0.87)
time	-0.587 * *	-0.296 * **	-0.360 * *	-0.179	-0.226 *	-0.309 * *
	(−2.21)	(−2.75)	(−2.26)	(−1.40)	(−1.68)	(−2.39)
treat		-0.053		-0.093		0.059
		(−0.39)		(−0.54)		(0.33)
logCompanySize	0.379 *	0.188 * *	0.156	0.202 * *	0.223 * *	0.175 *
	(1.69)	(2.43)	(1.15)	(2.14)	(1.96)	(1.84)
logDebts	0.153	0.004	0.045	0.034	0.108	-0.046
	(1.01)	(0.07)	(0.49)	(0.47)	(1.41)	(−0.64)
ROA	1.054	0.638	-0.186	1.275	1.240	1.778
	(0.38)	(0.69)	(−0.11)	(1.17)	(0.88)	(1.55)
logCap_inten	0.034	-0.132	-0.037	-0.090	0.072	-0.100
	(0.13)	(−1.55)	(−0.23)	(−0.86)	(0.52)	(−0.94)
logTobinQ	0.136	0.157 **	0.005	0.035	0.131	0.286 ***
	(0.66)	(2.02)	(0.04)	(0.37)	(1.26)	(3.03)
Year	0.132 ***	0.132 ***	0.096 ***	0.128 ***	0.036	0.145 ***
	(2.78)	(9.02)	(3.37)	(7.40)	(1.49)	(7.94)
Constant	-276.552 ***	-269.935 ***	-197.685 ***	-263.326 ***	-78.867 *	-295.086 * **
	(−2.97)	(−9.30)	(−3.53)	(−7.67)	(−1.67)	(−8.15)
Observations	7171	3871	7171	3090	7171	3208
R-squared	0.016		0.015		0.012	
Number of Stkcd	1080	510	1080	402	1080	412

whether the implementation of the virtual policy is effective. If this is the case, the effectiveness of the real policy should be investigated. The results of the placebo test in Table 4 suggest that the DID coefficient is not significant for GP applications and GI or GUM patents, demonstrating that the results of basic returns are not biased. After eliminating the impact of the pilot CETS policy, there is no difference in green technological innovation between the treatment and control groups. This further verified the reliability of the main conclusions of this study.

5.5. Heterogeneity analysis on enterprise ownership

An enterprise's ownership attributes affect its management and strategic choices, thus affecting its R&D investment and technological innovation. To explore the effect of the CETS on different types of enterprises, this study decomposes the overall sample into two subsamples: SOEs and NSOEs Table 5.

After controlling the fixed effect, in terms of the application number of GP, GI patents, and GUM patents, the DID coefficient of $treat_r \times time_t$ is significantly positive for SOEs and NSOEs. However, in comparison, the DID coefficient of SOEs is generally higher than that of NSOEs, which indicates that the induced influence of the pilot policy on enterprise green technology innovation has heterogeneity across enterprise ownership types. Specifically, the pilot policy can endorse the green technology innovation of SOEs and has a more considerable impact on GI innovation. Thus far, $\mathbf{H_3}$ has been verified.

6. Conclusions and policy implications

Using the applied GP data of A-share LC in Shenzhen and Shanghai, this study employs the DID model to analyze the impact of CETS on enterprise green innovation. The results demonstrate that the pilot CETS promotes green innovation in LC. Second, compared with GUM patents, pilot CETS is more favorable for giving impetus to GI patents. Third, compared with NSOEs, pilot CETS is more favorable for promoting SOEs' green innovation.

This study makes the following policy suggestions: First, China should gradually expand the pilot implementation of the CETS nationwide by summarizing the pilot experience and establishing characteristic cases, effectively driving national innovation and transformation, and offering technical support and ensuring the realization of the targets of "carbon peak" in 2030 and "carbon neutralization" in 2060. The government recognized this and announced that in July 2021, trading in the national CET market in the power generation industry would be launched at an appropriate time. On July 15, 2021, the Shanghai Environment and Energy Exchange announced that according to the overall arrangement of the state, national carbon emissions trading would open on July 16, 2021. Second, CETS plays a larger role in giving impetus to invention patents with higher levels of innovation and value. Therefore, it can be predicted that the quality of innovation in Chinese enterprises will further improve after expanding the application of the transaction pilot policy in the future. Countries should actively promote the implementation of policy support and material guarantees in the relevant fields. Third, China should provide targeted support to enterprises with different ownership types when implementing CETS. While continuing to fully utilize the positive driving role of SOEs in the field of green innovation, certain policy support should be provided to NSOEs, especially small- and medium-sized high-tech corporations, so that the market incentive mechanism can provide ample play to its role and unleash its potential in the green innovation field.

This study initially examined the impact of the CETS on enterprises' green innovation. However, there are still some aspects that need to be improved and expanded. First, in analyzing the mechanism of CETS for promoting enterprises' green innovation, this study focuses more on interpreting it from an economic theory perspective but fails to prove it in detail through empirical analysis using, for example, the mediating effect model. This should be improved and supplemented in future studies. Second, to analyze the heterogeneity of impact, this study interprets the results from an economic theory perspective, and we still need to conduct empirical tests to

Table 4
Placebo test.

VARIABLES	(1) logGreen	(2) logGreen invention	(3) logGreen utility model
dida	0.005	0.012	0.008
	(0.13)	(0.46)	(0.35)
logCompanySize	0.068 **	0.065 * **	0.023
	(2.19)	(2.59)	(1.05)
logDebts	0.029	0.011	0.030 **
	(1.31)	(0.61)	(2.05)
ROA	-0.283	-0.233	-0.228
	(−0.73)	(−0.81)	(−0.79)
logCap_inten	0.035	0.038 **	0.020
	(1.50)	(2.17)	(1.21)
logTobinQ	0.103 ***	0.073 ***	0.057 **
	(2.76)	(2.75)	(2.01)
Constant	-1.847 ***	-1.507 ***	-0.988 ***
	(−5.03)	(−5.26)	(−3.53)
Observations	2075	2075	2075
R-squared	0.054	0.048	0.039

Table 5
Heterogeneity analysis on enterprise ownership.

VARIABLES	(1) SOE logGreen	(2) NSOE logGreen	(3) SOE logGreen invention	(4) NSOE logGreen invention	(5) SOE logGreen utility model	(6) NSOE logGreen utility model
did	0.246 ***	0.141 ***	0.199 ***	0.096 ***	0.107 **	0.095 ***
	(3.38)	(5.26)	(3.10)	(4.69)	(2.42)	(4.54)
logCompanySize	0.211 ***	0.035 *	0.191 ***	0.047 ***	0.078 **	0.018
	(4.35)	(1.66)	(4.48)	(2.87)	(2.50)	(1.02)
logDebts	-0.036	0.107 * **	-0.059 *	0.066 ***	0.012	0.084 ***
	(−0.98)	(7.95)	(−1.79)	(6.59)	(0.54)	(8.41)
ROA	-0.693	1.076 * **	-0.295	0.871 ***	-0.738 **	0.712 ***
	(−1.18)	(3.86)	(−0.56)	(4.08)	(−2.13)	(3.36)
logCap_inten	-0.155 ***	0.050 * **	-0.137 ***	0.047 ***	-0.056 ***	0.034 **
	(−4.30)	(2.79)	(−4.19)	(3.65)	(−2.62)	(2.51)
logTobinQ	0.007	0.034	0.027	0.033	-0.031	0.012
	(0.14)	(1.16)	(0.66)	(1.50)	(−0.93)	(0.55)
Constant	-3.412 ***	-2.729 * **	-2.657 ***	-2.261 ***	-1.698 ***	-1.956 ***
	(−7.68)	(−7.84)	(−7.12)	(−8.07)	(−5.29)	(−6.57)
Observations	1467	5704	1467	5704	1467	5704
R-squared	0.155	0.068	0.128	0.065	0.111	0.061

determine what factors lead to different impacts of the CETS on different types of enterprises' green innovation. Third, we replaced the explained variables with a robustness test. To enhance robustness, it can be supplemented with other tests, such as considering and excluding the impact of other policies on enterprises' green innovation and adding interaction terms for grouping variables and time dummy variables in the regression to judge whether the CETS policy promotes innovation.

Conflict of interest

None.

Data Availability

Data will be made available on request.

Acknowledgments

This work was supported the National Natural Science Foundation of China (72003012;71803082), and the Youth Project of Jiangsu Social Science Foundation (20EYC001).

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