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Research article

Does the energy-consuming right trading system promote green technology innovation of enterprises?

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A R T I C L E I N F O

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A B S T R A C T

To achieve the high-quality economic development, China implemented the energy-consuming right trading system, aiming to leverage market-oriented environmental regulations to drive enterprises' green transformation. The purpose of this paper is to figure out whether the energy-consuming right trading system has promoted the green technology innovation of enterprises. Using the empirical analysis method, the paper samples 718 listed industrial enterprises from 2014 to 2019 and constructs a DID model to assess the impact. The results indicate a significant promotion of green technology innovation by the trading system. Non-state-owned and non-high-energy-consuming enterprises exhibit greater sensitivity to the energy-consuming right trading system. Additionally, the institutional environment plays a regulatory role in promoting green innovation of enterprises. Furthermore, it is found that the energy-consuming right trading system influences enterprises by enhancing capital allocation efficiency. The findings are valuable for the government in shaping energy policies and fostering the green transformation of enterprises.

1. Introduction

The transformation of enterprises' energy structure and optimization of innovation structure are crucial for the country to actively promote the energy revolution and successfully achieve the carbon peak and neutrality targets. Enhancing enterprises' green technology innovation capabilities not only improves investment efficiency and market competitiveness, but also facilitates the transformation of the national economic development model to "green and low-carbon" development. Due to a challenging market environment, limited capital investment, and other factors, the green innovation ability of enterprises in China is generally weak, and their environmental performance needs to be optimized [1–3]. Concurrently, with the proposal of the "double carbon" goal in China, the energy-consuming right trading system has been piloted in numerous cities to manage energy rights. In an era of growing resource scarcity, the development mode of extensive economic growth becomes challenging to sustain. In response, China selects pilot provinces to implement market-oriented environmental regulation policies. The government directs enterprises to augment capital investment through the implementation of the new system, enhances the sensitivity of enterprises' investment to opportunity, and optimizes internal capital allocation efficiency. Nevertheless, scholars hold diverse perspectives on the impact of this industrial policy. The paper aims to elucidate the impact of the policy on green innovation and conducts research from both theoretical and empirical perspectives, attempting to answer: does the energy right trading system influence green technology innovation in enterprises?

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Through what mechanism can the innovating effect be exerted?

Well-crafted industrial policies can establish crucial conditions for fostering innovation. Scholars have examined the influencing factors of green technology innovation, including marketization policy [4], intellectual property protection [5], decision-making objectives in green manufacturing [6], and environmental regulation [7,8]. Using natural experiments is a favorable approach to investigate the correlation between environmental regulation policies and enterprises performance. Specifically, with the introduction of the industrial policy of energy-consuming right trading, the academic community is deeply concerned about how this policy, addressing issues through property rights definitions, impacts enterprises' green innovation. As a new system in China, the energy-consuming right trading system bears remarkable similarity to the EU's white certificate system. Both systems direct enterprises to enhance their responsibilities for energy efficiency by introducing market trading mechanisms and environmental regulation policies related to warrant trading.

In the relevant documents with China as the research background, scholars have analyzed the system of energy-consuming right from the aspects of legal definition, institutional role, and institutional premise. According to Zhang [9], compared with other similar systems, this system of has its uniqueness. Additionally, he defined the legal attribute of energy-consuming right and examined the initial confirmation behavior of energy consumption. Han and Huang [10] believed that this system possesses control and incentive function, contributing to its decisive role in allocating energy elements. Recognizing the exclusive, tradable, and other property characteristics of the energy-consuming right is crucial. Tong et al. [11] emphasize that the fundamental principle of the system is to allocate energy-consuming right quotas fairly and effectively. Urgently guiding enterprises to enhance energy consumption efficiency and achieve the target of controlling the total energy-consuming cost is imperative.

In studies focusing on developed countries, scholars contend that the impacts of the white certificate system center on social, environmental, and economic effects. Investigating the nature and scale of the transaction costs borne by the responsible party in the tradable white certificate system, Mundaca [12] discovered that the white certificate system yields a net positive social effect by not only reducing external costs but also fostering technology transfer and cooperation. Furthermore, Mundaca and Neij [13] developed a comprehensive framework to assess the impact of the white certificate policy, covering energy conservation, environmental protection, cost benefits, transaction costs, and technological changes. This framework establishes a solid foundation for further empirical research. Transue et al. [14] conducted a quantitative study using New Hersey's data and concluded that the white certification, relying on market clearing prices, is more conductive than price discount in encouraging enterprises to invest more incentives during the early stages. Georg et al. [15] argued that the white certificate system enhances the efficiency of the energy market from the demand side and contributes optimizing resource allocation efficiency. Taking Italy as the research object, Stede [16] found that the white certificate system effectively shortens the investment recovery time while creating significant incentives for energy investment. Unlike the above research, Steve et al. [17] found that the tradable white certificate scheme failed to reduce the marginal cost of energy investment, eliminate free-riding behavior in enterprises, and lacked corresponding economic and environmental effects. According to Bertoldi et al. [18], while the white certification system is beneficial in reducing enterprise transaction costs and fostering market transformation, it may also result in an increase in the administrative cost ratio of energy-saving obligations. Giraudet et al. [19] organized the evaluation of white certification obligations in Britain, Italy, and France. They found that although scholars believed the white certification system could effectively address issues like liquidity restriction, information gaps, and organizational market failure, these conclusions lack quantitative analysis evidence. Therefore, their credibility was limited.

While these documents contribute to understanding the impact from various angles, they overlook examining the institutional environment and capital allocation efficiency when exploring regulatory effects and mechanism analysis. First, according to the Porter Effect, a market-oriented industrial regulation policy addresses external challenges of enterprises through property rights trading [20]. Given a clear definition of property rights, energy-consuming right can influence enterprises' marginal cost through market mechanisms. Furthermore, it can enhance internal capital allocation efficiency, thereby accomplishing the optimization and transformation of enterprises themselves. However, the majority of existing documents ignore the influence of energy-consuming right on altering capital allocation. Second, the impact of market-oriented environmental regulation policies can be constrained by the institutional environment. In China, the development stages and institutional environments of different regions are diverse. Various levels of marketization lead to distinct effects on industrial policies. In different institutional environments, it is essential to consider whether the trading policy of energy-consuming right still plays a decisive role. In addition, the majority of research on market-based environmental regulation is concentrated in developed economies. There are not only limited empirical studies from developing countries, but also fewer investigations on China's market-based environmental regulation policies. Moreover, there are even fewer articles addressing the contribution of these policies to green innovation at the micro-enterprise level [21–23].

Based on natural experiments, this paper conducts an empirical examination of the impact by using the DID method. It endeavors to reveal the regulatory role of the institutional environment, the transmission mechanism involving "energy-consuming right trading system pilot → optimization of enterprises' capital allocation efficiency → improvement in green technology innovation", and the varied effects on enterprises with heterogeneity in ownership and energy consumption levels. The conclusion holds potential reference value for the formulation of relevant policies. The contributions are as follows. First, it will enhance the government and academia's understanding of the green technology innovation effect of the energy-consuming right trading system. It is beneficial for pilot areas to formulate and enhance the specific rules of the policy based on local conditions. Second, with a comprehensive understanding of the key factors and mechanisms influencing the green innovation effect, the government can create favorable conditions and an environment for the policy, ultimately achieving the maximization of policy effectiveness.

2. Policy background and research hypothesis

2.1. Policy background

For an extended period, high energy consumption, pollution, and emissions have characterized China's traditional economic growth model. With the acceleration of economic activities, China's energy system is facing severe challenges and high uncertainty. According to statistics, emerging economies constituted the primary economic entities driving global primary energy demand growth in 2021. Notably, China's energy demand growth represented the largest share, contributing to 77% of the total energy demand growth among emerging economies. Escalating demand and a significant increase in carbon emissions have intensified the contradiction between China's economic growth and environmental protection, significantly impeding high-quality economic development. Consequently, the Chinese government proposes a comprehensive green and low-carbon transformation, aiming to alter the energy structure and transform the national economic growth momentum [24,25]. During the UN General Assembly in 2020, China declared a new goal of making a national independent contribution to achieving carbon peak and carbon neutrality. This was officially reiterated in the 2021 government work report, emphasizing the necessity for concrete efforts to achieve carbon peak and carbon neutrality and the formulation of action plans. The dual-carbon target spans a broad spectrum of fields and carries profound implications. China confronts a series of formidable challenges in promoting energy reform. In contrast to China, developed countries possess more experience in addressing the interaction between resources and the environment. For example, the white certificate system of the EU fosters the internalization of external costs through market-oriented policies. It rectifies the negative externalities of carbon emissions, yielding positive policy outcomes. Building on the success of the European Union, the Chinese government has proposed to establishing an energy-consuming right trading system and implementing a market-based environmental regulation policy through warrant trading to address the "high energy consumption" inherent in the current economic growth process at its source. Compared with the "command control" industrial policy, this policy exhibits two distinctive characteristics. First, regarding the cost and benefit of environmental regulation, the policy utilizes the price mechanism to efficiently manage the relationship between the supply and demand of energy. It addresses the negative externalities of enterprise production by leveraging the market, resulting in lower environmental regulation costs than the "command control" industrial policy and achieving a superior resource allocation effect [26,27]. Second, from the perspective of enterprises' enthusiasm, the energy-consuming right trading system can autonomously coordinate interests. It boosts enterprises' enthusiasm to reduce production costs, encourages heightened investment in scientific innovation, facilitates spontaneous technological changes, and complete the transformation of enterprises.

In 2017, the government launched the policy of paid utilization and trading of energy rights, implementing pilot programs in four provinces. Through the mechanism, the government allocates energy conservation obligations to energy-using enterprises using initial energy consumption matching indicators. This restricts the production of enterprises to a reasonable range of energy consumption. Any excess energy demand quota can be procured and utilized through market transactions for a fee. Simultaneously, enterprises consuming less than the initial energy quota can generate profits by selling surplus energy quotas in the market. Through proactive exploration in recent years, all regions have accrued valuable pilot experience. Zhejiang Province was the first province among the four to implement the policy. In the course of this policy, it mainly adopts the means of "capacity control", mandating high energy-consuming enterprises to conduct power consumption transactions within the scope of new high energy-consuming projects. The trading subject is also gradually transitioning from the initial transaction between enterprises and the government to transactions among enterprises. In comparison to other provinces, Fujian Province exhibits the most comprehensive overall planning of the trading system and the most comprehensive supporting policies. Fujian regulates the total annual quotas and implements differential management of indicator allocation for projects in different periods. Following the pioneering adoption of energy-consuming right trading by the cement and electric power industries, the pilot scope has expanded to encompass the copper smelting, electrolytic aluminum, crude oil processing, and ferroalloy smelting industries. Moreover, the local government actively encourages energy-consuming enterprises not included in the pilot scope to voluntarily participate in the policy. Henan Province closely aligns with Fujian Province in policy design. In 2018, Henan Province established "$1 + 4 + N''$ and other institutional systems, selecting four key cities— Zhengzhou, Pingdingshan, Hebi, and Jiyuan—to pioneer the pilot experiment. The system uses coal consumption as the determinant for rights confirmation, builds an efficient and transparent trading market, and formulates a reasonable plan encompassing the definition of the trading subject, initial quota allocation, trading supervision, and review of energy consumption data. Sichuan Province stands as the sole pilot province for energy policy in western China. The establishment of the project holds immense significance in solidifying the status of the Western environmental resources trading center. The local government has instituted standardized regulations concerning market subjects, energy consumption rights indicators, and legal responsibilities. Steel, cement, paper making, building ceramics, and chemical industries have been incrementally included as pilot enterprises with indicators allocated through a combination of pre-allocation and adjusted allocation. Currently, the optimization effect on the energy consumption structure in the pilot provinces has grown significantly. China's energy trading market has matured, with an expanded scope of trading. Hebei, Shandong, Hubei, and other regions have actively joined the energy-consuming right trading market.

2.2. Research hypothesis

The policy's primary aim is to regulate both the total amount and intensity of energy consumption [28,29]. Energy users can freely trade the total energy consumption index obtained in accordance with the law in the energy market. The policy steers enterprises to conserve energy and minimize energy waste by means of market-oriented reforms in energy elements. Simultaneously, it compels them to undergo transformation and upgrade. It has the characteristics of efficiency and flexibility. Similar to environmental regulation policy tools like sulfur dioxide and carbon emissions trading, the energy-consuming right trading policy is also used to deal with external issues through warrant trading and the market mechanism. In contrast to the rigid constraints of the command-and-control environmental regulation, this market incentive policy has the ability to emit price signals in the market. It can influence the energy-consuming behavior of enterprises through the signal transmission effect. Within the soft constraints of the energy-consuming policy, enterprises will take various measures, including enhancing scientific and technological innovation capacity, transforming, upgrading, and other countermeasures, based on the cost-benefit status of their energy consumption [30–32]. According to the Porter Hypothesis, enterprises will opt for innovation if the cost of innovation can offset regulation costs and enhance profitability in the market. Thus, relying on the innovation compensation effect, the energy-consuming right policy will steer enterprises toward adopting innovative technologies to conserve energy and expedite industrial upgrading. High energy-consuming enterprises with low efficiency face the risk of market elimination, if they fail to accelerate technological innovation or facilitate the internalization of external environmental costs. Despite increasing short-term costs, innovation will significantly boost productivity and enhance the long-term competitiveness of enterprises. Therefore, the first research hypothesis is proposed:

Hypothesis 1. The energy-consuming right trading system will promote green technology innovation of enterprises.

The institutional environment, contingent on the degree of marketization, significantly influences technology innovation [33]. The externality in enterprises' green technology innovation has a significantly positive impact. When one enterprise leads in green innovation, others are susceptible to potential opportunistic behavior. In addition, given the high cost, time-consuming nature, and high risk associated with technological innovation, the issue of insufficient innovation motivation is prevalent among enterprise in the industry [34]. Enterprises will only contemplate technological innovation if they can fully offset the cost of innovation. This phenomenon can be easily solved in regions with perfect marketization. In regions with mature institutional environments, greater attention would be devoted to protecting the property right of enterprises, thereby better safeguarding the innovation outcome and stimulate motivation. In addition, the energy-consuming right trading system is a typical market incentive environmental regulation policy, and the maturity of the institutional environment will also affect the effect of industrial policy. A higher degree of marketization results in richer market information provided for enterprises, favoring technological innovation. Furthermore, the dynamic economic incentive effect will become stronger. Thus, the second hypothesis is proposed:

Hypothesis 2. The higher the marketization process and the more perfect the institutional environment, the stronger the effect of the energy-consuming right policy to inspire green technology innovation.

The impact of an energy-consuming right trading system is achieved through optimizing capital allocation in three aspects. First, this policy can disrupt the equilibrium of the resource market's inefficient matching, optimize the allocation of external resources, and foster innovation of enterprises. The market transaction of the right to consume energy will accelerate the flow of factors, releasing production factors from enterprises with high energy consumption and low output, and reallocating them to enterprises with high production efficiency. Specifically, the investment in capital factors will yield more green technological innovation output and competitive advantages to enterprises, while mitigating the destructive impact of innovation. Second, the trading system of energy-consuming right has an incentive effect on optimizing the internal allocation of enterprise capital. Confronted with limited energy-consuming quotas, enterprises will enhance the rejuvenating effect of their R&D capabilities. They will improve their probability of success in green technological innovation by enhancing their awareness of innovation and development, updating existing equipment, and stimulating the green innovation vitality of their R&D personnel. Third, the trading system is conducive to reducing the marginal cost, improving the profits of enterprises, and enhancing their green innovation ability. As an environmental regulation, the right to consume energy has imposed additional cost pressure on enterprises. Considering the long-term economic profits, enterprises will choose to enhance the innovation ability to reduce environmental costs. According to the above research perspective, the third research hypothesis is proposed:

Hypothesis 3. The trading system of energy-consuming right will improve green technology innovation by stimulating the optimization of capital allocation.

3. Materials and methods

This paper selects enterprises for the sample period from 2014 to 2019, and the reasons for choosing this timeframe re as follows. The pilot policy was initiated in 2017, but after 2020, the entire world suffered from COVID-19, affecting China's macro-economy. This situation could decrease the accuracy of the conclusions. Therefore, this paper considers the period from 2017 to 2019 as the duration of the pilot policy. For comparison and to achieve symmetry, this paper selects 2014 to 2016 as the period preceding the implementation of the policy. During the sample selection process, this paper excluded the ST-listed companies with missing financial data and ultimately obtained 4308 annual samples of companies. The data are sourced from CSMAR and the annual report published by listed companies on www.cninfo.com.cn.

As one of the key issues in economic research, the measurement innovation activities in empirical research involves numerous indicators. Specifically, in the existing literature, most scholars opt for indicators such as green investment [35], green R&D activities [36], authorized numbers, or cited numbers. The explanatory variable for the number of green innovations is derived from the total number of green inventions and utility model patent applications of enterprises. The reason for this approach includes: first, green patent data is an indicator capable of reflecting the output of innovation behavior and demonstrating the performance of innovation in both quantity and quality dimensions [37]. Second, the green patent data of enterprises are highly accessible and comparable.

Additionally, to account for the right distribution of green patent data in reality and to prevent the loss of observation value when the micro-level patent is zero, we follow the approach of Corneggia et al. [38], adding 1 to the number of patents and taking the natural logarithm to process the enterprise green technology innovation data. Referring to similar research, this paper selects six different control variables. Appendix A provides the specific definitions and calculation of variables. Appendix B presents the descriptive statistical results, indicating that the average value of green technology innovation is 0.8698785, with values distributed between 0 and 7.352441. This implies significant variations in the green technology innovation level during the sample period. Moreover, other control variables also exhibit substantial fluctuations, providing an ideal research sample for investigation.

To effectively identify the impact, this paper introduces dummy variables. Specifically, it defines the grouping variable *Treat*, designating industrial enterprises in Zhejiang, Sichuan, Fujian, and Henan as the treatment group, and those in other provinces as the control group. Meanwhile, the dummy variable *Time* is introduced based on the implementation time of the trading system. The DID model is constructed as follows:

$$LnGreen_{it} = \alpha_0 + \alpha_1 Treat_i * Time_t + \beta X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{1}$$

In equation (1), $Treat_i * Time_t$ is the policy dummy variable of energy-consuming right trading system, μ_i is individual fixed effect of industrial enterprises; γ_t indicates fixed time effect; ε_{it} is a random error item.

4. Results

4.1. Basic estimation

The model is estimated by both multiple linear regression (OLS) and fixed effect regression (FE). Table 1 presents the regression result, displaying the average impact after controlling for individual and time-fixed effects. The regression coefficients are 0.408 and 0.210, and both are statistically significant. It suggests that China's energy-consuming right trading policy has significantly enhanced the green technology innovation of listed enterprises. Even after adding control variables, the regression results remain unchanged, with coefficients are 0.166 and 0.178 respectively. The pilot policy in 2017 had a significant positive impact on green technology innovation. The results of the two models are consistent, indicating the robustness of the regression results and verifying hypothesis 1.

4.2. Robustness test

To enhance the credibility of the empirical results, additional tests are conducted.

4.2.1. Parallel trend test

In the DID method, it is crucial that the two sample groups maintain a parallel time trend before the pilot policy. If the trend is

Table 1
Summary of the benchmark regression results.

Variable	(1)	(2)	(3)	(4)
	OLS-DID	OLS-DID	FE-DID	FE-DID
	lnGreen	lnGreen	lnGreen	lnGreen
Treat*Time	0.408***	0.166**	0.210***	0.178***
	(0.064)	(0.079)	(0.054)	(0.053)
SIZE		0.898***		0.684***
		(0.032)		(0.085)
NOE		0.000***		0.000***
		(0.000)		(0.000)
CR		−0.007		0.008
		(0.007)		(0.007)
ROA		−0.093		−0.083
		(0.155)		(0.114)
CAP		−0.003		−0.003
		(0.003)		(0.002)
ROFA		0		0
		(0.000)		(0.000)
Constant	0.837***	−8.036***	0.665***	−6.074***
	(0.018)	(0.303)	(0.024)	(0.817)
Control variables	NO	YES	NO	YES
Time fixed	YES	YES	YES	YES
Individual fixed	YES	YES	YES	YES
Observed value	4308	4308	4308	4308
R-squared	0.009	0.311	0.03	0.297

Note: The values in brackets are standard errors. *,**,*** corresponding to the significance of 10%, 5% and 1% respectively. The rest tables are the same.

inconsistent before the implementation of the system, it suggests that the identification result is biased, and the conclusion lacks reliability. To assess whether the two groups passed the test, we adopt the event analysis method proposed by Jacobson [39], which involves constructing the changing trend of green innovation among enterprises in pilot provinces and non-pilot provinces from 2014 to 2019. If the green innovation level of enterprises in pilot provinces and industrial enterprises in non-pilot provinces maintains a substantial degree of consistency before 2017, and there is a noticeable difference in innovation output between the two groups after 2017, it indicates the test is successful. Fig. 1 illustrates the parallel trend before and after the policy. The result indicates that, using the last period of the policy as the benchmark, before 2017, the curve exhibited relatively gentle fluctuations around zero. After 2017, influenced by the policy, green innovation began to change significantly, signifying that enterprises' green innovation was impacted by the energy policy, confirming the test's success.

4.2.2. Placebo test

To eliminate the economic consequences caused by random factors, we create a treatment group for the placebo test. The sample of 718 industrial enterprises was randomly sampled 1000 times, and the treatment group and control group were selected through randomization. The dependent variable is regressed to generate the kernel density distribution diagram, as depicted in Fig. 1. According to Fig. 1, the results show that the absolute value of t is mostly less than 2, and the p-value is mostly more than 0.1, indicating a discernible normal distribution. It suggests that the regression results of estimators under random sampling lack significance. By excluding the impact of other policies and random factors during the experimental period, we can attribute the difference between industrial enterprises in pilot provinces and non-pilot ones to the implementation of the energy-consuming right policy.

4.2.3. PSM-DID test

Differences among enterprises in the pilot area and those in the non-pilot area may among regression results. As the energy policy in this paper serves as an exogenous variable for industrial enterprises, its determination is difficult based on the individual characteristics of these enterprises to some extent. To alleviate sample selection bias, this paper combines double difference (DID) and propensity score matching (PSM) to bolster the robustness [40,41]. The enterprises in the pilot area are considered the treatment group, and the factors influencing green innovation include the region, enterprise size, profitability, etc. Hence, the enterprise size (SIZE), number of employees (NOE), liquidity ratio (CR), capital intensity (CAP), return on total assets (ROA), and return on fixed assets (ROFA) are chosen as the matching variables in the prediction model. The treatment group was matched with the most similar control group based on the propensity score. In this paper, the nearest neighbor matching method is used. Table 2 below presents the results of the propensity score matching balance test. It can be noted that, after matching the deviation of variables decreases, and the p-value of the *t*-test post-matching exceeds 10%, which means the matching effect is good.

Following PSM processing, we reassess the relationship between the energy-consuming right trading system and enterprises' green innovation. In Table 3, the coefficients of the core explanatory variables are significant, consistent with the earlier test results. It indicates that after PSM, the energy-consuming right trading system still exert a significant effect in inspiring enterprises' green innovation. The research results of this paper exhibit relative stability.

5. Discussion

5.1. Heterogeneity analysis

While the paper has demonstrated the effectiveness of the pilot policy of the energy-consuming right trading system, do different

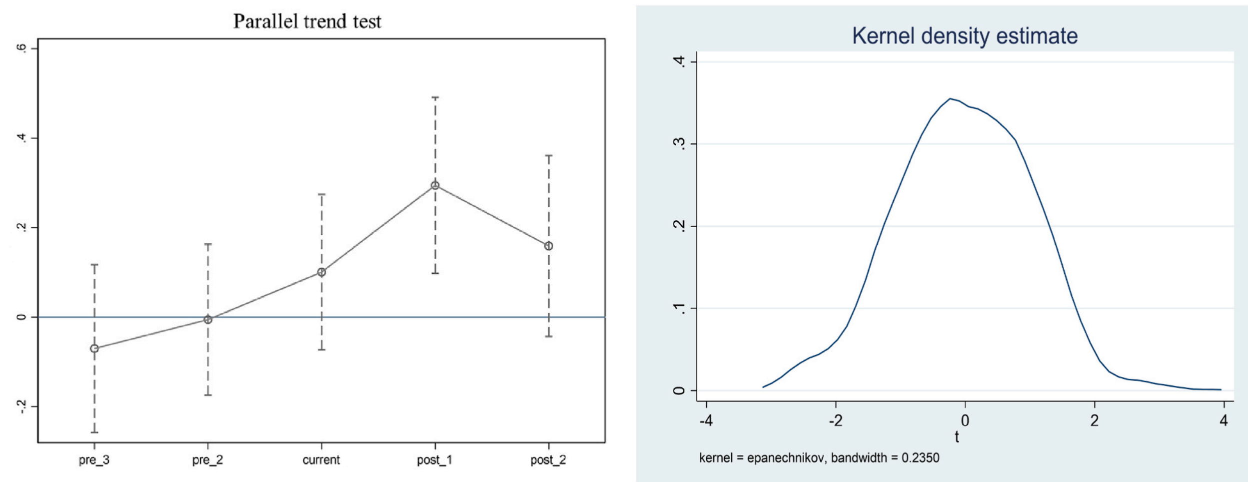

Fig. 1. Parallel trend test and placebo test.

Table 2
Tendency score matching balance test.

Variable	Sample	Mean		The deviation rate is (%)	Bias reduction ratio (%)	T checkout	
		Processing group	control group			T price	P > |t|
SIZE	Before	9.8225	9.8033	3.6	−79.4	0.81	0.419
	After	9.8228	9.7885	6.4		1.27	0.203
NOE	Before	5923.3	7726.7	−8.6	55.5	−1.68	0.092
	After	5922.7	5120.4	3.8		1.73	0.085
CR	Before	1.962	2.1564	−8.3	43	−1.78	0.075
	After	1.9607	2.0716	−4.8		−1.01	0.312
ROA	Before	0.03936	0.03042	9.2	54.3	2.03	0.043
	After	0.03982	0.03573	4.2		0.97	0.333
CAP	Before	2.3249	2.7383	−5.7	56.1	−1.11	0.268
	After	2.3276	2.1461	2.5		1.32	0.188
ROFA	Before	−1.9169	−2.4356	0.4	65.1	0.08	0.933
	After	0.03568	0.21667	−0.2		−0.83	0.408

Table 3
Results of the PSM-DID regression.

Variable	(1)	(2)	(3)	(4)
	OLS-DID	OLS-DID	FE-DID	FE-DID
	lnGreen	lnGreen	lnGreen	lnGreen
Treat*Time	0.419***	0.163**	0.203***	0 .174***
	(0.062)	(0.079)	(0.054)	(0.053)
SIZE		0.861***		0.634***
		(0.036)		(0.092)
NOE		0.000***		0.000***
		(0.000)		(0.000)
CR		−0.011		0.004
		(0.007)		(-0.004)
ROA		−0.130		0.005
		(0.170)		(0.142)
CAP		−0.017***		0.006
		(0.006)		(0.009)
ROFA		−0.001**		0.000
		(0.000)		(0.000)
Constant	0.826***	−7.644***	0.653***	−5.641***
	(0.018)	(0.350)	(0.025)	(0.881)
Control variables	NO	YES	NO	YES
Time fixed	YES	YES	YES	YES
Individual fixed	YES	YES	YES	YES
Observed value	4267	4267	4267	4267
R-squared	0.011	0.272	0.032	0.277

types of enterprises in pilot cities exhibit variations in the policy impact? Answering this question is beneficial for gaining a profound understanding the mechanism and boundary conditions of the energy-consuming right trading system. Thus, this paper examines the heterogeneity effect from the perspectives of non-productive characteristics and production characteristics of enterprises. Specifically, this part will examine the effect from the perspectives of enterprises' ownership and energy consumption level.

5.1.1. Enterprise ownership

Facing the identical industrial policy, diverse enterprises exhibit distinct responses. The group regression method is applied to examine whether the innovation effect varies among enterprises with different ownership. Table 4 presents the group inspection based on enterprise ownership. From (3) and (4), it can be seen that, both before and after adding control variables, the *Treat* Time* coefficients of non-state-owned enterprises are 0.245 and 0.218, indicating that a significant stimulation of green technology innovation by the energy-consuming right trading system. Conversely, the outcomes in the first two columns reveal that the *Treat* Time* coefficient of state-owned enterprises is positive; however, its value and significance of coefficient are lower than those in the last two columns. It means that the system lacks a comparatively strong and significant green innovating effect on state-owned enterprises. These findings indicate that, in comparison to state-owned ones, the energy-consuming right trading policy plays a relatively greater role in improving the green technology innovation of non-state-owned enterprises.

The Chinese government implements the energy-consuming right trading system to prompt enterprises to consider both profit and environmental protection in their decision-making. However, varying levels of local government intervention in enterprises with different ownership lead to divergent effects. Thus, evident heterogeneity is observed. To be specific, foremost, the majority of Chinese state-owned enterprises receive support from the local government. Consequently, they possess inherent advantages in resource

Table 4
FE-DID results under the influence of ownership heterogeneity.

Variable	(1)	(2)	(3)	(4)
	State-owned enterprises	State-owned enterprises	Non-state-owned enterprises	Non-state-owned enterprises
	lnGreen	lnGreen	lnGreen	lnGreen
Treat*Time	0.169*	0.143**	0.245***	0.218***
	(0.089)	(0.088)	0.069	(0.067)
Constant	0.935***	−5.998***	0.458***	−6.350***
	(0.036)	(1.301)	(0.033)	(1.100)
Control variables	NO	YES	NO	YES
SIZE		0.678***		0.711***
		(0.133)		(0.117)
NOE		0.000***		0.000
		(0.000)		(0.000)
CR		0.029		0.005
		(0.019)		(0.007)
ROA		−0.248		0.000
		(0.164)		(0.160)
CAP		0.000		−0.003
		(0.013)		(0.002)
ROFA		0.000		0.000
		(0.001)		(0.000)
Time fixed	YES	YES	YES	YES
Individual fixed	YES	YES	YES	YES
Observed value	1872	1872	2436	2436
R-squared	0.021	0.353	0.053	0.186

allocation compared to non-state-owned enterprises. State-owned enterprises typically face less survival pressure and exhibit less sensitivity to production costs. Therefore, the energy-consuming right trading system, applying cost pressure on enterprises' energy consumption, has an extremely limited impact on fostering green technology innovation in state-owned enterprises. Secondly, non-state-owned enterprises are more flexible. These enterprises can incentivize scientific research and technical personnel to pursue ongoing technological innovation through substantial bonuses and equity incentives. Thus, the impact of the energy-consuming right policy on green innovation is more pronounced in non-state-owned enterprises.

5.1.2. Enterprises' energy consumption level

The trading system of energy-consuming right is an important system for the government to exert pressure on energy-consuming

Table 5
FE-DID results under the influence of heterogeneity in energy consumption levels.

Variable	(1)	(2)	(3)	(4)
	High energy-consuming enterprises	High energy-consuming enterprises	Non-high energy-consuming enterprises	Non-high energy-consuming enterprises
	lnGreen	lnGreen	lnGreen	lnGreen
Treat*Time	0.145**	0.136**	0.350***	0.270***
	(0.066)	(0.065)	(0.095)	(0.093)
SIZE		0.406***		1.221***
		(0.108)		(0.151)
NOE		0.000***		0.000
		(0.000)		(0.000)
CR		0.005		0.017
		(0.008)		(0.012)
ROA		−0.118		0.106
		(0.137)		(0.214)
CAP		−0.002		0.000
		(0.007)		(-0.003)
ROFA		0.000		−0.001
		(0.000)		(0.003)
Constant	0.719***	−3.366***	0.529***	−11.330***
	(0.029)	(1.032)	(0.045)	(1.453)
Control variables	NO	YES	NO	YES
Time fixed	YES	YES	YES	YES
Individual fixed	YES	YES	YES	YES
Observed value	3084	3084	1224	1224
R-squared	0.029	0.271	0.032	0.392

enterprises by making full use of the market mechanism. Enterprises with different energy consumption may respond differently to this policy. Therefore, it is essential to explore the heterogeneity of this effect in the dimension of enterprise energy consumption levels.

Utilizing the classification criteria for high energy consumption industries outlined by the Chinese government in 2020, we categorize enterprises into high-energy consumption and non-high-energy consumption categories. The fixed double-difference model was used to regress samples. The result in Table 5 shows that, among non-high energy-consuming enterprises, the green innovation effect with the energy-consuming right surpasses at the 1% significant level. Considering the variables, the impact coefficient shifts from 0.350 to 0.270. It implies that the trading system of energy-consuming right has an incentive effect on non-high energy-consuming enterprises' green technology innovation. In contrast, the coefficient and significance level for high-energy-consuming enterprises are lower than those of non-high energy-consuming enterprises. Pre- and post-incorporation of control variables, the coefficients are 0.145 and 0.136, which implies that the energy-consuming right trading policy plays a more substantial and evident role in non-high energy-consuming enterprises.

In theory, the primary purpose of implementing the energy-consuming right trading policy is to encourage high-energy consumption enterprises to conserve energy and reduce unnecessary consumption. The industrial policy is considered reasonable and effective when high-energy consumption enterprises exhibit greater motivation for green innovation than non-high-energy consumption enterprises. However, this paper has obtained the opposite empirical results. How to explain this interesting empirical discovery? The level of innovation in green invention patents is relatively higher than that in green utility model patents. High-energy-consuming enterprises will experience higher energy demand, resulting in greater pressure on energy consumption compared to non-high energy-consuming enterprises. However, green utility model innovation is less practical for enterprises in enhancing energy-consuming efficiency. In the short term, high-energy-consuming enterprises are more inclined to allocate resources to high-quality green innovation that effectively addresses energy consumption challenges. Thus, when assessing the incentive effect on enterprises with different energy consumption intensities, it is imperative to consider the supplementary verification of innovation quality across enterprises with various energy consumption levels.

5.2. Analysis of impact mechanism

5.2.1. Regulation effect based on the institutional environment

Since the energy-consuming right system constitutes an industrial policy, using the market price mechanism to influence the energy consumption behavior of enterprises, its implementation effect is closely tied to the institutional environment. The measure of the regional institutional environment is the degree of marketization [42,43]. Provinces with favorable institutional environments typically exhibit high levels of marketization. High marketization regions benefit from the market's provision of an effective competition mechanism and price mechanism. Additionally, there is a stronger awareness of property rights protection, and factors exhibit greater mobility in these regions. Therefore, on the ground of property rights trading theory, it can be concluded that the tradable mechanism of energy-consuming right might produce more obvious policy effects in regions with higher levels of marketization.

Consequently, this paper utilizes marketization levels as an indicator to investigate the regulatory impact of the institutional environment on the green technology innovation of enterprises within the energy-consuming right trading system [44]. Based on the

Table 6
DDD regression results in the degree of marketization.

Variable	(1)	(2)	(3)	(4)
	OLS-DDD	OLS-DDD	FE-DDD	FE-DDD
	lnGreen	lnGreen	lnGreen	lnGreen
Treat*Time*Mkindex	0.408***	0.166**	0.210***	0.178***
	(0.064)	(0.079)	(0.054)	(0.053)
SIZE		0.902***		0.684***
		(0.031)		(0.085)
NOE		0.000***		0.000***
		(0.000)		(0.000)
CR		−0.008		0.008
		(0.006)		(0.007)
ROA		−0.112		−0.083
		(0.140)		(0.114)
CAP		−0.003		−0.003
		(0.003)		(0.002)
ROFA		0.000		0.000
		(0.000)		(0.000)
Constant	0.837***	−8.056***	0.665***	−6.074***
	(0.018)	(0.295)	(0.024)	(0.817)
Pairwise interaction terms	YES	YES	YES	YES
Control variables	NO	YES	NO	YES
Time fixed	YES	YES	YES	YES
Individual fixed	YES	YES	YES	YES
Observed value	4308	4308	4308	4308
R-squared	0.010	0.311	0.030	0.297

comprehensive ranking of China's marketization index from 2014 to 2019, this paper designates enterprises in the top 10 provinces as the experimental group and the remainder as the control group, constructing a triple difference model (DDD) rooted in the double difference model (DID) for regression analysis. Through the control of other irrelevant factors using multiple differences, a more accurate net policy effect can be determined. The triple difference model for verifying the regulatory impact of the institutional environment is constructed as follows:

Consequently, this paper uses the marketization levels as an indicator to investigate the regulatory effect of the institutional environment on the green technology innovation of enterprises within the energy-consuming right trading system [44]. According to the comprehensive ranking of China's marketization index from 2014 to 2019, this paper designates enterprises in the top 10 provinces as the experimental group and the rest as the control group, constructing a triple difference model (DDD) rooted in the double difference model (DID) for regression analysis. By controlling other irrelevant factors using multiple differences, a more accurate net effect can be obtained. The triple difference model for verifying the regulatory effect of the institutional environment is constructed as follows:

$$\begin{aligned} LnGreen_{it} &= \beta_0 + \beta_1 Treat_i * Time_t * Mkindex_i + \beta_2 Treat_i * Time_t + \\ &\beta_3 Time_t * Mkindex_i + \beta_4 Treat_i * Mkindex_i + \eta X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \end{aligned} \tag{2}$$

In equation (2), Mkindex is a dummy variable representing the institutional environment of the enterprise location. Specifically, the Mkindex dummy variable takes the value of 1 for Guangdong, Zhejiang, Beijing, Shanghai, Jiangsu, Shandong, Tianjin, Fujian, Hubei, and Chongqing, while it takes the value of 0 for other provinces. For cross-year data comparison, the index is calculated based on 2014 and is comparable across different years. Other variables are consistent with the definition provided earlier. Likewise, equation (2) is estimated by multiple linear regression (OLS) and fixed effect regression (FE) respectively.

Table 6 reveals that, while controlling for fixed effect, the coefficient of Treat * Time * Mkindex is positive. It shows after introducing the system, the policy has a stronger incentive effect on green innovation in regions with a higher degree of marketization compared to the control group. In other words, the more favorable the institutional environment, the stronger effect of the energy-consuming right trading system on the green innovation of enterprises. Therefore, hypothesis 2 can be verified.

5.2.2. Transmission mechanism based on the capital allocation

The above research indicates that the implementation of the trading system has significantly augmented the green technology innovation of enterprises. The subsequent crucial question is, through what channels does the trading system exert its influence on green technology innovation? Given that the introduction of this policy aims to regulate enterprises' behavior by affecting the energy use cost, changes in cost composition will inevitably alter the original capital allocation, impacting its efficiency. Therefore, to clarify the mechanism, this paper investigates the impact of the energy-consuming right trading system on the efficiency of enterprises' capital allocation. Capital allocation efficiency is reflected by the sensitivity of investment to investment opportunities. In enterprises, the more investment level and investment opportunities match each other, the higher efficiency of enterprises' capital allocation. Thus, this paper uses the "investment-investment opportunity" sensitive model to explore whether capital allocation serves as a transmission mechanism for enhancing green technology innovation in enterprises. The specific model is shown in equations (3) and (4).

Table 7
Results of the conduction mechanism test of the resource allocation effect.

Variable	(1)	(2)	(3)	(4)
	Invest	Invest	lnGreen	lnGreen
Treat*Time*Roa$_{it-1}$	0.110***	0.096***	2.594***	0.903
	(0.027)	(0.028)	(0.673)	(0.605)
Invest			3.060***	1.393***
			(0.416)	(0.356)
SIZE		0.009***		0.916***
		(0.002)		(0.034)
NOE		0.000		0.000***
		(0.000)		(0.000)
CR		−0.001***		−0.009
		(0.000)		(0.007)
CAP		0.001***		−0.004
		(0.000)		(0.003)
ROFA		0.000***		0.000
		(0.000)		(0.000)
Constant	0.040***	−0.046***	0.777***	−8.238***
	(0.001)	(0.016)	(0.026)	(0.331)
Pairwise interaction terms	YES	YES	YES	YES
Control variables	NO	YES	NO	YES
Time fixed	YES	NO	NO	NO
Individual fixed	YES	NO	NO	NO
Observed value	3590	3590	3590	3590
R-squared	0.005	0.041	0.02	0.312

$$Invest_{it} = \alpha_0 + \alpha_1 Treat_i * Time_t * Roa_{it-1} + \alpha_2 Treat_i * Time_t + \alpha_3 Time_t * Roa_{it-1} + \alpha_4 Treat_i * Roa_{it-1} + \eta X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (3)$$

$$LnGreen_{it} = \beta_0 + \beta_1 Invest_{it} + \beta_2 Treat_i * Time_t * Roa_{it-1} + \beta_3 Treat_i * Time_t + \beta_4 Time_t * Roa_{it-1} + \beta_5 Treat_i * Roa_{it-1} + \eta X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (4)$$

The *Invest* in the formula represents the current investment level of the enterprise. Roa_{it-1} is the return on assets with a lag of one period, which measures the investment opportunities of enterprises. The coefficient α_1 of the third term *Treat * Time * Roa_{it-1}* measures the effect on the investment efficiency of enterprises.

In Table 7, the result in column (1) shows that, in the model solely controlling for time and individual fixed effects without adding control variables, the coefficient of Treat * Time * Roa_{it-1} is significantly positive. Even after introducing the control variable in column (2), the coefficient remains positive. It means that after introducing the energy-consuming right trading system, the investment efficiency of enterprises in the experimental group has experienced a significant increase. It reveals that this decision has an incentive effect on enterprises' green technology innovation by altering capital allocation efficiency. Column (3) and (4) also exhibit positive coefficients, indicating the existence of a mediation effect. Through analysis, it can be noted that, after conducting the energy-consuming trading system, the sensitivity of enterprise investment in the experimental group to investment opportunities has risen. It indicates that the investment behavior of enterprises is efficient, capital allocation efficiency is enhanced, and ultimately, the green technology innovation of enterprises is promoted. Therefore, hypothesis 3 is verified.

5.3. Suggestion for future research

The analysis reveals that, akin to the tradable white certificate schemes in the EU, China's market-oriented regulatory system, characterized by property rights transactions, enables the energy-consuming right trading system to improve energy utilization efficiency through the following methods, particularly by promoting green technology innovation [45,46]. Furthermore, it accelerates the green transformation of enterprises and plays a pivotal role in inducing and sustaining technological changes [47]. In contrast to prior studies, this article discovers that the specific effects of China's market-oriented regulatory system are distinctive. Owing to the vast territory, factor endowments, and institutional environments that are not entirely consistent across different regions, significant differences in the degree of marketization exist. Considering the growing popularity of the energy-consuming right trading system worldwide, it is anticipated that an increasing number of countries will adopt this form of market-based environmental control policy. Consequently, future research directions should focus on supporting the widespread adoption of the energy-consuming right trading system and enhancing its applicability. As per the findings of this article, policy effects exhibit variations across regions. Additionally, concerning enterprise ownership, unlike most Western countries, China has a substantial proportion of state-owned enterprises. Substantial differences exist in energy consumption levels and attitudes towards market-based regulatory systems among enterprises, which will impact the effectiveness of environmental control policies. Consequently, when the government designs and operates the energy-consuming right trading system, comprehensive consideration of the heterogeneity of the domestic market is necessary, and blindly copying the tradable white certificate schemes in the EU should be avoided.

5.4. Suggestion for practice

Based on the analysis, valuable lessons and experiences can be derived for the government in the design and operation of the system.

First, the government should prioritize the policy and expedite its enhancement. Based on the calculation results, this paper discerns that the energy-consuming right trading system currently plays a pivotal role in fostering the development of enterprises' green technology innovation. It stands as one of the significant driving forces in advancing China's dual-carbon goal and promoting further high-quality development. Nevertheless, currently, the trading system is still in its nascent stage of development and is insufficient for the tasks it needs to fulfill. Some imperfections persist, including relatively independent and decentralized pilot markets, the absence of a more unified factor market, insufficient institutional flexibility, and a limited scope of factor flow.

Second, enterprises with diverse ownership and energy consumption levels should adopt differentiated strategies, and the government should bolster mixed-ownership reforms. In the enhancement of the energy-consuming right trading system, the government should fully consider firm heterogeneity, focus on classifying enterprises, and implement distinct policies tailored to different types of enterprises. Based on the results, state-owned enterprises are susceptible to principal-agent problems, and the innovative effect of non-state-owned enterprises is more apparent. Therefore, the government should incentivize enterprises to enhance the managerial structure and management mode of state-owned enterprises to improve capital allocation efficiency. It is also crucial to consider the energy consumption level of the enterprise when determining the initial energy consumption quota. Additionally, the local government should appropriately intensify the pressure on enterprises to save energy and encourage increased investment in high-quality innovation activities.

Third, the government should prioritize deepening market-oriented reforms and further advancing the development of the capital market. The empirical research conclusion of this paper demonstrates that the institutional environment plays a regulatory role. The institutional environment of different enterprises varies in the flow of factors, and the policy effects on green technology innovation differ in regions with various levels of marketization. Consequently, the mobility and flexibility of factors should be promoted through deepening market-oriented reforms, aiming to better propagate the technology innovation effect. In particular, the government should refrain from excessive interference in the investment and financing decisions of enterprises. It should encourage banks to independently arrange credit decisions and establish a favorable institutional environment for enterprises to undergo green transformation. Additionally, the key to enabling the transmission mechanism of capital allocation efficiency is to enhance the alignment between investment and investment opportunities and improve the financing mechanism through various means. Firstly, enterprises are encouraged to optimize direct financing mechanisms, such as equity financing and bond financing. Secondly, the cultivation of diverse external financing channels should be expedited to assist enterprises in overcoming financing difficulties.

5.5. Limitations of the study

While the current research addresses the question of whether the energy-consuming right trading system promotes green technology innovation in enterprises, it still has certain limitations. Firstly, the data was limited to the period between 2014 and 2019. Future directions should involve extending the sample time and integrating case studies to augment a deep and comprehensive understanding of the energy-consuming right trading system. Secondly, our research does not delve into the design details and operational characteristics of the energy-consuming right trading system. Thirdly, the impact of the implementation of the energy-consuming right trading system on changes in the organizational structure of both parties, the rights and obligations of energy distributors or suppliers, and energy conservation assessments still requires further exploration.

6. Conclusions

First, based on the above research results, the energy-consuming right trading system exhibits a significant positive effect on the green technology innovation of regulated listed enterprises with a one-year lag. Second, non-state-owned enterprises and those with lower energy consumption levels are more sensitive to the energy-consuming right trading system. The policy is more conducive to inspiring green technology innovation in these enterprises. Third, the institutional environment plays a regulatory role in the green technology innovation of enterprises, and the energy-consuming right trading system enhances it by improving capital allocation efficiency. In addition, the empirical result reveals the transmission mechanism: "establish energy-consuming right trading system→increase enterprise investment→raise capital allocation efficiency→enhance enterprise green technology innovation ". Finally, to enhance the effectiveness of the pilot policy, the pilot experience should be taken seriously. The local government should also prioritize deepening market-oriented reforms, expediting the construction of the capital market, and adopting differentiated strategies for enterprises with diverse ownership and energy consumption levels.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Wei Shao: Supervision, Resources, Methodology, Conceptualization. **Jiahui Liu:** Software, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Selection and description of the main variables

Type of variable	Variable Name	Variable Symbol	Variable Definition
Explained variable	Green Innovation	LnGreen	Ln (1 + number of patent applications)

(*continued on next page*)

(*continued*)

Type of variable	Variable Name	Variable Symbol	Variable Definition
Interactive items	Time Dummy Variable	Time	The year after the start of the policy pilot is assigned a value of 1, otherwise it is 0
	Regional Dummy Variables	Treat	The enterprise belonging to the policy pilot area is assigned a value of 1, otherwise it is 0
Control variables	Company Size	SIZE	The natural logarithm of the total company assets
	Number of Employees	NOE	Number of personnel in various forms of employment in the unit
	Current Ratio	CR	Current assets/Current liabilities
	Return on Total Assets	ROA	Net profit/Total assets
	Capital Intensity	CAP	Total assets/Operating income
	Return on Fixed Assets	ROFA	Net profit/Total fixed assets

Appendix B. Descriptive statistics for the main variables

Variable	Variable meaning	Observed Value	Mean	Standard Error	Minimum	Maximum
LnGreen	Green innovation	4308	0.8698785	1.145248	0	7.352441
Time	Time point	4308	0.5	0.500058	0	1
Treat	Make experiments	4308	0.1615599	0.3680893	0	1
SIZE	Company size	4308	9.806442	0.573126	8.181749	12.43667
NOE	Number of employees	4308	7435.296	25866.95	20	534,652
CR	Current ratio	4308	2.124997	2.63927	0.0757	42.7241
ROA	Return on total assets	4308	0.0318606	0.1065178	−3.164378	0.3789798
CAP	Capital intensity	4308	2.67151	9.008003	0.1138224	463.2342
ROFA	Return on fixed assets	4308	−2.351793	149.5008	−9710.104	265.9467

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