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ORIGINAL ARTICLE

Can the energy-consuming right transaction system improve energy efficiency of enterprises? New insights from China

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Abstract Whether the energy-consuming right transaction system (ECRTS) can achieve a win–win development in economic growth and energy saving is a practical issue that needs to be tested urgently. The existing studies lack results that test the policy effect of ECRTS from the enterprise perspective. This paper uses the ECRTS implemented in 2016 as a natural experiment drawing on the relevant data of Chinese listed enterprises from 2009 to 2020. It adopts a difference-in-difference model to assess the effect of ECRTS on energy efficiency. The research finds that ECRTS improves energy efficiency of enterprises, and ECRTS can improve energy efficiency by promoting technological innovation and optimizing the efficiency of capital allocation. Further, ECRTS is more conducive to improving the energy efficiency of state-owned enterprises, enterprises with executives financial background, high pollution enterprises, and enterprises in regions with low resource endowments. Moreover, the improvement of energy efficiency can further enhance the value of enterprises after enterprises participate in ECRTS. The study provides a direct answer to the key question of whether the ECRTS policy can actually support the high-quality economic development.

Keywords Energy-consuming right transaction system · Energy efficiency · Difference-in-difference · Technological innovation · Capital allocation efficiency

Abbreviations

ECRTS	Energy-Consuming Right Transaction System
EE	Energy Efficiency
DID	Difference-In-Difference
TI	Technological Innovation
CAE	Capital Allocation Efficiency
ER	Environmental Regulations
CV	Control variables
GFPP	Green Finance Pilot Policy
CTPP	Carbon Trading Pilot Policy

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PLC	Pilot Low-Carbon City
PSM	Propensity Score Matching
IV	Instrumental Variable
SOEs	State Owned Enterprises

Introduction

Energy is an important factor endowment in the process of economic development. Along with rapid economic development, China's total energy consumption has continued to climb from 570 million tons of standard coal in 1978 to 5.24 billion tons of standard coal in 2021, which is an increase of 819%, thus making China the world's largest energy consumer. The crude economic development model not only makes the energy use inefficient, but the excessive consumption of coal, oil, and other waste products such as sulfur dioxide and soot has caused a serious haze problem. The global greenhouse gas emission concentration continues to increase, which leads to an increasing warming trend, thus posing a threat to human life and social development (Wesseh and Lin, 2018). China's CO_2 emissions exceeded 11.9 billion tons in 2021, accounting for 33% of the total global emissions (IEA, 2022). To reduce pollution emissions, China has followed the global energy development trend and actively conducted an energy transition, resulting in a decrease in energy consumption intensity from 1.56 tons of standard coal million yuan in 1980 to 0.63 tons of standard coal million yuan in 2019, but a large gap still exists compared with the United States, Japan, and the United Kingdom, among others. China's urbanization rate is currently approximately at 65%, which is lower than the urbanization level of developed countries, indicating that China's infrastructure construction will continue for some time and total energy consumption will still have room for growth in the coming period. China's industrial structure, which is dominated by secondary industries and the characteristics of its coal-based energy consumption structure, largely limit the improvement of energy efficiency (BP, 2022). According to the BP World Energy Statistics Yearbook, China's energy efficiency is far below the world's advanced level, with China contributing 17.4% of the total global GDP with 26.1% of energy consumption in 2020, while the US contributes 24.7% of the total global GDP with only 15.8% of energy consumption (BP, 2022). Low energy efficiency not only affects the rate of energy consumption and the level of pollutant emissions, but also affects the sustainability of economic growth. Thus, China still needs to improve its energy efficiency level continuously and constantly.

China's 14th Five-Year Plan proposes to adhere to the concept of green development, promote the revolution in energy production and consumption, and build a clean, low-carbon, safe, and efficient energy system development strategy. China's 20th National Congress report also proposes to accelerate the promotion of green and low-carbon development and improve the overall efficiency of resource utilization. Choosing a reasonable and effective energy and environmental policy to improve energy efficiency becomes one of the most effective ways to achieve the dual carbon goal in China. ER can be divided into command-and-control ER and market-based ER. The Chinese government has mainly adopted command-and-control ER for a long time to allocate resources and manage the environment, such as establishing environmental standards and targets for regional and industrial enterprises through legal and administrative means, and calling out and punishing enterprises that violate the regulations. Command-and-control ER may increase the cost of energy conservation, curb enterprise innovation, and reduce the efficiency of resource allocation, and cannot fundamentally optimize the economic structure (Tu and Chen, 2015). Market-based ER have gradually emerged since China's 10th Five-Year Plan, such as sulfur dioxide emissions trading market and carbon emissions trading market, which are mainly borrowed from developed countries and have gradually played an increasingly important role in energy conservation and emission reduction in China. However, market-based trading permit ERs are aimed at pollution emissions, i.e., they belong to end-of-pipe treatment. Although such end-of-pipe ER have reduced pollutant emissions to a certain extent, they have failed to address the root causes of environmental pollution (Xue & Zhou, 2022). The Chinese government has started to focus on source input treatment and has proposed the "double control" goal of controlling total energy consumption and energy intensity in the 13th Five-Year Plan to achieve energy conservation and emission reduction thoroughly. The Chinese government introduced a pioneering ECRTS in 2016 and launched pilot projects on paid use and trading of energy-consuming rights in Zhejiang, Fujian, Henan, and Sichuan provinces to implement the "double control" target effectively. Energy-consuming rights trading refers to the act of trading the total energy-consuming indicators obtained by the participating entities under the premise of total energy-consuming control.

The proposed ECRTS is a useful exploration of energy control by market-based means in China and is greatly significant in solving the problems of energy depletion, environmental pollution, and energy economic efficiency. A comprehensive and accurate assessment of the policy effects of the ECRTS can help provide theoretical references and empirical support for local governments to improve the energy trading system and further establish the energy trading market in China. In the research on energy conservation of enterprises, the literature mainly focuses on environmental policies such as carbon tax, regional emission target constraints, and pollutant emission permit trading policies. There is currently limited research on the evaluation of ECRTS. As shown in Table 1, scholars have studied the impact of China's ECRTS on environmental pollution and economic development based on regional or industry level data (Zhang & Zhang, 2019; Wang et al., 2019; Wang et al., 2021), but there is no research on how ECRTS affects EE of enterprises. As the main body of China's economic growth and energy consumption, enterprises have different production capabilities and energy consumption levels. Studying the impact of ECRTS on EE of enterprises can help achieve sustainable development in China. At the same time, it is of great significance to supplement the research on energy permit trading policies in energy economics.

The potential marginal contributions of this paper are as follows: First, existing literature suggests that ECRTS can reduce environmental pollution, its impact on EE of enterprises has not yet been evaluated. We analyze the impact of the ECRTS on the EE of listed enterprises for the first time, provide an in-depth analysis of the intrinsic mechanism of the ECRTS to enhance EE, and deepen the research on the policy dividend of the ECRTS; Second, we construct quasi-natural experiments with the exogenous shock of regional energy-consuming trading pilots, evaluate the impact of ECRTS on EE using a DID method, and conduct a number of robustness tests in terms of research methodology. Third, most of the data used in the existing studies on ECRTS are focused on the provincial and city levels (Li & Lin, 2016; Wang et al., 2019; Zhang & Zhang, 2019), while the regional span can lead to bias in the assessment of policy effects. Analyzing the enterprises' responses to ECRTS and exploring the effects of policy implementation on enterprise EE would be more accurate. Fourth, in terms of research content, the impact mechanism and heterogeneity of the ECRTS are further investigated while assessing the impact of the ECRTS in improving the EE of enterprises. Fifth,

Table 1 The results of previous studies on ECRTS

Literature	Perspective	Topic	Method	Main result
Zhang and Zhang (2019)	Industrial	The impacts of ECRTS on economic growth and energy savings	non-parametric optimization model	The ECRTS could achieve a win–win situation for China's industrial economy and emission reduction
Wang et al. (2019)	Regional	The impacts of ECRTS on energy consumption and intensity	Integrated energy intensity decomposition model	The energy intensity under the tradable permits model could be reduced by about 14% compared to the actual energy intensity, and the total energy consumption was decreased by 7%
Wang et al. (2021)	Regional	The impacts of ECRTS on energy intensity	difference-in-difference model	Compared to non-pilot areas, ECRTS can effectively reduce the energy intensity of pilot areas

the analysis of economic consequences of ECRTS shows that with the implementation of ECRTS, improving the EE of pilot enterprises can further increase their enterprise value. The findings imply that by participating in energy rights transactions, enterprises can simultaneously improve their competitiveness and environmental protection. This article can provide empirical support for China to improve the ECRTS, further expand the scope of the pilot ECRTS, and even establish a national unified energy-consuming trading market, as well as solidify the path to achieve China's "double carbon" goal and fulfill the challenges of climate change.

Whether ECRTS promotes enterprises' EE is indeed of great practical significance for China to early achieve the "double carbon" goal. Therefore, this paper examines the impact of the ECRTS on EE using a DID approach based on the data of Chinese listed enterprises from 2009 to 2020. Moreover, this study uses a mediating effect model to analyzes the transmission mechanism of ECRTS on EE, and further examines the impact of heterogeneity on policy effects from multiple perspectives.The research framework of this paper is shown in Fig. 1.

The rest of this paper is arranged as follows: The second section reviews the relevant literatures. The third section is policy background and research hypothesis. The fourth section describes the empirical methods and data used in this paper. The fifth section is empirical analysis. The sixth section is the conclusions, policy implications and limitations.

Literature Review

Research on Market-based ER

As an environmental policy based on market mechanism, market-based ER can make use of market price mechanism, in which tradable pollution reduction can be distributed among pollution control subjects according to the principle of equal margins, and make the whole society achieve the pollution control goal at the lowest cost. This institutional arrangement can not only conserve energy and emission reduction, but also help to stimulate the technological progress of enterprises and realize the Porter effect (Montgomery., 1972; Stavins,

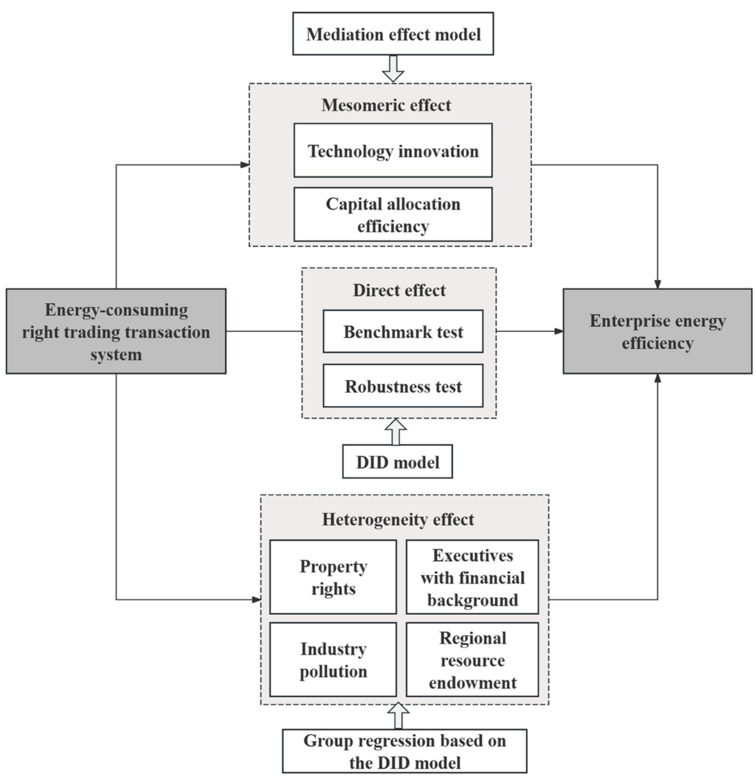

Fig. 1 Research framework

2003). Dales established an analytical framework for an emissions trading system and explored how to design a water ownership lease system to solve the water pollution problem. The market for emission rights and carbon credits has subsequently been widely discussed and tested in Europe and the United States, examining numerous aspects of the policy's emission reduction effect, cost effectiveness, and impact on green innovation. Most studies have affirmed the positive effects of environmental equity trading policies. For example, Carlson et al. (2000) measured that the US sulfur dioxide emissions trading market can save 1.6 billion US dollars in emission reduction costs per year compared with command-and-control ER. Bayer and Aklin (2020) determined that the European Union's (EU) carbon emissions trading system reduced approximately 1.2 billion tons of CO_2 emissions between 2008 and 2016. Calel and Dechezlepretre (2016) determined that the EU carbon emissions trading system triggered the rapid growth of low-carbon innovation.

The policy effects of market-based ER in China have also been extensively examined, and scholars have richly discussed China's sulfur dioxide emissions trading system and carbon trading system (Qi et al. 2021; Chen et al., 2021; Tang et al., 2021). For example, Tu and Chen (2015) examined the potential economic and environmental dividends realized in the short and long term by China's SO2 emissions trading mechanism using a DID method and DEA model, and exhibited that the Porter effect could not be realized by SO2 emissions trading in either the short or long term, but that emissions trading could drive significant emission reductions in the long term compared with command-and-control ER. Cui et al. (2021) used firm-level carbon emissions data in China to determine that carbon trading markets can effectively reduce firms' carbon emissions by reducing coal use. Zhou and Qi (2022) used a DID model to examine the environmental economic effects of carbon trading mechanism in China and determined that carbon trading mechanism can significantly improve green total factor EE by pushing pilot cities to upgrade their industrial structures.

Research on ECRTS

The EU's white certificates system is similar to China's ECRTS, which was formally established by the Italian government in 2005. The UK, France, Denmark and the Belgium's Flemish region have implemented this system and proved its superiority and effectiveness as a tool for energy conservation and emission reduction. Oikonomou et al. (2009) exhibited that the white certificates system can stimulate innovation, improve energy efficiency, and identify energy saving opportunities for market participants. Friedrich and Afshari (2015) argued that the white certificates system is a mechanism that can facilitate the development of energy efficiency markets and improve demand-side energy efficiency. Stede (2017) determined that the energy savings from the implementation of the white certificate system in Italy accounted for 2% of primary energy consumption in Italy through empirical studies. Franzò et al. (2019) considered white certificates as a successful example of improving energy efficiency in the industry. Khatoon et al. (2019) examined the benefits and key influences of introducing blockchain technology into the white certificates program to improve energy efficiency. Child et al. (2008) discussed the interaction between the white certificate system and other emission reduction policy tools in Europe, believing that the white certificate system can promote the role of existing policy tools. Meran and Wittmann (2012) showed that the market-based white certificate scheme is on the agenda in several European countries to reduce carbon emissions and further increase green energy production. Petrella and Sapio (2012) believed that the trading mechanism of the white certificate system has significant volatility in an imperfect market environment, but still achieves the goal of improving the environment.

Few studies on ECRTS exist in China. Li and Lin (2016) used a three-stage DEA model to measure green productivity and determined that the promotion and adoption of ECRTS stimulates the growth of green productivity. Zhang and Zhang (2019) estimated the energy conservation and economic potential of ECRTS from the perspective of industrial subsectors and expected that the ECRTS could achieve a win–win situation for China's industrial economy and emission reduction; Wang et al. (2019) determined based on provincial-level panel data that China's energy intensity and total energy consumption decreased under the energy-consuming rights trading mode. Wang et al. (2021) empirically tested the effect of ECRTS on energy intensity based on provincial-level panel data, and found that compared to non-pilot areas, ECRTS can effectively reduce the energy intensity of pilot areas.

Influence factors of EE

Recent studies have identified several factors that remarkably affect EE, such as broadband infrastructure (Wen et al., 2022), information and communication technology (Zhu et al., 2023), market fragmentation of energy resource prices (Guo & Liu, 2022), digitalization (Gao et al., 2022), internet development (Wu et al., 2021), outward foreign direct investment (Ren et al., 2022), green finance (Zhou et al., 2023a, 2023b), and government resource allocation efficiency (Hao et al., 2020). With the strengthening resources, environmental constraints, and the continuous improvement of energy and environmental policies, numerous studies focused on the impact of environmental policies on energy efficiency. Anderson et al. (2010) found that the pilot areas of carbon trading will have a relatively higher possibility of environmental innovation, which is conducive to the improvement of EE. Based on the national panel data of seven major economies in the world, Roula (2017) determined that R&D investment is conducive toward promoting EE under the influence of environmental policies. Curtis and Lee (2019) determined that ER can significantly and positively affect total factor EE. Dirckinck-Holmfeld (2015) found that the Danish government's environmental permit is relatively vague and cannot effectively improve EE. Xie et al. (2017) examined the effect of different ER measures on total factor EE in the industrial sector and found a nonlinear relationship between command control ER and total factor EE. Gao et al. (2023) found that China's river chief system policy can improve the EE of enterprises by optimizing energy structure and promoting technological innovation based on industrial enterprises data. Scholars have explored the effect of green finance on EE based on the data of Chinese provinces or cities. Results show that green finance can effectively promote the improvement of EE (Su et al., 2022; Zhou & Qi, 2022; Zhou et al., 2022).

Scholars have reached a consensus on the superiority and effectiveness of white certificates system in improving energy efficiency, saving energy consumption, improving the environment, and saving costs. The literature on ECRTS is scarce, and the studies mainly focus on the policy effects of ECRTS at the provincial and industry levels, and we have not seen any study on the Porter effect of ECRTS at the firm level. As the mainstay of China's economic growth and energy consumption, the EE level of industrial enterprises is crucial to the implementation of the dual carbon goal. Examining the policy effects of the ECRTS from the enterprise perspective and discovering the EE and economic performance of enterprises under the ECRTS is scientifically and practically relevant. Therefore, re-evaluating the impact of China's pilot ECRTS on EE from the enterprise level is necessary to provide support for further improvement and promotion of the ECRTS.

Policy background and research hypothesis

Policy background

ER is an important tool for the government to address climate change and environmental management, and as policies continue to evolve, ER tools have become increasingly abundant. Since August 1973, when China introduced its first comprehensive environmental resource standard, China has gradually built up a system of command-and-control ER, market-based ER and voluntary ER after decades of exploration and practice. China already began to try and explore the use of market mechanisms to solve environmental pollution problems and achieved many useful results as early as the 1980s. For example, China implemented a pilot program in 2002 for total sulfur dioxide emission control and emissions trading in seven provinces, which include Shandong, Jiangxi and Jiangsu. The Ministry of Finance, together with several ministries and commissions, approved the launch of a system of paid use and trading of emission rights in 11 provinces since 2007, including Tianjin, Jiangsu, Zhejiang and Shaanxi, gradually shifting from unpaid allocation of emission targets to paid allocation and transfer through the secondary market, and gradually increasing the objects of pollutant trading from chemical oxygen demand and sulfur dioxide to ammonia nitrogen, total phosphorus and nitrogen oxides. The National Development and Reform Commission issued *the Notice on the Pilot Project of Carbon Emissions Trading* and launched carbon trading pilot projects in seven provinces in 2013, including Beijing, Tianjin, Chongqing and Hubei. The aforementioned market-based ER have laid a solid experience foundation for a sound system of paid use of environmental resources.

T reduces energy consumption further, implements the national autonomous emission reduction contribution and promotes the low-carbon transformation of China's economy. The Chinese government first proposed the concept of ECRTS in 2015. In July 2016, the Chinese government launched a pilot ECRTS in four provinces, namely Zhejiang, Fujian, Henan, and Sichuan. The government required each pilot area to conduct a pilot ECRTS in accordance with the national total energy consumption control goal, taking factors such as the level and stage of economic and social development in the region, industrial structure and layout, energy conservation potential, and resource endowment into account. The four pilot provinces of Zhejiang, Fujian, Henan, and Sichuan have all introduced and improved their work plans and management methods, and formally opened paid use and trading of energy rights in combination with regional characteristics, and made positive progress since then (Zhang & Zhang, 2019). As the pilot policy has been conducted for seven years, can the ECRTS promote the improvement of EE? This will be the main content to be examined in this study.

Research hypothesis

In the context of total energy consumption control, local governments issue energy-consuming rights quotas to polit enterprises, thus commoditizing energy-consuming rights. Once the energy consumption of enterprises exceeds the quotas allocated by government, they must buy the quotas, or they will be punished accordingly. As rational economic agents, enterprises pursuing profit maximization will respond to the stimulus of the ECRTS with appropriate adaptive behavior to avoid the additional cost of excessive energy consumption, thus effectively using the free energy-consuming quotas. Under the energy trading mechanism, local government energy conservation departments will stimulate enterprises to achieve energy conservation and emission reduction by limiting the energy use targets of high-energy-consuming areas and high-energy-consuming enterprises. The paid use of energy-consuming rights undoubtedly increases the additional cost of enterprises. Energy-consuming enterprises will adjust their production mode and adopt advanced and applicable energy-conserving technologies and equipment under the cost control incentive mechanism, thus improving EE.

According to Coase's theory of property rights, as long as the property rights are clear and the transaction costs are almost zero, the final result of market equilibrium is to achieve the Pareto optimum in resource allocation regardless of who is given the property rights at the beginning (Coase, 1960). After the implementation of energy-consuming rights trading policy, a transparent information disclosure system, sound credit evaluation system, supervision and management system will be realized (Pashigian, 1982), which will reduce the compliance cost and transaction cost of corporate entities, improve the liquidity of the trading market, and increase the enthusiasm of other entities to participate in carbon reduction. Therefore, the ECRTS can motivate enterprises to reduce energy consumption and make profits through market transactions. The ECRTS allows enterprises to trade energy-consuming right quotas under certain rules, and enterprises can choose to buy or sell quotas according to their own conditions. Those enterprises with higher energy-saving technologies can profit from their surplus energy-consuming quotas in the ECRTS when the price of energy-consuming right is higher than the marginal cost of energy saving and emission reduction. When the price of energy-consuming right is lower than the marginal cost of energy saving and emission reduction, enterprises can buy energy-consuming quotas in the ECRTS. When enterprises expect the price of energy-consuming right to rise, they may even over-invest in energy-saving technologies. Therefore, the ECRTS can promote an efficient allocation of energy factors through market-based means, pushing energy factors to gather in strategic emerging industries and energy-efficiency benchmark demonstration enterprises on a priority basis, thus promoting the improvement of the EE level of the whole industry. We propose the following hypothesis: China's ECRTS can improve the EE of enterprises.

Model and data

DID model

The DID model has become a common method for evaluating the implementation effect of a policy (Pippel & Seefeld, 2016). Since the model is well-known, we only provide a brief summary in the interest of brevity. To describe the policy impact and effectively overcome the related endogenous problems, we use the DID methodology to analyze the effect of ECRTS on EE. Take the pilot and non-pilot enterprises as the treated and control groups, respectively, and add other variables that have an impact on the EE effect. By comparing the differences between the control and treated group prior and subsequent to the implementation of the policy, the net effect of ECRTS on EE is measured. To test hypothesis, based on the ECRTS implemented in 2016, this study constructs the following model to test the impact of ECRTS on EE.

$$EE_{it} = \alpha_0 + \alpha_1 Treat_i \times Time_t + \alpha_2 CV_{it} + \mu_i + \gamma_t + \varepsilon_{it}, \quad (1)$$

where, *EE* is the dependent variable, indicating the EE level of the enterprise *i* in the year *t*. The key explanatory variables *Treat*×*Time*, *Treat* is a dummy variable of the treatment group, representing the enterprises in pilot areas. We assign 1 as the treatment group, and 0 as the rest. *Time* is the time dummy variable before and after the implementation of the ECRTS. The value of the *Time* is 1 after the implementation of the ECRTS. The value of the *Time* is 0 before the implementation. *CV* is shorthand for several different control factors that influence EE. μ and γ represent the firm and year-fixed effect, respectively. We are most concerned about the double difference term *Treat*×*Time*, whose estimated coefficient represents the net impact on the EE of enterprises before and after the implementation of the ECRTS. If the a_1 is significantly positive, which indicates that the ECRTS can improve the EE of enterprises and verifies the research hypothesis.

After obtaining the basic conclusions of this paper through Eq. (1), this paper uses methods such as parallel trend and placebo test, PSM, and IV to test the robustness of the conclusions. Subsequently, we use a mediating effect model to empirically test the two transmission channels which ECRTS affects EE. Next, we test the heterogeneity impact of ECRTS on different enterprises through group regression. Finally, we further analyze the economic effects of ECRTS based on adjusting Eq. (1).

Data and variable

Data source

The Chinese A-share listed firms from 2009 to 2020 were selected as the research object and processed the data as follows: (1) excluding firms with abnormal status; (2) excluding the firms in non-industrial industriess; (3) excluding firms that have been listed for less than 1 year; (4) excluding firms with serious lack of control variables; (5) winsorizing the main continuous variables at the 1% level. The firm data come from the Wind database.

Variable definition

ECRTS This paper constructs an interaction term for the dummy variable enterprise type and implemented time of ECRTS. We investigate the relationship between these two variables. *Treat*×*Time* measures the net effect of ECRTS on EE. *Treat* is used to define pilot enterprises, setting *Treat* of pilot enterprises to 1 and *Treat* of non-pilot enterprises to 0. *Time* is used to identify the time of ECRTS on the basis of the time point of policy occurrence.

EE According to Chen and Chen (2019), the EE of enterprises is expressed by the industrial output value per unit energy consumption, that is, the ratio of an enterprises' industrial output to its energy consumption. We use operating income as the proxy indicator of industrial output. For comparison purpose, referring to Su et al. (2022), we convert all types of energy consumption into tones of standard coal and the EE of enterprises are measured accordingly.

Control variables (CV) The below CV are elected to capture the possible impact of other relevant factors on EE. The CV mainly include enterprise age(lnage), operating income (lnincome), liability ratio (lnlev), return on assets (roa), R&D investment (rd), capital

Table 2 Variables' definitions

Variable	Definition	Measurement
ECRTS	Energy-consuming right transaction system	The interaction term for the dummy variable enterprise type and implemented time
EE	Energy efficiency	The industrial output value per unit energy consumption
lnage	Enterprise age	The logarithm of the enterprise age
lnincome	Operating income	The logarithm of enterprise operating income
lnlev	Asset liability ratio	The logarithm of ratio of total liabilities to total assets
roa	Return on assets	The ratio of the total profit to the total assets
lncapital	Capital stock per capita	The logarithm of ratio of net fixed assets to number of regular employees
rd	R&D investment	The logarithm of the enterprise R&D investment costs
top1	Ownership concentration	The logarithm of the shareholding ratio of the largest shareholder
TI	Technological innovation	The logarithm of the number of invention patent applications
CAE	Capital allocation efficiency	The enterprise investment level

stock per capita (lncapital), and ownership concentration (top1).

Table 2 reports the variables' definitions and Table 3 reports the descriptive statistics.

Results and discussion

Benchmark results

We estimate the impact of ECRTS on EE through Eq. (1). Table 4 reports the results of the ECRTS effect on EE. The first column shows the raw data without controlling the CV and the fixed effect of firm and year, whereas Columns (2) to (3) display the regression outcomes of adding the CV, year and firm fixed effect. Table 4 reveals that the estimated coefficients of *Treat*×*Time* are all significantly positive, revealing that the pilot policies have increased EE of enterprises. Therefore, the hypothesis is verified.

Robustness test

Parallel trend and placebo test

The validity of the DID technique is contingent on satisfying the parallel trend hypothesis. before ECRTS carry out, the same trends should be evident in the experimental and control groups. The current study takes the release of the ECRTS in 2016 as the cut-off point, and constructs the following model.

Table 3 Descriptive statistics

	Observation	Mean	Standard deviation	Minimum	Maximum
EE	13,766	0.0099	0.1472	0	7.5757
lnage	13,766	21.638	1.5473	0	28.7183
lnincome	13,766	1.48143	0.4951	0.18337	2.3865
lnlev	13,766	0.1306	1.6818	-2.9358	2.0891
roa	13,766	0.0588	0.1178	-0.5117	0.4245
lncapital	13,766	12.7726	1.01723	9.2969	15.7135
lnrd	13,766	12.7973	8.3688	0	22.2231
top1	13,766	2.3636	1.1571	-0.1515	3.9599

Table 4 The effect of ECRTS on EE

	(1) EE	(2) EE	(3) EE	(4) EE
Treat × Time	0.0458***	0.056***	0.0467***	0.0146**
	(0.00555)	(0.00636)	(0.00696)	(0.0073)
lnage		0.0148	0.0338***	0.0116***
		(0.00929)	(0.0123)	(0.00265)
lnincome		-0.0116***	-0.0107***	-0.00774
		(0.00332)	(0.00333)	(0.006)
roa		0.0951***	0.113***	0.0276
		(0.0271)	(0.0282)	(0.018)
lncapital		0.014***	0.0124***	-0.000587
		(0.00359)	(0.00361)	(0.00098)
lnlev		0.00402***	0.00120	-0.000197
		(0.00151)	(0.00156)	(0.000551)
top1		-0.0120***	-0.0141***	-0.000255
		(0.00268)	(0.00265)	(0.00124)
rd		0.000282	0.000264	0.000215
		(0.000324)	(0.000317)	(0.000245)
ID Effect	NO	NO	NO	YES
Year Effect	NO	NO	YES	YES
Observations	13,766	13,766	13,766	13,766
R-squared	0.001	0.009	0.012	0.826

*, **, *** represents significance level at 10%, 5%, 1% respectively, with robust stand errors in parentheses. The following tables are the same

Table 5 Parallel trend and placebo test

	(1) EE	(2) EE	(3) EE	(4) EE	(5) EE
Treat × Time			-0.0092	-0.0135	-0.0142
			(0.0151)	(0.0342)	(0.0236)
Treat × Time2013	-0.00298	-0.00407			
	(0.00968)	(0.00969)			
Treat × Time2014	-0.000599	-0.00179			
	(0.00952)	(0.00954)			
Treat × Time2015	0.00244	0.0033			
	(0.00968)	(0.00971)			
Treat × Time2016	0.0107***	0.00961**			
	(0.0035)	(0.00485)			
Treat × Time2017	0.0366***	0.0356**			
	(0.00118)	(0.0169)			
Treat × Time2018	0.00527***	0.00593**			
	(0.00151)	(0.0026)			
CV	NO	YES	YES	YES	YES
ID Effect	YES	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES	YES
Observations	13,766	13,766	6884	6884	6884
R-squared	0.623	0.816	0.512	0.519	0.517

Table 6 Excluding the impact of ER

	(1) EE	(2) EE	(3) EE	(4) EE	(5) EE	(6) EE
Treat × Time	0.0175*	0.0173**	0.0152**	0.0153**	0.014*	0.0145**
	(0.0097)	(0.0083)	(0.00722)	(0.00728)	(0.00719)	(0.00725)
CV	NO	YES	NO	YES	NO	YES
ID Effect	YES	YES	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES	YES	YES
Observations	11,616	11,616	10,188	10,188	13,766	13,766
R-squared	0.744	0.746	0.882	0.882	0.811	0.826

$$EE_{it} = \beta_0 + \sum_{t=2013}^{2018} \beta_t Treat_i \times \text{Time}_t + \beta_1 CV_{it} + \mu_i + \gamma_t + \varepsilon_{it}, \quad (2)$$

We estimate the parallel trend test through Eq. (2). Column 1 and 2 of Table 5 reports the results of parallel trend. The DID coefficients (*Treat × Time2016, Treat × Time2017, Treat × Time2018*) have become significantly positive, which means that the parallel trend test is passed. To rule out the possibility that the influence of the ECRTS on EE is interfered with by other non-observed missing variables and random factors, the placebo test was conducted. We assumed that the establishment periods of ECRTS were in 2013, 2014, and 2015. Column 3 to 5 of Table 5 reports the results of placebo test. The coefficients of *Treat × Time* are insignificant, which means that the placebo test is passed.

Excluding the effect of ER

During the research period of this study, some ER implemented in China may interfere with the results of this study, and it is necessary to eliminate the interference of these ER. In 2017, China implemented the GFPP and carried out green finance innovation in five provinces, including Zhejiang, Guangdong and Guizhou et al. The GFPP may affect the EE of enterprises in the pilot area through financial means. In this regard, we removed the samples in green finance pilot areas and later conducted regression. As column 1 to column 2 in Table 6 shows, the DID coefficients are positive, which proves that the effect is still robust. In 2013, China has launched a CTPP. The CTPP aims to encourage enterprises to reduce carbon emissions through market-oriented means, which is likely to have an impact on EE of enterprises. In this regard, the samples in pilot areas are removed and re-estimated. The DID coefficients in column 3 and column 4 are significantly positive. China has actively carried out carbon emission reduction practices at the city level, such as implementing a PLC to promote the low-carbon transformation. The Chinese government was responsible for initiating the first group of PLC in 2010. To broaden the scope of emission reduction efforts, the Chinese authorities embarked on the 2nd and 3rd batches of PLC in 2012 and 2017. To eliminate the interference of PLC, the study adds a cross-multiplication term of city fixed effect and year fixed effect in Eq. (1) to eliminate the impact of PLC. The DID coefficients in column 5 and 6 of Table 6 remain significant at the 10% level.

PSM

Given the current policy implementation background in China, the central government's selection of ECRTS may take into account factors such as regional economic development level and infrastructure improvement, affecting whether pilot areas are approved by the government's intentions. PSM can effectively solve the selection problem and control

Table 7 Other robustness tests

	(1) EE	(2) EE	(3) EE	(4) EE
Treat × Time	0.0175***	0.0173***	0.019*	0.0195*
	(0.0048)	(0.0521)	(0.0106)	(0.0118)
CV	NO	YES	NO	YES
ID Effect	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES
Observations	9610	9610	6884	6884
R-squared	0.854	0.866	0.832	0.878

selectivity bias. We selected control variables as identifying characteristics of the sample and used propensity PSM to match enterprises in pilot enterprises and non-pilot enterprises to eliminate sample selection bias and obtain bias-free estimates. Then, DID model is used to regress the matching results. As column 1 and 2 in Table 7 shows, the DID coefficients are positive, suggesting that the conclusion of this study has good robustness.

Reduce sample interval

The DID method may be more accurate in the estimation of short-term period samples (Zhou et al., 2023a, 2023b). The sample time of this paper is from 2009 to 2020. During the sample period of this paper, there may be other unobservable factors that interfere with the results. Therefore, we reduce the sample time to 2014 to 2018, and then re-estimate based on Eq. (1). The DID coefficients in column 3 and 4 of Table 7 are significantly positive, which shows that ECRTS can effectively improve the EE of enterprises. After reducing the sample interval, although the regression coefficient has changed, it is still significant at the 10% level, which further proves the robustness of the conclusions of this paper.

IV estimation

Although this study uses the DID method to remove variation over time and other unobservable factors to a certain extent, the selection of pilot areas may still be non-random. Thus, this study uses the IV method to address the problem of endogeneity further. The selection of IV must follow two key assumptions; namely, correlation and exogeneity. Referring to Lin and Tan (2019), the slope of the city is chosen as the IV for whether to include the pilot ECRTS, mainly for the following reasons: First, the smaller the city's slope is, the flatter the city, the higher the degree of industrial agglomeration, the higher the energy consumption, and the higher the possibility of being selected as a pilot area, i.e., the slope of the city satisfies the correlation condition. Therefore, the concern of this paper is whether the coefficient of $IV \times Time$ is significant, if it is significant, it indicates that the IV fulfills the correlation condition. Otherwise, it does not fulfill the correlation condition. Second, because the city slope is naturally formed, it cannot directly or indirectly affect the EE of enterprises and satisfies the exogeneity condition. The two-stage results of IV estimation are reported in Table 8. Column 1 presents the regression result of the first stage. The interaction term coefficient between IV and the time variable is significant, indicating that IV fulfills the correlation conditions. Column 2 shows the regression result of the second stage. The DID coefficient is still significantly positive, indicating that ECTRS can still significantly improve EE after eliminating the endogenous problem in the selection of cities in the experimental group.

Table 8 IV estimation

Variables	(1) Treat × Time	(2) EE
IV × Time	0.243*** (0.0784)	
Treat × Time		0.166** (0.083)
CV	YES	YES
ID Effect	YES	YES
Year Effect	YES	YES
Observations	13,766	13,766
R-squared	0.835	0.713

Mechanism analysis

A mediation effect model is constructed to test whether PFTZ can improve EE through TI and CAE.

$$Med_{it} = \alpha_0 + \beta_1 Treat_i \times Time_t + \beta_2 CV_{it} + \mu_i + \gamma_t + \varepsilon_{it}, \quad (3)$$

$$EE_{it} = \alpha_0 + \lambda_1 Treat_i \times Time_t + \lambda_2 Med_{it} + \lambda_3 CV_{it} + \mu_i + \gamma_t + \varepsilon_{it}, \quad (4)$$

where *Med* is the mediating variable. The mediating mechanism variables selected comprise TI and CAE. The logarithm of the number of invention patent applications is selected as the proxy variable of TI. This study uses the enterprises' investment level as the proxy variable for CAE, which is measured by the ratio of the enterprise's investment to total assets. The mediating effects of CAE and TI can be tested through the significance of β_1, λ_1, and λ_2.

Table 9 Test results of mechanism research

	(1) TI	(2) EE	(3) CAE	(4) EE
Treat × Time	0.131***	0.0123**	0.059*	0.0127**
	(0.0334)	(0.0059)	(0.032)	(0.0058)
TI		0.0171*		
		(0.0095)		
CAE				0.032*
				(0.017)
CV	YES	YES	YES	YES
ID Effect	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES
Observations	13,766	13,766	13,766	13,766
R-squared	0.468	0.81	0.512	0.823

TI

We estimate the mediation effect of TI through Eq. (3) and Eq. (4). The DID and *TI* coefficients in Columns 1 to 2 of Table 9 are significant, indicating that TI is the mediating variable for ECRTS to improve EE. The ECRTS is an energy-saving and consumption-reducing policy, whose core objective is to provide full play to the role of market mechanism to promote the redistribution of energy quotas between units with high energy efficiency and low energy consumption and units with low energy efficiency and high energy consumption, to improve the efficiency of energy allocation. When enterprises use more energy than the allocated standard, they need to purchase energy quotas in the ECRTS, which can increase their production costs. Enterprises seeking to maximize profits will choose TI to reduce energy consumption per unit of production to reduce the cost burden caused by the implementation of the policy, thus avoiding the purchase of energy consumption. The external pressure created by the policy implementation will motivate firms to modify their existing equipment (Qi et al., 2021) or introduce high-efficiency production equipment to change their inefficient energy use fundamentally. TI and upgrading creates conditions for enterprises to form economies of scale, which reduces their production costs by driving up the overall production level and compensates for innovation R&D expenditures, thus forming a virtuous circle that continuously motivates enterprises to engage in technological innovation. The ECRTS also provides a trading platform for surplus energy quotas, and enterprises can sell energy-consuming rights indicators to obtain economic returns and use the profits for technological optimization, providing continuous financial support for their technological innovation and R&D (Xue & Zhou, 2022). Under the double-control constraint of energy consumption, the ECRTS enables enterprises to give full play to their subjective initiative to promote TI, thus causing an improvement in EE.

CAE

We estimate the mediation effect of CAE through Eq. (3) and Eq. (4). The DID and *CAE* coefficients in Columns 3 to 4 of Table 9 are significant, indicating that CAE is the mediating variable for ECRTS to improve EE. The initial allocation of energy-consuming right indicators under the ECRTS policy is based on the energy consumption in recent years, the energy consumption level of industry EE leaders or the target task of eliminating excess capacity. The marginal cost of enterprises will further increase and may even threaten their survival because the government attaches more importance to energy conservation and consumption reduction and the market demand for green economic development increases, thus facing the possibility of stopping production and withdrawing from the market (Zhou et al., 2023a, 2023b). Insufficient energy quotas signal to enterprises that they are using resources inefficiently, which means that their resource allocation efficiency could be further optimized. Rational enterprises will choose to change their production mix based on long-term economic interests, shift resources from high-energy-consuming products to low-energy-consuming products or eliminate inefficient products, optimize the overall CAE of enterprises by adjusting productive investments, and improve the EE.

Heterogeneity analysis

Heterogeneity of enterprise property rights

Previous studies have concluded that SOEs have significant institutional advantages, ECRTS may have heterogeneous effects on EE across ownership types. Columns 1 and 2 of Table 10 exhibit the heterogeneous effects of ECRTS on the EE of SOEs

Table 10 Estimation results of heterogeneity

	(1) EE	(2) EE	(3) EE	(4) EE
Treat×Time	0.0256**	0.00581	0.019	0.0183***
	(0.0108)	(0.0113)	(0.036)	(0.057)
CV	YES	YES	YES	YES
ID Effect	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES
Observations	8126	5604	4332	9434
R-squared	0.748	0.875	0.706	0.733

Table 11 Estimation results of heterogeneity

	(1) EE	(2) EE	(3) EE	(4) EE
Treat×Time	0.0186**	0.0091*	0.0331	0.0273***
	(0.008)	(0.0051)	(0.056)	(0.0094)
CV	YES	YES	YES	YES
ID Effect	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES
Observations	5628	8138	4812	8954
R-squared	0.649	0.778	0.706	0.733

and non-SOEs. The results show that ECRTS has a greater effect on the improvement of EE of SOEs compared to non-SOEs. On the one hand, SOEs bear greater pressure to reduce emissions and greater energy conservation tasks, and focus more on coal conservation (Zhou et al., 2022). On the other hand, SOEs have greater asset sizes, lower financing constraints, and have greater advantages in investing in production equipment or pollution control equipment. SOEs have a stronger ability to resist risks in independent research and development investment and are more equipped with innovative conditions. Therefore, ECRTS has a stronger incentive for SOEs to improve EE.

Heterogeneous of executives with financial background

Column 3 of Table 10 shows that in the sample enterprises without financial background of executives, the DID coefficient is insignificant. Column 4 of Table 10 shows that in the sample enterprises with financial background of executives, the DID coefficient is positive at the significance. This indicates that ECRTS can motivate enterprises with financial background of executives to improve EE, while its impact on enterprises without with financial background of executives is not obvious. This may indicate that the leadership with financial background may be more predictive of policy than the senior personnel without financial background. They are better able to judge the future economic trend and the future development direction of enterprises by combining national policies and international economic and financial trends, to infer the next policy direction of the country and make adequate preparations in advance. Management with financial backgrounds may also have strong policy understanding and reaction ability. Its own financial expertise can easily understand the intention of the policy and respond quickly, after the ECRTS is implemented. This will enable enterprises to participate in ECRTS as soon as possible, help them obtain the policy dividends provided by the ECRTS policy, and promote EE.

Heterogeneous of industry pollution level

The pollution intensity varies significantly across industries and differences may exist in the EE. Based on Zhou et al., (2023a, 2023b), the sample is divided into polluting and clean industries to discuss the effect of heterogeneity. Columns 1 and 2 of Table 11 show that the coefficients of high polluting industries and clean industries are significantly positive, while the coefficients of high polluting industries are significantly higher than those of clean industries, indicating that the implementation of ECRTS is more helpful to improve the EE of enterprises in polluting industries. The stronger the environmental enforcement, the higher the cost of violation faced by enterprises, the less likely they will choose to steal and leak emissions and other violations, and the more likely they will follow ECRTS regulations. While the ECRTS policy is more stringent in regulating highly polluting industries, and highly polluting industries are facing the pressure of industrial restructuring to remove production capacity, which makes the industry's profit seriously squeezed. Enterprises realize the necessity of changing production methods and improving EE, and increase their R&D efforts and introduce efficient production technologies, thus improving their EE.

Heterogeneous of regional resource endowment

Abundant natural resources may also be an obstacle toward regional economic development, and a resource curse effect exists in the EE of enterprises in regions with abundant resource endowments (Wang et al., 2022b). Therefore, for enterprises in resource-rich regions, further exploring whether ECRTS can improve their EE is necessary. According to existing research practices (Zhou & Qi, 2022), various regions in China are divided into high resource endowment regions and low resource endowment regions based on resource endowment. The regression results are shown in Columns 3 and 4 of Table 11. Regression results show that ECRTS significantly improves enterprises' EE in areas with low resource endowments, while the impact of ECRTS on EE is insignificant within areas with high resource endowments. The impact of ECRTS on EE of enterprises in different regions with different resource endowments presents significant differences. Most regions with high resource endowments develop resource-based industries, resulting in increased pollution emissions. Accordingly, ECRTS provides high compliance costs. Relying on production technology innovation and green technology innovation to achieve pollution reduction requires a certain amount of time. Enterprises often choose end-of-pipe treatment to reduce pollution emissions, which may also crowd out investment in research and development resources, which is inconducive to improving EE (Wang et al., 2022b). Energy prices in regions with high resource endowments are relatively low, and enterprises can offset the adverse effects of ECRTS by expanding production scale, leading to resource influx into the production chain, innovation crowding out, and ultimately making the impact of ECRTS less significant.

Economic effect of ECRTS

The following model is constructed by referring to Wang et al. (2022a) to investigate whether the improvement of EE of enterprises participating in ECRTS can further enhance the enterprise value with the implementation of ECRTS.

$$Vaule_{it} = \alpha_0 + \alpha_1 Treat_i \times Time_t \times EE_{it} + \alpha_2 CV_{it} + \mu_i + \gamma_t + \varepsilon_{it}, \quad (5)$$

Table 12 Economic effect of ECRTS

	(1) Value	(2) Value
Treat×Time×EE	0.00543***	0.0061***
	(0.00193)	(0.00169)
CV	NO	YES
ID Effect	YES	YES
Year Effect	YES	YES
Observations	13,766	13,766
R-squared	0.907	0.916

The explained variables in Eq. (5) represent the enterprise value. The enterprise value is expressed as the sum of the equity market value, net debt market value, and non-tradable equity market value. The non-tradable equity market value is replaced by net assets. The larger the value, the higher the enterprise value. We estimate the economic effect of ECRTS through Eq. (5). Columns 1 and 2 of Table 12 reports the coefficients of $Treat \times Time \times EE$ are significant, which indicate that the improvement of EE can further enhance the value of enterprises after enterprises participate in ECRTS. With the government's emphasis on sustainable green development and the call for environmental protection related policies, the public is increasingly paying attention to the enterprises' environmental information. Relevant studies indicate that the capital market will react to environmental information of listed enterprises (Chen et al., 2006; Wang et al., 2022a, 2022b). Ma and Shen (2022) determined that corporate environmental pollution scandals can lead to a decline in corporate value by studying the public's response to media exposure of corporate environmental protection. By participating in the ECRTS, enterprises can improve EE and reduce pollution, which can demonstrate their support for green causes, reflect their sense of social responsibility, and improve their reputation. At the same time, the environmental benefits brought by the improvement of EE and the reduction of carbon emissions also further accumulate the green reputation of enterprises, enhance investor confidence in enterprises, encourage investors to purchase corporate stocks more actively, and enhance enterprise value.

Conclusions, policy implications and limitations

Conclusions

Whether the implementation of energy-consuming right transaction system can achieve economic growth effects while giving full play to the effectiveness of the policies has been an important topic of concern to the academic community. Based on the data of listed enterprises in China from 2009 to 2020, this paper uses a difference-in-difference model to explore the impact, mechanism, and heterogeneity of energy-consuming right transaction system on energy efficiency of enterprises. Energy-consuming right transaction system can promote the improvement of energy efficiency of enterprises. The energy-consuming right transaction system promotes the enterprises' energy efficiency by promoting technological innovation and optimizing the efficiency of capital allocation. The energy-consuming right transaction system is conducive toward improving the energy efficiency of state-owned enterprises, enterprises with executives financial background, high pollution enterprises, and enterprises in regions with low resource endowments. The improvement of energy efficiency can further enhance the value of enterprises after enterprises participate in energy-consuming right transaction system. This research has important implications for understanding the energy policy because of China's rapid economic growth and serious pollution problem. This paper expands the literature in evaluating the effectiveness of energy-consuming right transaction system and provides a decision-making reference for improving the design of energy-consuming right transaction system, and promoting the realization of dual control goals for energy consumption. Also, this is the first empirical research in exploring the impact of energy-consuming right transaction system on energy efficiency in the Chinese context, which is an important complement to current studies that focus on developed countries.

Policy implications

This study proposes the following policy implications based on the aforementioned conclusions:

First, the implementation of energy-consuming right transaction system can effectively improve the energy efficiency of enterprises. The government should follow the trend of market-oriented reform and expand the scope of pilot projects in an orderly manner based on successful policy experiences. While using energy-consuming rights indicators to constrain enterprises' energy-consuming behavior, fully utilize the market-oriented nature of energy-consuming right transaction system to stimulate the enterprises' awareness of independent energy conservation and emission reduction. Appropriate increases in energy-consuming rights quotas are used as incentives for enterprises that invest heavily in research and development funds to upgrade production technology and equipment, thus allowing enterprises to have surplus indicators to sell on the trading market in exchange for additional financial support. The government needs to establish an effective punishment mechanism and strengthen the supervision and management of regional regulatory agencies, improve the construction of laws and regulations related to energy-consuming right transaction system, and provide effective protection for energy-consuming right transaction system.

Second, non-state-owned enterprises have significant financing constraints and are faced with serious capital shortages. The cost effects generated by regulating energy-consuming right transaction system may have a negative impact on the normal production and operation activities of enterprises. The government should increase financial support for non-state-owned enterprises, assist enterprises in the transformation of production methods, and stimulate technological innovation and research through financial, tax, and other means. Adjust the initial allocation mechanism for energy-consuming rights, increase regulatory efforts in low energy consumption industries, and enhance the motivation for energy efficiency improvement in low energy consumption industries.

Third, promoting enterprise technological innovation and optimizing the efficiency of enterprise capital allocation are important mechanisms for energy-consuming right transaction system to improve enterprises' energy efficiency. Therefore, enterprises should start with innovation, improve team research and development efficiency, introduce high-tech research, and development talents and innovative talents, as well as conduct innovative development strategies. The government should increase foreign investment and talent introduction, and provide financial support to enterprises through subsidies and finance to ensure the smooth progress of enterprise innovation and research and development.

Fourth, enterprises should pay attention to green financing tools such as green bonds and green credit when making production decisions, and can use the green finance market and relevant policy incentive systems to promote energy conservation, emission reduction and green development of enterprises. Enterprises should actively disclose carbon asset information, disclose the trading status of carbon assets and various energy consumption situations, accept public supervision, and promote the achievement of the "dual carbon" goal.

Fifth, in the context of carbon neutrality, the BRICS countries, representatives of emerging developing countries, have proposed their own adaptation policies and carbon emission reduction targets. However, all the BRICS countries still rely heavily on fossil fuels, which poses a real challenge to emission reduction. As an effective market-oriented emission reduction policy, the energy-consuming right transaction system has achieved remarkable results in China. Therefore, China's energy-consuming right transaction system experience can provide a reference for other developing countries under the international pressure of curbing emission and temperature rise.

Limitations

Due to differences in resource allocation efficiency and technological innovation levels among different pilot areas, the impact of energy-consuming right transaction system on energy efficiency varies among different pilot areas. This paper does not further investigate the heterogeneous impact of energy-consuming right transaction system on energy efficiency in different regions. In the future, we will examine the role of energy-consuming right transaction system in Zhejiang, Fujian, Henan, and Sichuan on energy efficiency, respectively. In addition, this study only examined the intermediary channels of capital allocation efficiency and technological innovation. The energy-consuming right transaction system may also affect energy efficiency through other ways, which were examined later in this study.

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Declarations

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