Study on the influence of carbon trading pilot policy on energy efficiency in power industry

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Abstract

Purpose – To cope with climate change and achieve the dual carbon goal, China has actively promoted the implementation of carbon trading pilot policy, among which the power industry plays an important role in China's carbon emission reduction work. The purpose of this paper is to study the influence of carbon trading policy on the energy efficiency of power industry and achieve the comprehensive goal of carbon emission reduction, carbon peak and carbon neutralization.

Design/methodology/approach – This paper constructs the difference-in-differences model based on 2012–2019 provincial data to study the impact of carbon trading policy on energy efficiency in the power industry and its effect path. Heterogeneity analysis was conducted to compare the effects of carbon trading policy in eastern, central and western regions as well as at different levels of power structures.

Findings – Carbon trading policy can significantly improve the energy efficiency of the power industry, and the policy effect is more significant in eastern and western regions and areas with high power structure. Mechanism analysis shows that carbon trading policy mainly influences the energy efficiency of power industry by environmental protection investment, power consumption demand and industrial structure.

Originality/value – This paper uses provincial panel data to deeply study the influence of carbon trading policy on energy efficiency of the power industry and its effect path. By constructing the difference-in-differences model, this paper empirically analyzes the governance effect of carbon trading policy. Meanwhile, it controls individual and time effects to solve the endogeneity problem prevalent in previous literature.

Keywords Carbon trading, Carbon emissions, Electric power industry, Energy efficiency

Paper type Research paper

1. Introduction

Since the reform and opening up, China has become the second largest economy in the world, but the energy consumption and environmental pollution caused by the increase in economic activities have seriously threatened the realization of China's green sustainable

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development goals. Environmental resources are the common wealth of mankind, but because of its indivisible public attributes, it leads to the wanton destruction and waste of natural resources, and environmental pollution has significant negative externalities, and economic subjects will choose to bear the consequences of environmental pollution by society when balancing personal interests and social costs (Coase, 1960). Therefore, the government must intervene and formulate relevant policies and regulations to control. China has successively issued laws and regulations such as The Environmental Protection Law and The Air Pollution Prevention and Control Law, and it has become inevitable to transform the traditional economic development model to the path of circular and low-carbon sustainable economic development (Ye *et al.*, 2022). Carbon trading market is an important policy tool to achieve carbon neutrality (Xie *et al.*, 2021). As the largest carbon trading market in the world, the European carbon emission trading system has an obvious effect on promoting low-carbon emission reduction (Co *et al.*, 2013). To promote the orderly development of carbon emission reduction, China also started carbon emission trading pilot in 2011. China's carbon emissions have shown a rapid growth trend since the reform and opening up. According to the statistical data of Company (2021), China's carbon emissions increased from 8.83 billion tons to 9.90 billion tons from 2011 to 2020 (Xu *et al.*, 2022; Company, 2021), which shows the situation of emission reduction is grim. The power industry is the world's largest source of CO_2 emissions (IEA, 2018), as well as in China (Wang *et al.*, 2021). At present, the power structure of the power industry is still dominated by thermal power generation. According to statistics, although the proportion of thermal power generation decreased from 80.8% in 2010 to 67.9% in 2020 (Wang *et al.*, 2022), it is still in a leading position, and the energy efficiency of the power industry needs to be further improved. At the Climate Ambition Summit, General Secretary Xi announced some further commitments for 2030: China's CO_2 emissions per unit gross domestic product (GDP) will fall by more than 65% from 2005 levels (Xi, 2020). It can be seen that China's environmental protection task is still difficult in the future, and paying attention to the impact of carbon trading policy on the energy efficiency of the power industry has important research significance for optimizing China's power structure, reducing carbon emission and achieving the "dual carbon" goal.

In terms of studies on carbon trading policy, most scholars take carbon emission reduction as the evaluation standard of policy and believe that carbon trading policy can indeed achieve carbon emission reduction targets (Sun *et al.*, 2020; Li *et al.*, 2022; Yang *et al.*, 2021). Some scholars hold the opposite view and believe that carbon trading policy is not entirely beneficial (Pan *et al.*, 2021). In addition, many studies have found that carbon trading policy has some spillover effects of promoting economic growth (Cecilia *et al.*, 2019) and increasing R&D investment in renewable energy (Marcin *et al.*, 2019), which can achieve the policy effect targets by effect path such as environmental protection investments (Liu *et al.*, 2022), industrial structure, energy structure and technological upgrading (Ren and Fu, 2019).

Carbon emission reduction is an important means for China's social development to achieve a comprehensive green transformation and improve the quality of the ecological environment. China is committed to effectively supporting high-quality economic development with low energy consumption and carbon emissions and supporting economic and social systemic changes with profound changes in the energy industry, so it is necessary to solidly promote carbon emission reduction work and help achieve the "double carbon" goal. As one of the most important energy consumption industries and pollutant emission industries, the selection of CO_2 emission reduction paths and the formulation of emission reduction plans in the power industry play a key role in achieving carbon peaking and carbon neutrality goals for the country. As for the research on carbon emissions from the power industry, some scholars think about the influencing factors of carbon emissions from the power industry. It is not difficult to find that technological innovation (Peng and Tao, 2018), regional economic development (Cao and Jiang, 2018; He *et al.*, 2020), industrial structure adjustment and energy consumption (Yu, 2021) have become the focus of previous scholars. Another part of scholars studied the emission reduction path of the electric power industry, they predicted the carbon peak time in China (Yuan *et al.*, 2014; *Wang et al.*, 2017) and believed that carbon emission reduction targets in the power industry can be achieved by adjusting industrial structure (Pei *et al.*, 2016), optimizing power structure and making full use of environmental protection investment (Li *et al.*, 2021). To promote the development of carbon emission reduction, carbon pricing policy has become an effective tool for more and more countries to stimulate carbon emission reduction. Many scholars have studied its effect in two forms – carbon tax (Yu and Lv, 2017; Duan *et al.*, 2019) and carbon trading policy (Li *et al.*, 2015; CAFS Research Group, 2018). As for the research on the impact of carbon trading policy on the power industry, scholars believe that carbon pricing mechanism, carbon financial instruments (Chen and Zhao,2021) and carbon information disclosure system (Liu *et al.*, 2021) can be used to improve carbon trading policy to further promote carbon emission reduction in the power industry.

Through the review of the previous literature, this paper found the following deficiencies: From the perspective of research scope, most scholars in the past paid attention to the performance of power enterprises and chose to conduct in-depth research from the national perspective rather than the provincial perspective. From the perspective of research objects, in the past, scholars mostly studied the influencing factors of carbon emissions in the power industry from a macro perspective, lacked operability and lacked research on energy efficiency in the power industry from a micro perspective. From the perspective of research methods, there was a lack of policy effect research on the construction of the difference-in-differences model. Based on this, the possible marginal contribution of this paper is to study the impact and its role path of carbon trading policy on energy efficiency in the power industry based on the provincial panel data from 2012 to 2019, take the energy efficiency of the power industry as the research object, empirically analyze the governance effect of carbon trading policy by constructing the difference-in-differences model and control individual and time effects to solve the endogenous problems prevalent in the previous literature. This study in depth analyses its impact mechanism, explores the role path of improving the energy efficiency of the power industry and provides a favorable basis for promoting the national carbon trading market and further improving the carbon trading system.

2. Theoretical analysis and research hypothesis

Carbon trading policy is an institutional initiative that uses market mechanism to control and reduce greenhouse gas emissions and promote green and low-carbon development, regarding carbon emission rights as a commodity to buy and sell and allocating enterprises' carbon emission credits by market means. The power industry is the key to reducing carbon emissions because it emits more carbon than any other industry. High-carbon emission power generation enterprises need to purchase the excess part of the emission quota from the carbon market, while the remaining carbon credits of low carbon-emitting power generation enterprises can be sold in the carbon market to earn profits. Therefore, to expand the living space of enterprises, both sides constantly adjust their business strategies to effectively promote the overall carbon emission reduction work of the power industry and improve energy efficiency. Based on this, this paper proposes the following hypotheses:

H1. Carbon trading policy can improve energy efficiency in the power industry.

Any reform will face resistance. To reduce greenhouse gas emissions and promote green and low-carbon development, the government must increase input of various factors to achieve the set goals. While carrying out the pilot work of carbon emission right trading, the National Development and Reform Commission has taken corresponding preferential policies and measures to continuously increase environmental protection investment, promote the power industry to adjust its business strategy and then improve its own energy efficiency to realize the increase of emission reduction benefits. Based on this, this paper proposes the following hypotheses:

H2. Carbon trading policy can improve energy efficiency in the power industry by increasing environmental protection investment.

With the deepening of China's energy reform, carbon trading policy has become an important way to improve China's energy demand side efficiency. Through the market mechanism, carbon trading policy affects the electricity consumption behavior of electricity market subjects and slows down the growth of electricity demand of various subjects. Therefore, the power industry is bound to continuously improve energy efficiency through the elimination of outdated units, development of clean energy and other measures to achieve the optimal allocation of resource factors. Based on this, this paper proposes the following hypotheses:

H3. Carbon trading policy can improve energy efficiency in the power industry by slowing the growth of electricity demand.

Under the condition of market economy, the adjustment of industrial structure becomes the key to realize high-quality economic development and effective allocation of resources. The Guidance Catalogue for Industrial Structure Adjustment issued by the National Development and Reform Commission mentioned the encouragement, restriction and elimination category for providing guiding adjustment of the development in the power industry. It will promote the power industry to reduce the thermal power production quota, reduce the total energy consumption, optimize the technical level of the power industry, improve its energy structure and then improve the energy efficiency of the power industry. Based on this, this paper proposes the following hypotheses:

H4. Carbon trading policy can improve the energy efficiency in the power industry by optimizing the industrial structure.

3. Model construction and data description

In the second half of 2013, seven provinces and cities, including Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Shenzhen and Hubei, launched carbon emission trading pilot programs. Considering the availability of data, this paper selects balanced panel data from 30 provinces from 2012 to 2019 to estimate the impact of carbon trading policy on energy efficiency in the power industry. Since the carbon trading pilot was actually launched in the second half of 2013, this paper takes 2014 as the external impact point of the policy. Because of the lack of data in Xizang and the urban attributes of Shenzhen, to ensure the uniformity of the research scope, this paper chooses six pilot provinces of carbon emission trading as the experimental group (except Shenzhen) and other provinces as the control group (except Xizang) as the final samples. The data in this paper are all from China City Statistical Yearbook, China Electric Power Statistical Yearbook, National Bureau of Statistics and EPS database. The meanings and data sources of the main variables are shown in the following Table 1.

3.1 Model setting

This paper uses the difference-in-differences model to identify the carbon trading policy influence on energy efficiency of the power industry. To solve the endogenous problems prevalent in the existing literature, this paper will observe the degree of influence of carbon trading policy in the energy efficiency of the power industry in four cases: without adding control variables, adding control variables, controlling individual effects alone and controlling individual and time effects at the same time. The model set up is as follows:

$$Y_{it} = \beta_0 + \beta_1 * treat_i + \beta_2 * post_t + \beta_3 * DID + \alpha * control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

Y_{it} represents the energy efficiency of the power industry, expressed by the coal consumption of power plants with 6,000 kW and above (g/kWh); $DID = treat_i * post_t$ is the core explanatory variable of the model; If $treat_i = 1$, then it means that the city is a pilot city of carbon trading policy; otherwise, $treat_i = 0$; If $post_t = 1$, then the year is greater than or equal to 2014; otherwise, $post_t = 0$; If $DID = 1$, then it means that the city is the pilot city of carbon trading policy at the time; otherwise, $DID = 0$. $control_{it}$ represents the control variables, μ_i and γ_t represent the individual fixed effect and time fixed effect and ε_{it} represents the residual term.

3.2 Selection of variables

The explained variable Y_{it} represents the energy efficiency of the power industry, measured by the coal consumption of power plants with 6,000 kW and above (g/kWh). The power

Variable category	Variables	Meaning	Data sources
Explained variable	The energy efficiency of the power industry (Y)	The coal consumption of power plants with 6,000 kW and above (g/kWh)	China Electric Power Statistical Yearbook
Control variables	Energy consumption structure (Con)	The ratio of total coal consumption to total energy consumption in China	EPS database
	Economic development level (GDP)	The regional development level (100m yuan)	China City Statistical Yearbook
	Government size (Gov)	General public budget expenditure (100 million yuan)	National Bureau of Statistics
	Power structure (Power)	proportion of installed thermal power generation capacity	China Electric Power Statistical Yearbook
Intermediary variables	Environmental protection investment (Inv)	Local fiscal environmental protection expenditure (100m yuan)	National Bureau of Statistics
	Electricity demand (Dem)	The electricity consumption of the whole society (billions of kilowatt hours)	China Electric Power Statistical Yearbook
	Industrial structure (Ind)	The ratio of GDP added value of tertiary industry to GDP added value of secondary industry	China City Statistical Yearbook

Table 1. The meanings and data sources of the main variables

generation coal consumption = power generation coal consumption quantity/capacity, and the greater the coal consumption of power generation, the lower the energy efficiency of power industry.

Core explanatory variable $DID = treat_i * post_i$; if $DID = 1$, then it means that the city is the pilot city of carbon trading policy at the time; otherwise, $DID = 0$.

For the control variables, the existing research on the use of data to verify the carbon reduction and emission reduction path of the power industry only controls the factors related to the power industry. On this basis, this paper introduces the control variables from the two aspects of macro factors and power industry factors. First, economic development level (GDP)and government size (Gov) are introduced as macro factors, and energy consumption structure (Con) and power structure (Power) are introduced as factors in the power industry. Energy consumption structure (Con) is measured by the ratio of total coal consumption to total energy consumption in China; economic development level (GDP) is measured by the regional development level (100m yuan); government size (Gov) is measured by general public budget expenditure (100m yuan); and power structure (Power) is measured by proportion of installed thermal power generation capacity.

Intermediary variables include the following variables: environmental protection investment (Inv) is measured by local fiscal environmental protection expenditure (100m yuan); the electricity demand (Dem) is measured by the electricity consumption of the whole society (billions of kilowatt hours); and industrial structure (Ind) is measured by the ratio of GDP added value of tertiary industry to GDP added value of secondary industry. Descriptive statistics of variables are shown in Table 2.

4. Empirical analysis and discussion

4.1 Baseline regression results

To test *H1*, this study empirically studies the impact of carbon trading policy on energy efficiency of the power industry based on the above Model (1). Table 3 analyzes the influence of carbon trading policy on energy efficiency in the power industry under four conditions: Column (1) without control variables, Column (2) with control variables, Column (3) with individual effects alone and Column (4) with individual and time effects simultaneously.

As shown in Table 3, DID coefficients in the above four cases are all significantly negative, indicating that the implementation of carbon trading policy helps reduce coal consumption for power generation and promote the improvement of energy efficiency. From the control variables, the influence of energy consumption structure, economic development level and power structure on coal consumption is positive, which indicates that the higher the economic development level is, the greater the coal consumption is, the lower the energy efficiency is. As the energy consumption structure is the ratio of total coal consumption to

Variable category	Variables	*N*	Mean	SD	Minimum	Maximum
Explained variable	Y	240	295.4	18.98	201.1	342
Control variables	Con	240	0.387	0.146	0.0121	0.687
	GDP	240	24805	20107	1528	107987
	Gov	240	5083	2693	864.4	17298
	Power	240	0.655	0.217	0.124	0.987
Intermediary variables	Inv	240	151.5	98.87	21.23	747.4
	Dem	240	2001	1412	210	6696
	Ind	240	1.326	0.720	0.611	5.234

Table 2. Descriptive statistics of variables

Variables	(1) Y	(2) Y	(3) Y	(4) Y
DID	−23.74*** (3.074)	−8.765*** (2.920)	−13.00*** (2.330)	−10.37*** (2.337)
Con		60.13*** (6.955)	54.59*** (11.49)	18.98 (12.67)
GDP		0.000315** (0.000134)	0.000419** (0.000178)	0.000209 (0.000174)
Gov		−0.00276*** (0.000991)	−0.00215** (0.00101)	0.000476 (0.00106)
Power		−27.47*** (4.454)	51.13*** (9.882)	12.04 (11.41)
Control variables	NO	YES	YES	YES
Individual effect	NO	NO	YES	YES
Time effect	NO	NO	NO	YES
Constant	298.9*** (1.191)	297.6*** (4.773)	220.1*** (11.45)	269.8*** (13.90)
Observations	240	240	240	240
R^2	0.200	0.473	0.920	0.933

Notes: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 3. Baseline regression results

total energy consumption and the power structure is the proportion of installed capacity of thermal power generation, it indicates that the higher the proportion of coal consumption and installed capacity of thermal power generation is, the higher the coal consumption of power generation is, the lower the energy efficiency is. The influence of government size on coal consumption of power generation is significantly negative, which indicates that the expansion of government size will lead to the reduction of coal consumption of power generation and the improvement of energy efficiency.

4.2 Robustness test

4.2.1 Parallel trend test. This paper uses difference-in-differences model to assess the effect of carbon trading policy on the premise that the parallel trend test is satisfied, which means that there is no difference between the experimental group and the control group before being affected by the policy, so the difference-in-differences result can represent the net effect of the policy.

In Figure 1, the dotted line represents the implementation year of carbon trading policy. The left side of the dotted line indicates that before 2014, the coal consumption of power generation in the experimental group and the control group showed a decreasing trend, and the decreasing trend was basically the same. On the right of the dotted line, after the implementation of carbon trading policy, the decreasing trend of coal consumption for power generation in the experimental group and the control group began to differ, in which the decreasing trend of coal consumption of power generation in the experimental group was significantly larger than that in the control group. Therefore, it is qualified to study the influence of carbon trading policy on energy efficiency of power industry by using the difference-in-differences model.

4.2.2 Dynamic effect test. As the implementation of carbon trading policy is a continuous process of dynamic change, it is necessary to consider the dynamic marginal effect of the policy on the energy efficiency of the power industry. This paper tests the dynamic effect of carbon trading policy and further verifies the parallel trend of the energy efficiency of the power industry mentioned above. The specific approach is as follows: the policy dummy variables and the dummy variables of each year before and after the policy are, respectively, used to form interaction items, and the first period before the policy is selected as the benchmark group. Then these virtual interaction items and control variables are regressed by the explained variables, as shown in Figure 2.

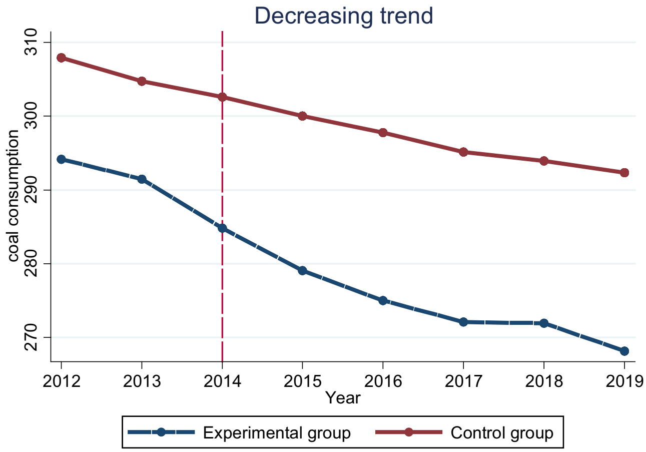

Figure 1.
Parallel trend test

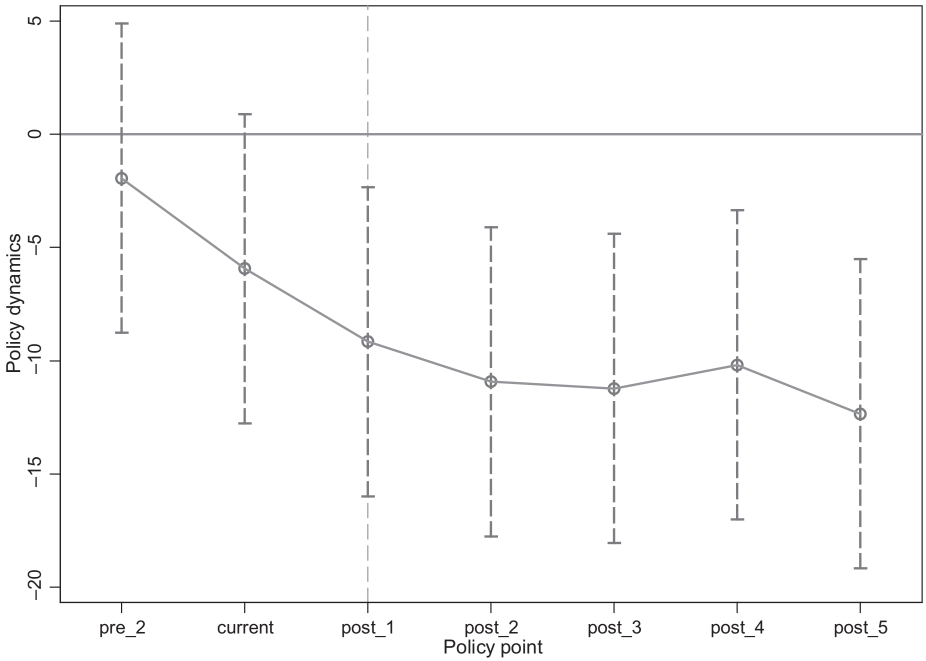

Figure 2.
Dynamic effect test

In Figure 2, *current* represents the policy implementation in 2014, in which the interaction coefficient before the policy implementation is not significantly different from 0, indicating that there is no significant difference between the experimental group and the control group before the policy implementation, which satisfies the parallel trend hypothesis, while the coefficient of the interaction term after the implementation of the policy is significantly different from 0 and the degree gradually increases, indicating that there is a significant negative effect and the policy effect is gradually obvious after the implementation of the policy. The possible reason is that with the implementation of carbon trading policy, the effect path of improving energy efficiency in the power industry is gradually clear and the policy effect is gradually prominent.

4.2.3 Adding control variables. Considering the different regional conditions of the experimental group and the control group, population size (Pop), the opening level (Open) and technological innovation (Tec) are added into the control variables for regression to solve the problem of possible endogeneity problem, and population size is measured by the year-end resident population (ten thousand people), the opening level is measured by the total import and export ($) and technological innovation is measured by local financial expenditure on science and technology (100m yuan) to test the robustness of the analysis results. As shown in Column (1) of Table 4, the results are similar to those of baseline regression after the addition of control variables, indicating that the results in this paper are robust.

4.2.4 Exclude interference from other policies. In addition to carbon trading policy, the energy efficiency of the power industry will also be affected by other environmental policies. Therefore, this paper chooses the New Environmental Protection Law of 2014 and the Environmental Protection Tax Law of 2018. As shown in Columns (2) and (3) of Table 4, the impact of carbon trading policy on energy efficiency in the power industry is still significant after controlling the impact of these policies, which further verifies the robustness of the results of this paper.

4.2.5 Random grouping. Random grouping is a counterfactual test, which randomly selects six new carbon trading pilot provinces as the virtual sample to return. If carbon trading policy has no significant impact on the new build virtual samples, then the results of this paper is robust; otherwise, it represents the credibility of this study conclusion remains to be further improved. As shown in Column (4) of Table 4, the impact of carbon trading policy on virtual samples is not significant, indicating that the results of this paper are robust.

Variables	(1) Y	(2) New environmental law	(3) Environmental tax	(4) Random
DID	−8.849*** (2.311)	−10.12*** (2.440)	−10.03*** (2.464)	1.879 (2.227)
Con	21.59* (12.39)	14.68 (13.11)	17.41 (14.03)	17.37 (13.43)
GDP	−2.05 e-05 (0.000198)	0.000265 (0.000185)	0.000233 (0.000200)	0.000243 (0.000186)
Gov	0.00180 (0.00118)	0.000109 (0.00112)	0.000353 (0.00119)	−0.000337 (0.00110)
Power	12.57 (11.02)	6.583 (12.39)	9.978 (12.68)	−8.137 (10.92)
Pop	0.00425 (0.00570)			
Open	8.29 e-07*** (2.18 e-07)			
Tec	−0.0150 (0.0110)			
Control variables	YES	YES	YES	YES
Individual effect	YES	YES	YES	YES
Time effect	YES	YES	YES	YES
Constant	241.2*** (34.45)	277.7*** (15.06)	273.6*** (15.29)	291.8*** (13.56)
Observations	240	210	210	240
R^2	0.938	0.933	0.930	0.926

Notes: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 4. Robustness test

4.3 Heterogeneity analysis

Different provinces have differences in resource endowment, economic development level and energy consumption structure, so they will react differently to carbon trading policy. However, as a developing country with unbalanced regional development, China's policy implementation effects are often heterogeneous at the regional level. Similarly, the implementation of carbon trading pilot work is not accomplished in a day but a systematic construction project, so the implementation effect of carbon trading policy should be analyzed from multiple aspects. This paper further analyzes and compares the effects of carbon trading policy in the case of the eastern, central and western regions and different horizontal power structures.

As shown in Columns (1)–(3) of Table 5, carbon trading policy has a significant effect on the improvement of energy efficiency in eastern and western regions but has no obvious impact on the central region. On the one hand, provinces in eastern China have higher technological level and sufficient capital. Carbon trading policy can continuously improve the energy efficiency of the power industry through technological effects and realize the certainty improvement of future profits of the power industry. The western region can realize the combined operation of hydropower, wind power and photovoltaic power generation to continuously improve the quality and utilization level of clean energy power generation (Pan *et al.*, 2018). Therefore, the carbon trading policy significantly improves the energy efficiency of the power industry in eastern and western regions. On the other hand, because of the disharmony of the spatial and temporal distribution of clean energy, the clean energy generation in the central region has poor stability and continuity, resulting in its low proportion. Meanwhile, the lack of capital, technology and environmental awareness makes it difficult to improve the energy efficiency of the power industry.

As shown in Columns (4) and (5) of Table 5, carbon trading policy is more effective in improving energy efficiency for high level power structures, which will be more responsive to carbon trading policy because of their weaker lock-in and inertia effects, while the opposite is true for low-level power structures. The optimization of power structure requires the coordinated development of electricity with energy, economy, environment and other

Variables	(1) East	(2) Center	(3) West	(4) High level	(5) Low level
DID	−7.827** (3.543)	−3.819 (3.365)	−25.14*** (7.590)	−7.936*** (2.684)	−5.092 (5.368)
Con	48.80* (25.00)	6.566 (14.03)	40.07 (30.18)	22.01 (18.25)	25.53 (18.86)
GDP	0.000153 (0.000213)	4.45 e-05 (0.000349)	0.00182** (0.000855)	−9.20 e-05 (0.000197)	0.000782** (0.000353)
Gov	0.000544 (0.00123)	0.00274 (0.00230)	−0.00380 (0.00458)	0.00173 (0.00116)	−0.000889 (0.00204)
Power	−48.91** (23.39)	17.03 (13.61)	61.80** (26.72)	−43.25** (17.27)	29.65* (16.04)
Control variables	YES	YES	YES	YES	YES
Individual effect	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES
Constant	266.7*** (21.63)	266.8*** (14.32)	266.6*** (25.21)	319.7*** (18.85)	254.6*** (15.16)
Observations	(21.63)	80	72	120	120
R^2	0.961	0.915	0.713	0.968	0.833

Notes: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 5. Heterogeneity analysis

factors. It is very important to develop and use clean energy (Jia et al., 2021). Therefore, the higher the proportion of clean energy in power generation, the higher the energy efficiency will be.

4.4 Analysis of influence mechanism

The above analysis shows that carbon trading policy can reduce the coal consumption of power generation and significantly improve the energy efficiency of the power industry. In addition, we also pay attention to the effect path of carbon trading policy on the energy efficiency of the power industry. Based on the stepwise regression test used by Baron and Kenny (1986) in the sociological mediation study, this paper empirically analyzes the mediating role of environmental protection investment, electricity demand and industrial structure in the process of carbon trading policy affecting the energy efficiency by designing the following influencing mechanism Models (2)–(4). The results are shown in Tables 6, 7 and 8:

$$Me_{it} = \beta_0 + \beta_4 * DID + \alpha * control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (2)$$

$$Y_{it} = \beta_0 + \beta_5 * Me_{it} + \alpha * control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (3)$$

$$Y_{it} = \beta_0 + \beta_6 * Me_{it} + \beta_7 * DID + \alpha * control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (4)$$

In this study, Me_{it} represents intermediary variables; they are environmental protection investment, electricity demand and industrial structure. Model (2) verifies the relationship between *DID* and intermediary variables. If β_4 is significant, then it indicates that carbon trading policy can significantly affect the selected intermediary variable. Model (3) verifies the relationship between each intermediary variables and the explained variables. If β_5 is significant, then it indicates that the intermediary variable can significantly affect the energy efficiency of the power industry. Model (4) verifies the relationship of *DID*, intermediary variables and explained variables. If β_6 and β_7 are all significant, then it

Variables	(1) Inv	(2) Y	(3) Y
DID	25.50* (14.64)		−9.894*** (2.345)
Con	−123.4 (79.36)	16.13 (13.22)	16.65 (12.69)
GDP	−0.000657 (0.00109)	0.000257 (0.000180)	0.000196 (0.000174)
Gov	0.0419*** (0.00661)	0.000560 (0.00119)	0.00127 (0.00115)
Power	−207.9*** (71.45)	−13.22 (10.87)	8.126 (11.60)
Inv		−0.0247** (0.0117)	−0.0188* (0.0113)
Control variables	YES	YES	YES
Individual effect	YES	YES	YES
Time effect	YES	YES	YES
Constant	210.1** (87.08)	297.0*** (13.46)	273.8*** (14.04)
Observations	240	240	240
R^2	0.903	0.928	0.934

Notes: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 6. Mechanism test of environmental protection investment

indicates that intermediary variables have partial mediating effects; if only β_7 is significant, then it indicates that intermediary variables have complete mediating effects.

Columns (1)–(3) in Table 6 verify the intermediary effect of environmental protection investment in the process of carbon trading policy affecting the energy efficiency of the power industry, in which environmental protection investment is measured by local financial environmental protection expenditure (100m yuan). The DID coefficient (25.50*) in Column (1) is significantly positive at the level of 10%, indicating that the implementation of carbon trading policy can promote the increase of environmental protection investment; the environmental investment coefficient (−0.0247**) in Column (2) is significantly negative at the level of 5%, indicating that the increase of environmental protection investment reduces the carbon consumption of the power industry and will further improve its energy efficiency. The DID coefficient (−9.894***) and the environmental investment coefficient (−0.0188*) in Column (3) are significantly negative at the levels of 1% and 10%, respectively, indicating that environmental protection investment has a partial intermediary effect in the process of carbon trading policy affecting the energy efficiency of the power industry, which can significantly improve the energy efficiency of the power industry, and test *H2*.

Columns (1)–(3) in Table 7 verify the intermediary effect of electricity demand in the process of carbon trading policy affecting the energy efficiency of the power industry, in which electricity demand is measured by the electricity consumption of the whole society (100m kWh). The DID coefficient (−154.8**) in Column (1) is significantly negative at the level of 5%, indicating that under the background of the continuous increase in electricity consumption in the whole society, the implementation of carbon trading policy can significantly reduce the growth rate of electricity consumption in the whole society and slow down the pace of electricity demand growth; the electricity demand coefficient (−0.00519**) in Column (2) is significantly negative at the level of 5%, indicating that the slowdown in the growth rate of electricity consumption in the whole society has reduced the coal consumption of power generation in the power industry, which will further improve its energy efficiency. The DID coefficient (−11.44***) and the electricity consumption demand coefficient (−0.00690***) in Column (3) are significantly negative at the level of 1%, indicating that the electricity demand in the process of carbon trading policy affecting the

Variables	(1) Dem	(2) Y	(3) Y
DID	−154.8** (71.61)		−11.44*** (2.317)
Con	−609.1 (388.1)	16.04 (13.21)	14.78 (12.49)
GDP	0.0306*** (0.00534)	0.000442** (0.000195)	0.000419** (0.000184)
Gov	0.0272 (0.0323)	−0.000473 (0.00107)	0.000663 (0.00104)
Power	−855.6** (349.5)	−15.48 (11.07)	6.144 (11.34)
Dem		−0.00519** (0.00238)	−0.00690*** (0.00227)
Control variables	YES	YES	YES
Individual effect	YES	YES	YES
Time effect	YES	YES	YES
Constant	1797*** (425.9)	304.3*** (14.27)	282.2*** (14.22)
Observations	240	240	240
R^2	0.989	0.928	0.936

Notes: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 7. Mechanism test of electricity demand

energy efficiency of the power industry has a partial intermediary effect, which can significantly improve the energy efficiency of the power industry, and test *H3*.

Columns (1)–(3) in Table 8 verify the intermediary effect of the industrial structure in the process of carbon trading policy affecting the energy efficiency of the power industry, in which the industrial structure is measured by the ratio of the added value of the GDP of the tertiary industry to the GDP added value of the secondary industry. The DID coefficient (0.166***) in Column (1) is significantly positive at the level of 1%, indicating that the implementation of carbon trading policy can promote the transformation and upgrading of industrial structure; the industrial structure coefficient (−10.61***) in Column (2) is significantly negative at the level of 1%, indicating that the optimization of industrial structure reduces the carbon consumption in the power industry and will further improve its energy efficiency. The DID coefficient (−9.160***) and the industrial structure coefficient (−7.301**) in Column (3) are significantly negative at the levels of 1% and 5%, respectively, indicating that the industrial structure has a partial intermediary effect in the process of carbon trading policy affecting the energy efficiency of the power industry, which can significantly improve the energy efficiency of the power industry, and test *H4*.

5. Conclusions and suggestions

Carbon trading policy is an important mechanism for using market economy to reduce greenhouse gas emissions and promote environmental protection. Based on panel data of 30 provinces from 2012 to 2019, this paper uses the difference-in-differences model to evaluate the impact of carbon trading policy on energy efficiency in the power industry. The results are as follows: carbon trading policy does improve the energy efficiency of the power industry, and this result is robust by adding control variables, eliminating the interference of other policies and random grouping. Heterogeneity analysis shows that the impact of carbon trading policy on energy efficiency is more significant in the east, west and areas with higher power structure. Through mechanism analysis, this paper explores the effect path of carbon trading policy on energy efficiency and finds that there are some intermediary effects in environmental protection investment, electricity demand and industrial structure; carbon trading policy can improve the energy efficiency of the power

Variables	(1) Ind	(2) Y	(3) Y
DID	0.166***		−9.160*** (2.391)
Con	0.225 (0.254)	21.54* (13.01)	20.62 (12.59)
GDP	−1.46 e-05*** (3.49 e-06)	0.000111 (0.000186)	0.000102 (0.000180)
Gov	6.54 e-05*** (2.11 e-05)	0.000330 (0.00110)	0.000953 (0.00107)
Power	−0.470** (0.228)	−10.72 (10.61)	8.613 (11.43)
Ind		−10.61*** (3.529)	−7.301** (3.520)
Control variables	YES	YES	YES
Individual effect	YES	YES	YES
Time effect	YES	YES	YES
Constant	1.098*** (0.278)	300.9*** (13.44)	277.8*** (14.32)
Observations	240	240	240
R^2	0.981	0.929	0.934

Notes: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 8. Mechanism test of industrial structure

industry by influencing environmental protection investment, electricity demand and industrial structure.

In the face of the dual requirements of reducing energy consumption per unit of GDP and CO_2 emissions by 13.5% and 18%, respectively, during the "14th Five-Year Plan" period, China is accelerating green and low-carbon development and continuing to strengthen the coordinated governance of energy conservation and carbon reduction. In view of the above conclusions, this paper puts forward the following suggestions: First, gradually expand the scope of implementation of carbon trading policy in a timely manner. Through quantitative analysis, this paper understands that the carbon trading policy has played an important role in improving the energy efficiency of the power industry, which further verifies the correctness and necessity of the implementation of the carbon trading policy. Based on this, the government should conduct scientific discussions on the basis of the implementation of the previous carbon trading policy and realize the necessary improvement of corresponding policies and supporting measures. Second, the power structure in different regions must be developed in coordination with energy, economic and environmental factors, and the proportion quota of thermal power and clean energy should be promoted smoothly according to the local actual situation, while China should constantly promote technological innovation to improve the energy efficiency of the power industry. Third, China is a vast country with large regional differences, so it is necessary to differentiate the formulation and implementation of policies and explore the appropriate development path and mode according to the actual situation of each region. Fourthly, the Government should pay more attention to carbon trading policy and enhance environmental protection investment and financial guarantee, and at the same time, the Government should constantly optimize the upgrading of industrial structure to promote the rational layout and coordinated development of regional economy. Finally, China needs to learn from the experience of other countries in formulating carbon emissions trading rules, and domestic rules can also lead the development of international carbon emissions trading rules. With the continuous improvement of China's carbon trading policy, China should continue to promote cooperation with various governments and international institutions. On the one hand, China can actively promote the experience and practice of China's carbon trading policy and help the construction of carbon emission trading rules in other countries to gradually integrate with China. On the other hand, China can also introduce some provisions that effectively resolve existing difficulties, continuously improve China's carbon emission trading rules and establish a more fair and reasonable international carbon emission trading mechanism through the joint efforts of all countries to promote the governance of global climate change.

In addition, this paper also has certain limitations when studying the impact of carbon trading policy on energy efficiency in the power industry and its role path. First, this paper only selects environmental protection investment, electricity demand and industrial structure as intermediary variables, and there may be other indirect influence channels that are not taken into account. Second, although the advanced estimation methods and mature tool variables are selected as much as possible in this paper and a variety of robustness tests are carried out to ensure the scientific nature of the results, they cannot completely solve the endogenous problem. Future research can focus on further improvement from the aspects of influence channels, mature tool variables and research method selection, so as to ensure the scientific rationality of research.

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