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Original Research

Energy Conservation and Emission Reduction Effect and Potential Emission Reduction Mechanism of China's Thermal Power Generation Industry – Evidence from Carbon Emission Trading Policy

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Abstract

Based on the panel data of 30 provinces and municipalities in China from 2006 to 2020, the carbon emission trading policy was adopted as the quasi-natural experiment. The effect of energy conservation and emission reduction in the thermal power industry from the two dimensions of carbon dioxide emissions and green total factor productivity were evaluated. A difference-in-difference model was used to empirically analyze the effect of carbon emissions trading policy on energy conservation and emission reduction in the thermal power industry. The results show that the carbon emission trading policy could reduce the carbon dioxide emissions of the thermal power industry, but had no impact on the green total factor productivity of the thermal power industry. The analysis of potential emission reduction mechanism found that the reduction of carbon dioxide emissions was achieved by reducing thermal power generation, and the reduction of thermal power generation was caused by the decision of the power planning department. The discussion on the effect of carbon emissions trading policy found that the carbon emissions trading policy did not produce carbon spillover effect, and the pilot areas and neighboring provinces were actively turned to new energy power generation under the influence of the carbon emissions trading pilot policy. Under the constraint of ecological environment, China's thermal power industry needs to accelerate the transformation of energy conservation and emission reduction.

Keywords: carbon emission trading policy, energy conservation and emission reduction, thermal power industry, carbon peak and neutrality target

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Introduction

In September 2020, the central government promised to the world that it would strive to achieve carbon peak by 2030 and carbon neutrality by 2060 in China, that is, the " Carbon Peak and Neutrality " target. The proposal of the "Carbon Peak and Neutrality" target demonstrates China's firm determination to actively respond to climate change and take the path of green and low-carbon development, which will have a profound impact on China's social and economic operation mode, ecological and environmental quality, industrial structure layout and life consumption mode in the future. Especially in the field of energy and electricity, the proposal of this goal will produce systemic changes in multiple dimensions. As a market-oriented environmental regulation, the carbon emission trading scheme has been recognized as an effective method of reducing carbon emissions compared with command-and-control environmental regulation, since the concept of carbon trading was proposed in the "Kyoto Protocol" (Schafer, 2019; Zhang and Duan, 2020) [1, 2]. For the sake of carbon emission reduction and sustainable economic development, in October 2011, the National Development and Reform Commission of China approved seven provinces in Beijing, Shanghai, Tianjin, Hubei, Chongqing, Guangdong and Shenzhen to carry out carbon emission trading pilot projects, marking the official launch of China's pilot carbon market construction. Since the first launch of the carbon emission trading system in Shenzhen in June 2013, other pilot regions have successively launched the carbon emission trading system. On July 16, 2021, the national carbon market was officially launched for trading. The electric power industry is a key industry for our country to achieve carbon peaking and carbon neutrality. It should not only reach the peak itself, but also support the whole society to reach the peak as soon as possible and contribute to the low-carbon transformation of the whole society. Although the demand for clean energy is gradually increasing, the electricity consumption of the whole society is growing rapidly with the development of the national economy. The thermal power generation industry occupies a dominant position in China's power supply structure and is an important industry related to the national economy and people's livelihood. Therefore, in the face of China's increasing energy demand and increasingly tight carbon emission constraints, the thermal power industry, as an important energy sector and the main source of carbon emissions in China, has become the key to ensure the power demand for China's economic and social development and the smooth realization of the "Carbon Peak and Neutrality" Target.

The marginal contribution of this paper is mainly reflected in the following aspects: First, evaluate the energy saving and emission reduction effect of the thermal power industry from the two dimensions of total carbon dioxide emissions and green total factor productivity, and on this basis, evaluate the impact of carbon emissions trading policy; Second, the research on regulated industries by carbon emission trading policy has been increased; Thirdly, this paper finds that the carbon emissions trading policy has a positive spillover effect, which indicates that the power planning department controls thermal power generation from the total amount considering energy conservation and emission reduction and intentionally shifts the Clean energy, which also enriches the research of energy transition related articles.

Literature Review

With the prominence of environmental problems, scholars have begun to research China's economic growth performance and its changes under environmental constraints (Tu and Liu, 2011; Lin and Tan, 2019) [3, 4]. Scholars have studied the environmental efficiency of the thermal power industry in the existing literature. Wang and Jia (2012) used the non-parametric Malmquist-Luenberger index method to measure the total factor energy efficiency of the thermal power industry in 30 provinces in China from 2000 to 2008 [5]. It was found that after considering environmental constraints, the growth of technological progress decreased significantly, resulting in a much lower growth rate of total factor energy efficiency in the thermal power industry than when environmental constraints were not considered. Zhu (2016) used the same method to measure and decomposition the total factor productivity of the thermal power industry in 30 provinces and cities in China from 2007 to 2013, but came to a different conclusion that environmental regulation was conducive to the growth of the total factor productivity of the thermal power industry [6]. The conclusions of Zhu (2016) are generally similar to those of Bai and Song (2009). The difference is that Bai and Song found that environmental regulation does not apply to all regions in improving the efficiency of thermal power industry, that is, environmental regulation has regional heterogeneity in improving the efficiency of thermal power industry [7]. As the global climate warms, greenhouse gas emissions increase. The emission of carbon dioxide has received more and more attention from the international community. Scholars gradually focused on carbon dioxide emissions as unexpected output to measure the carbon emission efficiency index of thermal power generation industry. Sun et al. (2016) concluded that cities with different carbon emission efficiency levels should adopt different emission reduction policies according to the actual situation of their technical progress index and technical efficiency index. Based on the non-parametric production economic theory [8]. Zhang (2022) founded that low-carbon technology innovation is the main driving factor to improve carbon TFP, and the energy conservation and emission reduction efficiency of thermal power enterprises need to be improved [9].

As a typical environmental policy deployed to control pollution emissions by market means, whether the carbon emissions trading policy can achieve energy conservation has attracted the attention of many scholars. Therefore, research examining the effectiveness of the carbon emissions trading policy has gradually increased (Wang et al., 2018; Zhang and Zhang, 2019; Yang et al., 2020; Wang et al., 2022) [10-13]. Bai et al. (2021) conducted a mechanism analysis on the energy saving and emission reduction effects of carbon emission trading policy [14]. The results showed that energy efficiency improvement and energy structure transformation are both important paths for carbon emission trading policy to achieve energy saving and emission reduction goals. The main driving force for energy conservation and emission reduction comes from the transformation of the energy structure, rather than the improvement of energy efficiency.

With the further refinement of research, some scholars have begun to pay attention to the impact of carbon emissions trading policy on micro-enterprises. Xiao et al. (2021) showed that the carbon emission trading policy significantly improved the total factor productivity of Chinese enterprises, and its policy effect was stable without time lag. Further analysis found that the improvement of total factor productivity was not affected by the heterogeneity of enterprise ownership but was influenced by the heterogeneity of the industry [15]. Song et al. (2021) used the multi-period PSM-DID method to empirically test the impact of carbon emissions trading on corporate green innovation. The study found that carbon emissions trading policy can significantly promote corporate green innovation [16].

Few scholars have studied the impact of carbon emissions trading policy on a specific industry. Tan and Lin (2022) showed that carbon emissions trading policy significantly reduced carbon dioxide emissions from energy-intensive industries, but their output did not increase significantly, i.e., carbon intensity decreased. Finally, it is concluded that to achieve a win-win situation of reducing carbon dioxide emissions and promoting economic development, external technological breakthroughs are required [17]. Chen and Lin (2021) showed that the carbon emission trading policy played an important role in effectively promoting energy conservation and emission reduction, and also promoted the optimal allocation of input factors [18].

According to previous studies, this paper finds that there are few studies on the effect of carbon emissions trading policy on energy conservation and emission reduction in the thermal power industry. The core issue discussed in this paper is the effectiveness of carbon emission trading policy in energy conservation and emission reduction of China's thermal power industry. Does the thermal power industry in the pilot area reduce carbon dioxide emissions or improve green total factor productivity? Therefore, it is of practical significance to study the energy conservation and emission reduction effect of thermal power industry under the carbon emission trading policy for other energy intensive industries to gradually integrate into the national carbon emission trading market and to make a commitment to the sustainable development of our society and the realization of the "Carbon Peak and Neutrality" Target.

The paper is organized as follows: Section 2 reviews relevant literature. The methods and data used in this paper are introduced in Section 3. The results and discussion are presented in Sections 4 and 5. Section 6 summarizes the findings and puts forward policy recommendations.

Materials and Methods

Super-SBM-GML Model

The Globe-Malmquist-Luenberger (GML) index is used to calculate the carbon dioxide emission efficiency index of thermal power generation industry to measure the GTFP of thermal power generation industry (Dong-hyun Oh, 2010) [19]. Assuming constant returns to scale, the non-radial and non-angular Super-SBM efficiency value of province i in year t, which includes desired output and undesired output, is:

$$E_C^G(K_i^t, L_i^t, E_i^t, Y_i^t, C_i^t) = \theta^*$$

$$= \min \frac{1 + \frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{x_{io}}}{1 - \frac{1}{S_1 + S_2}\left(\sum_{r=1}^{S_1}\frac{S_r^d}{y_{ro}^d} + \sum_{k=1}^{S_2}\frac{S_k^u}{y_{ko}^u}\right)}$$

$$s.t.\begin{cases} x_{io}^t \geq \sum_{t=1}^{T}\sum_{j=1, j\neq o}^{n}\lambda_j^t x_{ij}^t - S_i^-, i = 1,2,\dots,m \\ y_{ro}^{dt} \leq \sum_{t=1}^{T}\sum_{j=1, j\neq o}^{n}\lambda_j^t y_{rj}^{dt} + S_r^d, r = 1,2,\dots,S_1 \\ y_{ko}^{ut} \geq \sum_{t=1}^{T}\sum_{j=1, j\neq o}^{n}\lambda_j^t y_{kj}^{ut} - S_k^u, k = 1,2,\dots,S_2 \\ S_i^- \geq 0, S_r^d \geq 0, S_k^u \geq 0, \lambda_j^t \geq 0 (\forall i, r, k, j) \end{cases} \tag{1}$$

Where, min(·) represents the minimum value function. $E_C{}^G$ represents the efficiency value obtained by the evaluated DMU with reference to the global frontier Super-SBM under constant returns to scale (CRS). (K_i^t, L_i^t, E_i^t, Y_i^t, C_i^t) represents the input-output set of province i.

GML index has intertemporal comparability and can effectively solve the problem of infeasible solution of linear programming. Since DMUs all refer to the same production frontier during the study period, GML index is a single index, and the model is as follows:

$$GML(t,t+1)=\frac{E_C^G(K^{t+1}, L^{t+1},E^{t+1},Y^{t+1},C^{t+1})}{E_C^G(K^t, L^t,E^t,Y^t,C^t)}$$
$$=\frac{E_C^{t+1}(K^{t+1}, L^{t+1},E^{t+1},Y^{t+1},C^{t+1})}{E^t(K^t, L^t,E^t,Y^t,C^t)}$$
$$\times[\frac{E_C^G(K^{t+1}, L^{t+1},E^{t+1},Y^{t+1},C^{t+1})}{E_C^{t+1}(K^{t+1}, L^{t+1},E^{t+1},Y^{t+1},C^{t+1})}\times\frac{E_C^t(K^t \ L^t,E^t,Y^t,C^t)}{E_C^G(K^t \ L^t,E^t,Y^t,C^t)}]$$
$$=GEC(t,t+1)\times GTC(t,t+1) \tag{2}$$

Where, GML(t,t+1) represents the GML index from period t to period t+1. If GML(t,t+1)>1, it means that the efficiency of the evaluated DMU under the global reference set has improved from period t to period t+1; If GML(t,t+1)=1, the efficiency remains unchanged; If GML(t,t+1)<1, the efficiency is reduced. GEC(t,t+1) and GTC(t,t+1) are the global technical efficiency index and the global technical progress index from period t to period t+1, respectively.

Difference-in-Differences Model

The core issue of this paper is to evaluate the effectiveness of carbon emission trading policy on energy conservation and emission reduction in thermal power industry. DID is a commonly used method in environmental policy evaluation (Dong et al., 2019; Chen et al., 2022) [20,21]. This paper takes the thermal power industry in 30 provinces in China from 2006 to 2020 as the research object, taking 6 pilot provinces and cities as the experimental group and the rest as the control group. In terms of the division of the pilot period, this paper takes 2014 as the policy intervention period. Set 2006-2013 as non-pilot period and 2014-2020 as pilot period. The model is as follows:

$$Y_{it}=\alpha_0+\alpha_1 treat_i\times post_t+\alpha_2 Control_{it}+\delta_i+\gamma_t+\varepsilon_{it} \tag{3}$$

Where Y_{it} is the outcome variable and $treat_t$ is a dummy variable of a province, which is equal to 1 if province i is included in the carbon emissions trading pilot, and equal to 0 otherwise. $post_t$ is a time dummy variable with a value of 1 in the year the carbon emissions trading pilot runs and 0 in other years. $Control_{it}$ is a set of control variables, δ_i represents the region fixed effect, and γ_t represents the year fixed effect. ε_{it} represents random disturbance term The coefficient α_1 represents the net effect of the carbon emissions trading policy on carbon emissions in the thermal power industry, and is the focus of this paper.

Model of Latent Mechanism Variable Analysis

Furthermore, this paper refers to the practice of Deschenes O. (2020) [22], and constructs the following DID model to identify the influence mechanism:

$$Mec_{it}=\beta_0+\beta_1 treat_i\times post_t+\beta_2 Control_{it}+\delta_i^{'}+\gamma_t^{'}+\varepsilon_{it}^{'} \tag{4}$$

Where, Mec_{it} is the potential mechanism variable; If the coefficient is significant and the sign is in line with expectations, it indicates that the implementation of carbon emission trading policy can affect the outcome variable through the corresponding mechanism variable.

Model of Dynamic Regression Analysis

The premise of using the DID model is that the model satisfies the parallel trend assumption. Before the implementation of the carbon emission trading policy, there should be no significant difference in the change trend of economic development quality between the provinces and cities that implement the policy (the experimental group) and those that do not (the control group). Therefore, referring to Jacobson et al. (1993) event study method, this paper constructs a parallel trend hypothesis test-dynamic effect regression analysis model. (Jacobson L.S. et al.) [23]. In order to avoid the interference of other policies in the same period, this paper uses the time frame of 6 years before and 6 years after the implementation of the pilot carbon emissions trading policy. Subtract 2014 from the first 6 years, and subtract 2014 from the last 6 years to generate a time dummy variable, which is then multiplied by the treatment group dummy variable, take the year before the start of the policy as the base period for dynamic effect regression. The model settings are as follows:

$$Y_{it}=\varphi_0+\sum_{t=2008}^{2020}\varphi_t treat_i\times post_t^{'}+\varphi_1 Control_{it}+\delta_i^{''}+\gamma_t^{''}+\varepsilon_{it}^{''} \tag{5}$$

Where, $post_t'$ is the year dummy variable (t = 2008, ..., 2020). If the year is 2008, $post_t' = 1$, and the rest are 0. φ_t is an important coefficient in parallel trend test, and its significance indicates that there is a significant difference between the experiment group and the control group in the impact of carbon emission trading pilot policies on the outcome variables.

Variables

Explained Variables

(1) Carbon dioxide emissions from thermal power generation industry (CO_2). This paper uses the emission co-efficient method provided by IPCC (Intergovernmental Panel on Climate Change) to measure the carbon dioxide emissions of thermal power generation industry.

(2) Green total factor productivity (GTFP). The paper refers to the previous research methods and research index selection, and finally selects six indicators: installed capacity, employees, standard coal, utilization

hours of power generation equipment, thermal power generation, and carbon dioxide emissions of thermal power generation industry to construct an index system with four inputs, one expected output and one undesired output. Based on the Super-SBM-GML index model to measure the GTFP of thermal power generation industry.

Explanatory Variables

The core explanatory variable that this paper focuses on is the interaction term of the treatment group dummy variable and the time dummy variable $treat_t \times post_t$.

Latent Mechanism Variables

Thermal power generation (FD): the annual thermal power generation of each province is selected for representation; Coal consumption (Coal): this paper chooses the coal consumption of thermal power generation to be expressed by measurement; Standard coal consumption (Coe) for power generation: It is one of the important assessment indicators for the production efficiency of power enterprises in the industry and is commonly used to measure the theoretical power generation efficiency of power enterprises.

Control Variables

The paper selects the real GDP per capita (pgdp) to measure the economic development level of a region; Electricity consumption per capita (pelc) to measure the electricity demand and electrification level of an area; Energy Structure (ES). Considering that coal is the main energy type used in the thermal power industry, this paper uses the proportion of coal consumption to total energy consumption to measure the energy structure of a region; The power generation structure (FS) is measured by the proportion of regional thermal power generation to total power generation; R&D investment (RD) represents the R&D investment of each province by the internal expenditure of each province's research and development funds; Industrial structure (IN3) This paper chooses the ratio of the added value of the tertiary industry to regional GDP to represent the differences in regional industrial structure.

Other Variables

Variables used in the discussion on the policy effect of carbon emission trading: thermal power generation (FP), new energy generation (hydropower, nuclear power, wind power and solar power) (Cele) and total power generation in neighboring provinces; New Energy generation in pilot areas (SCele).

Data Sources

The data required in this paper are from China Electric Power Yearbook, China Electric Power Statistical Yearbook, China Labor Statistical Yearbook, China Population and Employment Statistical Yearbook, China Energy Statistical Yearbook, China Science and Technology Statistical Yearbook, China Coal Industry Yearbook, EPS database, and local statistical yearbooks and statistical bulletins of each sample province.

Results and Discussion

Results

The Effect of Energy Conservation and Emission Reduction in Thermal Power Generation Industry

Since the original data of each variable are of different units and orders of magnitude, this paper first carries out standardization processing and then empirical regression analysis. Firstly, this paper explores the impact of carbon emission trading policy on the energy conservation and emission reduction effect of thermal power generation industry in pilot areas.

The regression results of the impact of carbon emission trading policy on carbon dioxide emissions (CO_2) and green total factor productivity (GTFP) in the thermal power industry were shown in Table 1. Among them, columns (1) and (3) are the regression results of carbon emission trading policy affecting carbon dioxide emissions (CO_2), and columns (2) and (3) are the regression results of carbon emission trading policy affecting green total factor productivity (GTFP). According to the regression results in Columns (1) and (2), after controlling the year and region fixed effects, the impact of carbon emission trading policy on carbon dioxide emissions is negative at the significance level of 1%, while the impact on GTFP is positive but not significant. The results show that carbon emission trading policy can effectively promote the emission reduction of China's thermal power industry, but it is not obvious to improve the GTFP of the thermal power industry. This is because if the thermal power industry wants to improve the GTFP, it needs to invest a lot of manpower, capital and time in improving the power generation efficiency of units or improving the utilization rate of coal combustion. However, China's thermal power generation industry is mainly dominated by state-owned enterprises and has been in a natural monopoly state for a long time. Columns (3) and (4) are the regression results after the control variables are added, and the results remain basically unchanged, indicating that the empirical results of this paper have certain robustness.

The per capita electricity consumption (pele) and power generation structure (FS) are significantly positive for CO_2 regression coefficient. It shows that the increase of per capita power consumption and the increase of the proportion of thermal power generation will enlarge the carbon dioxide emissions of the thermal power

Table 1. Energy saving and emission reduction effect of carbon emission trading policy.

	(1)	(2)	(3)	(4)
VARIABLES	CO_2	GTFP	CO_2	GTFP
treat*post	-0.0524***	0.0158	-0.0366***	0.0249
	(0.0132)	(0.0331)	(0.0101)	(0.0396)
pgdp			0.0720	-0.0310
			(0.0576)	(0.172)
pele			0.507***	-0.0479
			(0.0777)	(0.182)
IN3			-0.257**	-0.0397
			(0.109)	(0.344)
FS			0.188***	0.118
			(0.0353)	(0.163)
ES			0.149***	0.0494
			(0.0405)	(0.138)
RD			0.209***	-0.159
			(0.0454)	(0.131)
Constant	0.212***	1.032***	-0.124**	0.994***
	(0.00290)	(0.00729)	(0.0613)	(0.242)
Regional fixed effects	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	450	450	450	450
R-squared	0.912	0.104	0.960	0.108

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% levels, respectively.

industry. This shows that the current power generation mode in China is mainly thermal power generation, which almost covers the production and life of China. The carbon emission trading policy is proposed to help the high-carbon industry optimize the energy structure and guide China's production and lifestyle towards low-carbon green transformation. The regression coefficient of R&D investment (RD) is significantly positive, indicating that the current R&D investment in China's industrial sector may have technology path dependence, resulting in insufficient investment in green technology R&D, and the improvement effect of green technology level is not obvious. The research and development investment in the field increases output efficiency while increasing energy consumption and pollution emissions, causing energy rebound effect. The regression coefficient of energy structure (ES) is significantly positive, indicating that China's thermal power generation mainly relies on coal consumption for power generation, and the optimization of energy structure is of great significance to thermal power generation and power industry.

Potential Mechanism Analysis of Energy Conservation and Emission Reduction in Thermal Power Generation Industry

(1) Reduce coal consumption, thermal power generation, eliminate coal-fired power plants or improve power generation efficiency. From the above analysis, the trading policy of carbon emission has significantly reduced the carbon dioxide emissions of the thermal power industry in the pilot areas, but has not significantly improved the GTFP of the thermal power industry. Therefore, this section will further explore the potential mechanism of carbon emission reduction in the thermal power generation industry. Considering that China's power industry is strictly regulated, the power generation capacity of power plants is managed by provincial authorities and coordinated with regional and national dispatch organizations that manage inter-provincial flows. China's electricity production and consumption are strictly controlled by the planning department.

Therefore, it is hypothesized that the feasible way to reduce carbon dioxide emissions in the thermal power

Table 2. Analysis on potential mechanism of energy conservation and emission reduction of carbon emission trading policy.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Coal	FD	Coe	Coal	FD	Coe
treat*post	-0.0533***	-0.0504***	-0.0317***	-0.0313***	-0.0527***	-0.0477***
	(0.00845)	(0.0101)	(0.00943)	(0.00990)	(0.0107)	(0.00876)
pgdp				0.0623	0.0735	0.0578
				(0.0560)	(0.0523)	(0.0438)
pele				0.496***	0.479***	-0.138**
				(0.0771)	(0.0748)	(0.0541)
IN3				-0.247**	-0.486***	0.418***
				(0.106)	(0.111)	(0.114)
FS				0.185***	0.307***	-0.140***
				(0.0345)	(0.0398)	(0.0443)
ES				0.174***	0.139***	0.0736**
				(0.0397)	(0.0424)	(0.0293)
RD				0.170***	0.375***	0.00702
				(0.0467)	(0.0403)	(0.0229)
Constant	0.214***	0.250***	0.485***	-0.125**	-0.0941	0.302***
	(0.00277)	(0.00308)	(0.00202)	(0.0587)	(0.0668)	(0.0662)
Regional fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	450	450	450	450	450	450
R-squared	0.910	0.928	0.885	0.961	0.967	0.903

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% levels, respectively.

industry in the short and medium term is to reduce coal consumption, reduce thermal power generation, eliminate coal-fired power plants or improve power generation efficiency. Therefore, this section further uses DID regression to identify the impact of carbon emission trading policy on Coal consumption (Coal), thermal power generation (FD) and standard coal consumption (Coe) of power generation.

The impact of carbon emission trading policy on Coal consumption (Coal), thermal power generation (FD) and standard coal consumption (Coe) of power generation were reported in Table 2. Among them, columns (1) and (4) are the regression results of the impact of carbon emission trading policy on Coal consumption (Coal), columns (2) and (5) are the regression results of the impact of carbon emission trading policy on thermal power generation (FD), and columns (3) and (6) are the regression results of the impact of carbon emission trading policy on standard coal consumption (Coe) of power generation. Columns (4), (5) and (6) are the regression results after the control variables are added, and the results remain basically unchanged. This shows that the carbon emission trading policy significantly reduces the coal consumption and thermal power generation in the pilot areas, and improves the power generation efficiency in the pilot areas. This also confirms the previous hypothesis that the feasible way to reduce carbon dioxide emissions in the thermal power industry in the short and medium term is to reduce coal consumption, thermal power generation or improve power generation efficiency.

(2) Reasons for the decrease in thermal power generation. Through the regression coefficients reported in Table 2, it is found that the carbon emission reduction of the thermal power generation industry in the pilot areas is mainly through reducing thermal power generation. Therefore, this section wants to further explore the reasons for the reduction of thermal power generation: whether it is the voluntary reduction of power plants or the total amount control of the planning department. Due to the strict regulation of China's power sector, 70 percent of electricity was still sold by dispatch orders at managed prices in 2018, despite the gradual market-oriented reform of the power sector that began

in 2015 (China Electricity Council, 2019). Therefore, it is assumed that the reduction of thermal power generation in the pilot area is caused by the decision of the planning department.

Although the reduction of power generation reduces coal consumption and carbon dioxide emissions, their fixed costs remain the same, such as equipment depreciation costs, large labor costs, etc, which means that the reduction in power generation also leads to profits reduction. At present, China's annual coal consumption for power generation accounts for about half of its annual coal consumption, coal-fired power generation accounts for about 65% of the national power generation, and the cost of coal-fired power accounts for about 70% of the total cost of coal-fired power enterprises. Therefore, in order to determine the reduction in power generation is the result of planning department decisions. Based on the completeness, consistency and availability of data, this paper collected the spot price of coal, standard coal consumption of power generation, average feed-in tariff of coal-fired power plants and carbon trading prices from carbon emission exchanges in each pilot region after the implementation of carbon emission trading policy from 2014 to 2019.

According to the standard coal consumption and coal spot price of power generation, the coal price generated by the power plant to produce 1WMh electricity is calculated. The price of carbon allowances to be purchased to produce 1WMh of electricity is calculated by considering that the power plant may choose to produce electricity beyond the quota standard. The on-grid price of coal-fired power plants (i.e., the income generated by producing 1WMh electricity), generation cost (i.e., the cost generated by producing 1WMh electricity), and (generation + quota) cost (i.e., the cost generated by generating 1WMh electricity and the cost of purchasing carbon emission quota were reported in Table 3.

After the implementation of the carbon emission trading policy, the on-grid electricity price in each pilot area is much higher than the marginal cost in Table 3. Therefore, the reduction in thermal generation is more likely to be caused by the planning department.

Robustness Check

(1) Parallel trend test-dynamic effect analysis method. The premise of using the difference-in-difference model for the study is that the treatment group and the control group satisfy the parallel trend assumption. That is, there is no difference between the treatment group and the control group before the policy implementation, and there is a difference between the treatment group and the control group after the policy implementation. For this reason, this paper adopts the event research method to carry out dynamic effect regression.

The regression results of the dynamic effect are shown in Table 4. Therefore, there is no significant difference between the treatment group and the control group before the implementation of the policy, which satisfies the hypothesis of parallel trend.

(2) Placebo test. In order to ensure that the regression results of this paper are caused by the carbon emissions trading policy and exclude the interference of other unknown factors, this paper conducts a placebo test by randomly assigning pilot provinces and cities. Specifically, 500 random samples were conducted from 30 provinces and cities, and 6 provinces and cities were randomly selected as the virtual experimental group each time, and the remaining 24 provinces and cities were used as the virtual control group for regression analysis. If in the random sampling process, the independent variable *post×treat* has no significant effect on the explained variable, it shows that the regression results in this paper are robust.

(3) The mean of the regression estimates after random assignment was shown from Fig. 1 to 4, where the red dotted line represents the benchmark regression results in this paper. It can be found that compared with the regression results of random sampling, the benchmark regression results are significantly outliers. The mean value of the *post×treat* estimated coefficient in random sampling is almost zero, and the P-values are basically above 0.1, indicating that carbon emissions trading policy have no significant effect in random sampling experiments. The regression results in this paper are unlikely to be driven by unknown factors.

Change windows of time. Different time windows may lead to different results. In order to investigate whether different time ranges will affect the regression results of this paper. This paper considers removing the first two years (2008-2020) (in Table 5), the last two years (2006-2018) (in Table 6) or two years on each side (2008-2018) (in Table 7) from the original time window (2006-2020) to verify the robustness of the conclusion.

As can be seen from Table 5 to 7, the results of the three groups of robustness tests in 2008-2020, 2006-2018 and 2008-2018 show that the carbon emissions trading policy still significantly reduces the thermal power industry in the pilot area. and has a positive but insignificant effect on the carbon emission efficiency of thermal power industry. The reduction of carbon dioxide emissions from the thermal power industry in the pilot areas is achieved by reducing the amount of thermal power generation to reduce coal consumption.

Overall, the empirical results show that the carbon emission trading policy fails to significantly improve the GTFP of the thermal power industry in the pilot areas. The carbon emission trading policy significantly reduces carbon dioxide emissions from the thermal power generation industry in the pilot areas, but this is achieved by reducing thermal power generation, reducing coal consumption and improving power generation efficiency.

Table 3. Summary of feed-in tariff, generation cost and (generation + carbon quota) cost in pilot areas.

Region	Year	On-grid tariff for coal-fired power plants (yuan/MWh)	Cost of generation (yuan/MWh)	(Power generation + Carbon quota) cost (yuan/MWh)
Beijing	2014	514.61	170.52	183.62
Beijing	2015	480.70	126.18	136.20
Beijing	2016	454.99	139.47	149.49
Beijing	2017	426.54	186.38	196.75
Beijing	2018	359.80	191.79	203.15
Beijing	2019	359.80	170.14	183.91
Tianjin	2014	430.30	218.50	227.23
Tianjin	2015	408.47	169.44	175.95
Tianjin	2016	385.63	187.54	193.54
Tianjin	2017	375.79	249.42	252.95
Tianjin	2018	365.50	253.84	257.33
Tianjin	2019	365.50	221.77	225.36
Shanghai	2014	457.74	212.60	223.43
Shanghai	2015	437.96	172.45	179.33
Shanghai	2016	400.46	194.31	199.97
Shanghai	2017	411.27	261.29	271.26
Shanghai	2018	415.50	267.94	278.59
Shanghai	2019	415.50	237.00	248.59
Chongqing	2014	445.73	225.15	230.74
Chongqing	2015	424.05	183.86	189.04
Chongqing	2016	380.53	201.76	207.79
Chongqing	2017	394.71	272.26	276.58
Chongqing	2018	396.40	279.22	282.24
Chongqing	2019	396.40	249.70	254.34
Hubei	2014	466.85	216.29	223.07
Hubei	2015	451.01	179.06	187.24
Hubei	2016	394.92	199.73	204.69
Hubei	2017	408.84	264.03	268.30
Hubei	2018	416.60	269.82	276.57
Hubei	2019	416.60	242.93	254.39
Guangdong	2014	536.36	218.50	233.64
Guangdong	2015	495.71	175.45	181.03
Guangdong	2016	460.87	194.31	197.91
Guangdong	2017	444.70	257.64	261.65
Guangdong	2018	453.00	271.70	276.01
Guangdong	2019	453.00	240.39	247.03

Table 4. Regression results of dynamic effects of carbon emission trading policy.

	(1)	(2)	(3)	(4)
Variable	CO_2	Coal	FD	Coe
before6	0.00127	0.000504	0.0161	0.0218
	(0.0177)	(0.0169)	(0.0245)	(0.0217)
before5	-0.0108	-0.00805	-0.00133	0.0189
	(0.0177)	(0.0161)	(0.0228)	(0.0200)
before4	-0.0174	-0.0142	-0.0127	0.0109
	(0.0134)	(0.0125)	(0.0187)	(0.0171)
before3	-0.0246*	-0.0208	-0.0130	0.00224
	(0.0140)	(0.0144)	(0.0168)	(0.0169)
before2	-0.0301**	-0.0288**	-0.0288**	0.000167
	(0.0139)	(0.0138)	(0.0142)	(0.0159)
current	-0.0286**	-0.0230*	-0.0403***	-0.0206
	(0.0138)	(0.0137)	(0.0153)	(0.0160)
after1	-0.0364**	-0.0303**	-0.0453**	-0.0390*
	(0.0149)	(0.0146)	(0.0181)	(0.0219)
after2	-0.0455***	-0.0367**	-0.0505***	-0.0443*
	(0.0170)	(0.0161)	(0.0188)	(0.0226)
after3	-0.0414**	-0.0362**	-0.0508**	-0.0434**
	(0.0175)	(0.0171)	(0.0215)	(0.0180)
after4	-0.0672***	-0.0589***	-0.0800***	-0.0438**
	(0.0214)	(0.0207)	(0.0250)	(0.0190)
after5	-0.0746***	-0.0663***	-0.0878***	-0.0546**
	(0.0213)	(0.0205)	(0.0238)	(0.0212)
after6	-0.0724***	-0.0664***	-0.0936***	-0.0664***
	(0.0214)	(0.0198)	(0.0268)	(0.0220)
Constant	-0.134**	-0.134**	-0.106	0.290***
	(0.0608)	(0.0584)	(0.0669)	(0.0688)
Control variable Regional fixed effect Year fixed effect	Control Yes Yes	Control Yes Yes	Control Yes Yes	Control Yes Yes
Observations	450	450	450	450
R-squared	0.961	0.962	0.968	0.905

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% levels, respectively.

Discussion

From the above analysis, it can be shown that the carbon emission trading policy has significantly reduced the carbon dioxide emissions of the thermal power generation industry in the pilot areas. Therefore, how do pilot areas cope with thermal power production reduction? What is the policy effect of carbon emission trading policy on the power industry in the pilot areas? These are worthy of discussion and study. There are two ways to choose this holiday, one is to choose to import electricity through neighboring provinces to meet the power consumption demand of their own province, and the other is to switch to “clean” power generation such as hydropower, wind power, nuclear power, photovoltaic solar power generation and so on under the influence of policies in pilot areas.

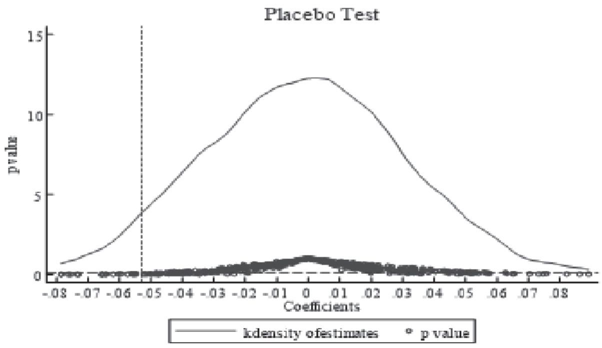

Fig. 1. Placebo test of CO_2.

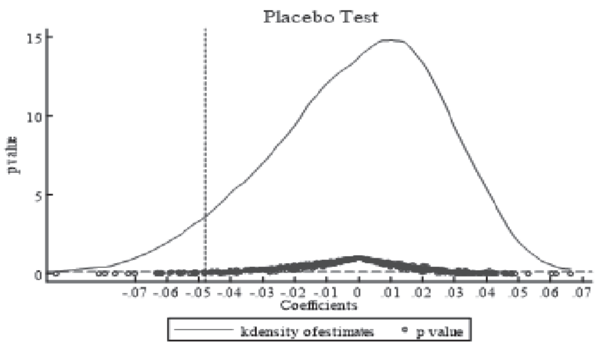

Fig. 2. Placebo test of coal consumption.

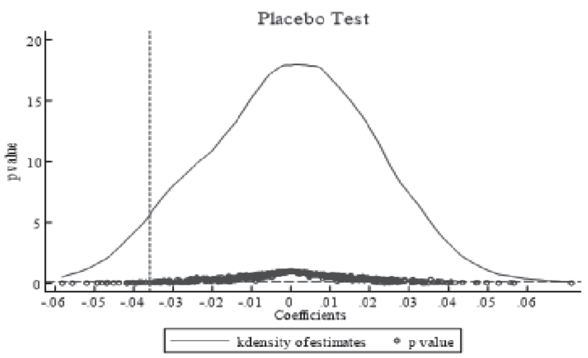

Fig. 3. Placebo test of thermal power generation.

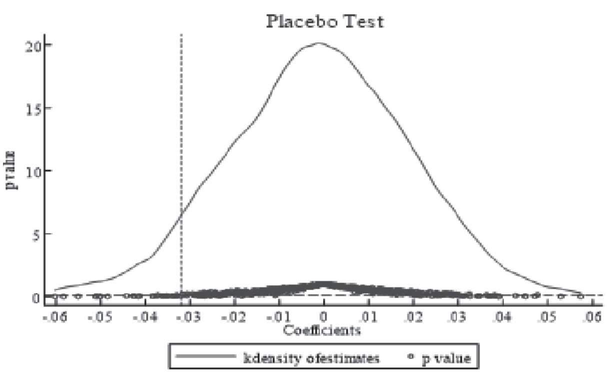

Fig. 4. Placebo test of Standard coal consumption for power generation.

(1) Carbon spillover effects. If neighboring provinces have increased thermal power generation, this implies a carbon spillover effect, which indicates that the carbon emission reduction effect of the carbon emission trading policy on the carbon dioxide emissions of the thermal power industry in the pilot area is overestimated. Therefore, based on data integrity, consistency and availability, the neighboring provinces of each pilot area are determined based on the national cross-provincial electricity exchange, and Jiangsu, Zhejiang, Henan, Hunan, Guangxi, Sichuan, Guizhou and Yunnan are finally identified as these eight neighboring provinces. In addition, the thermal power generation (FP), generating capacity of new energy (hydro, nuclear, wind) (Cele) and total power generation (ele) of each province and city from 2006 to 2020 were selected as the explained variables, and DID regression was conducted to evaluate the carbon spillover effect of carbon emission trading policy on these neighboring provinces, and the influence of the original pilot areas was excluded in the regression.

The impact of emissions trading policies on carbon spillovers in neighboring provinces was reported in Table 8. Among them, carbon dioxide emissions (CO_2) in Column (1) and thermal power generation (FP) in Column (2) decrease significantly, while total power generation (ele) in Column (3) and new energy power generation (Cele) in Column (4) increase significantly. This suggests that the emissions trading policy does not produce carbon spillovers, but rather produces positive spillovers. Because carbon emissions and thermal power generation of thermal power generation industry in neighboring provinces have significantly decreased, total power generation and new energy power generation (hydropower, wind power and nuclear power) have significantly increased. This indicates that neighboring provinces increase new energy generation while reducing thermal power generation, and thermal power generation is closely related to carbon emissions.

(2) “Clean” power generation. The original pilot area increases “clean” power generation to compensate for the reduction in thermal power generation was assumed. Power generation data of hydropower, nuclear power and wind power in each region from 2006 to 2020 are collected. The difference-in-difference (DID) regression was used to assess whether carbon emissions trading policy have increased new energy generation (SCele).

Table 9 reports the impact of carbon emission trading policy on new energy generation in pilot areas. Among them, columns (1) and (2) show the results of the new energy generation in all pilot areas affected by the carbon emission trading policy, which has a positive impact but is not significant. The reason may be that the external conditions required by new energy power generation in some pilot areas are not suitable. Thermal power accounts for more than 90% in Beijing, Tianjin and Shanghai, and the dependence on thermal power generation is very high. For wind power, nuclear power and solar power these technologies and supporting facilities to build a certain amount of time.

Table 5. Robustness test of carbon emissions trading policy from 2008 to 2020.

	(1)	(2)	(3)	(4)
VARIABLES	CO_2	Coal	FD	Coe
treat*post	-0.0174**	-0.0129*	-0.0347***	-0.0518***
	(0.00735)	(0.00701)	(0.01050)	(0.00853)
Control variable	Control	Control	Control	Control
Constant	-0.00674	-0.0195	0.0561	0.353***
	(0.0595)	(0.0554)	(0.0626)	(0.0618)
Regional fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	390	390	390	390
R-squared	0.978	0.979	0.981	0.901

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% levels, respectively.

Table 6. Robustness test of carbon emissions trading policy from 2006 to 2018.

	(1)	(2)	(3)	(4)
VARIABLES	CO_2	Coal	FD	Coe
treat*post	-0.0475***	-0.0420***	-0.0606***	-0.0420***
	(0.0121)	(0.0118)	(0.0123)	(0.0102)
Control variable	Control	Control	Control	Control
Constant	-0.133**	-0.131**	-0.140**	0.334***
	(0.0618)	(0.0592)	(0.0668)	(0.0686)
Regional fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	390	390	390	390
R-squared	0.959	0.960	0.969	0.903

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% levels, respectively.

Table 7. Robustness test of carbon emissions trading policy from 2008 to 2018.

	(1)	(2)	(3)	(4)
VARIABLES	CO_2	Coal	FD	Coe
treat*post	-0.0248***	-0.0198***	-0.0435***	-0.0423***
	(0.00798)	(0.00753)	(0.0118)	(0.00911)
Control variable	Control	Control	Control	Control
Constant	-0.0716	-0.0649	-0.0787	0.336***
	(0.0644)	(0.0596)	(0.0726)	(0.0625)
Regional fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	330	330	330	330
R-squared	0.977	0.978	0.978	0.904

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% levels, respectively.

Table 8. Carbon spillover effect of carbon emission trading policy.

	(1)	(2)	(3)	(4)
VARIABLES	CO_2	FP	ele	Cele
did	-0.0268***	-0.0270***	0.0366***	0.0941***
	(0.00781)	(0.00858)	(0.0110)	(0.0132)
Control variable	Control	Control	Control	Control
Constant	0.00412	0.0639	0.629***	0.897***
	(0.0723)	(0.0683)	(0.0964)	(0.107)
Regional fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	360	360	360	360
R-squared	0.960	0.973	0.952	0.907

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% levels, respectively.

Table 9. The impact of carbon emissions trading policy on new energy power generation in pilot areas.

	(1)	(2)	(3)	(4)
VARIABLES	SCele	SCele	SCele	SCele
treat*post	0.0104	0.0152	0.0786*	0.0567***
	(0.0201)	(0.0257)	(0.0437)	(0.0153)
Control variable	No	Control	No	Control
Constant	0.387***	0.333***	0.109***	0.969***
	(0.00448)	(0.102)	(0.00373)	(0.117)
Regional fixed effect Year fixed effect	Yes Yes	Yes Yes	Yes Yes	Yes Yes
Observations	450	450	390	390
R-squared	0.104	0.111	0.829	0.904

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% levels, respectively.

In addition, the geographical location and urban area of these four municipalities are different from those of other provinces. Moreover, the four municipalities are economically developed areas in China with dense population and do not have good conditions to develop wind power generation, nuclear power generation and photovoltaic solar power generation.

Considering the influence of the above factors in Beijing, Shanghai, Tianjin and Chongqing, this section excludes Beijing, Shanghai, Tianjin and Chongqing, and only compares the impact of carbon emission trading policies on new energy generation at the provincial level. Columns (3) and (4) in Table 9 are the results that only consider the two pilot provinces of Hubei and Guangdong compared with other provinces, and the results show that Hubei and Guangdong have significantly increased the new energy generation.

In recent years, China has attached great importance to the development of new energy and energy storage, and has introduced a series of policies and measures to vigorously promote the rapid development of both. In terms of new energy, the National Development and Reform Commission, the National Energy Administration and other competent government departments have introduced a number of targeted measures to ensure the high-quality development of new energy, focusing on the guidance mechanism of responsibility weight of renewable energy power consumption, grid-connected consumption, affordable Internet access, financial support, green power trading, peak regulation capacity construction and other aspects.

Conclusions and Policy Recommendations

Conclusions

This paper focuses on the thermal power generation industry with large carbon emissions in China, takes the carbon emission trading pilot policy as a quasi-natural experiment, calculates the green total factor productivity of the thermal power generation industry based on the Super-SBM-GML index model, and empirically tests the energy saving and emission reduction effect of carbon emission trading policy on the thermal power generation industry by using the difference in differences model. The paper discussed the potential emission reduction mechanism and the reasons behind it, and discuss the policy effect of carbon emission trading policy. The results show that:

First of all, for the highly regulated thermal power industry, the carbon emission trading policy significantly reduces the carbon dioxide emissions of the thermal power industry in the pilot areas, but does not significantly improve the GTFP of the thermal power industry. Secondly, in the analysis of the potential emission reduction mechanism in the thermal power generation industry, it is found that the main reason for the reduction of carbon dioxide emissions in the thermal power generation industry is the reduction of thermal power generation. Further analysis shows that the marginal benefit of thermal power generation in pilot areas is about twice the marginal cost. This indicates that the reduction in thermal generation is more likely to be caused by the policies of the power planning department rather than by the optimization decisions of the power plants. Finally, for the discussion on the effect of carbon emission trading policy, the empirical results show that carbon emission trading policy has a positive spillover effect, which not only reduces the thermal power generation of neighboring provinces and increases the new energy generation of neighboring provinces, but also increases the new energy generation of pilot provinces (Hubei province and Guangdong Province).

Policy Recommendations

As the main energy supplier in China, the thermal power industry is facing issues such as how to reduce coal consumption, reduce emissions and improve the cleanliness of emissions, which also shows the deep-seated problems of China's current energy structure. Transforming the energy structure is the fundamental strategy for China's energy conservation and emission reduction, including achieving carbon neutrality in the future. The research conclusions of this paper make the following suggestions for China to accelerate the transformation of energy conservation and emission reduction in the thermal power industry under the constraints of the ecological environment, and then make the following suggestions for the whole society to win the carbon neutrality strategy and policy formulation:

(1) Promoting integrated energy services. Building an integrated energy system is an important part of China's energy revolution, and is also a hot spot of current academic and engineering research. The construction of thermal power generation should, on the basis of ensuring stable supply, play its role of supporting power supply and supporting power supply for important load centers. In promoting the development of new energy, we should play the role of flexible adjustment of the main power supply, and constantly improve the efficiency and efficiency of existing coal-fired power plants. Play the role of regional energy base in energy allocation, manage power consumption through load adjustment, and use distributed power supply to reverse power supply, so as to achieve coordination and cooperation, timely collect power generation information, and carry out peak shaving and valley filling.

(2) Study the development path of low-carbon technology and actively respond to carbon emissions trading. The proposal of carbon peak and carbon neutral targets points out the direction for the overall planning of air pollution prevention and greenhouse gas emission reduction. The thermal power industry should actively carry out research on the application of carbon reduction and efficiency enhancement technology, pay attention to the use of clean energy, carbon dioxide capture, utilization and storage (CCUS) technology, zero-carbon technology and other low-carbon new technologies, and plan ahead to grasp the opportunities, and carry out research on CCER (certified voluntary emission reduction) projects related to wind power and photovoltaic, and make full use of the group's internal resources to allocate carbon assets and study the carbon trading synergy mechanism.

(3) Strengthen policy support and guidance. China's energy industry is developing towards a diversified, clean, low-carbon and digital direction, and the task of clean and low-carbon transformation is arduous. On the basis of fully understanding the development of comprehensive energy industry, it is necessary to establish and improve the comprehensive energy service support system and mechanism, and advocate energy conservation and emission reduction in the whole society. National government departments need to further introduce policies to guide thermal power generation enterprises to carry out technology investment and upgrading in order to improve their technological innovation level in energy conservation and emission reduction. At the same time, both central enterprises and local enterprises should be taken into account, and market monopolies should be further broken, market mechanism reforms such as power grid bidding and carbon emission trading mechanism should be accelerated, competition among power generation enterprises should be stimulated, outdated and inefficient power generation enterprises should be eliminated, and "supply-side reform" of power generation industry should be effectively realized.

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Conflict of Interest

The authors declare no conflict of interest.

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