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Can Carbon Emission Trading Policy Improve the Emission Performance? Evidence From China

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Abstract: The carbon emission trading system (ETS) has become one of the most crucial environmental regulations for emission mitigation and energy conservation in China. This thesis uses the difference-in-difference (DID) model to analyze the causal influence of China's ETS on carbon emission performance. The results show that the implementation of the ETS is an effective way to mitigate carbon intensity and total carbon dioxide emissions (12%), thus promoting carbon emission reductions. In contrast, economic development, energy intensity and population size hindered the carbon reduction process, while industrial structure had no significant impact on carbon reduction. Further PSM-DID models confirmed the reliability of the above conclusions. Based on these conclusions, this study provides inspiration and suggestions for the implementation of the nationwide ETS in the new stage of environmental governance.

Keywords: Carbon emission trading, emission performance, carbon intensity, difference-in-difference model.

1. Introduction

Increased greenhouse gas emissions have exacerbated climate change, posing a severe threat to human survival, social, economic, and environmental sustainability. In 2005, an emission trading mechanism aimed at promoting the transformation of a low carbon development——the EU Emissions Trading System (EU-ETS), was established and has received more and more attention around the world (ICAP, 2018). Globally, 39 countries have adopted or plan to adopt carbon pricing tools (carbon taxes or carbon trading) to cut down carbon emissions.

As the world's top emitter of carbon, China is faced with increasingly prominent climate change issues and great concern from the international community. In order to meet emission reduction targets and balance economic expansion and environmental protection, the Chinese government has begun to regulate the emission of greenhouse gases, particularly carbon dioxide. Following the Kyoto Protocol, China began to implement the voluntary CDM emission reduction model; thereafter, China approved Beijing, Shanghai, Tianjin, Chongqing, Guangdong and Hubei to conduct pilot work on carbon emissions trading in 2011.

The Emission trading system has now become the most widely recognized way to reduce emissions globally, and it works by limiting total emissions from high emitting industrial sectors. Within this limit, companies can buy and sell emission allowances. As more countries implement carbon ETS, the research on the emission reduction effects and mechanisms will undoubtedly provide

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theoretical and empirical support for policy implementation worldwide. Therefore, considering the insufficient of the existing literature and the significance of this research question, this study calculates the carbon intensity and carbon emissions in each of China’s 29 provinces from 2004 to 2019 using DID model, and investigates if the establishment of carbon ETS can improve emission performance.

This thesis contributes to the existing literature as follows. First, this paper adopts both the DID and PSM-DID models to estimate the results, and through reasonable model construction and empirical research to explore the emission mitigation effect of China's regional carbon ETS, so as to obtain a more robust estimate in the case of a large sample data set. Second, by reviewing the study on the policy effect of the ETS and the development of China's carbon market, this paper analyzed the rationality of the policy from a theoretical level. Finally, this study can complement the literature on quantitative analysis of the effectiveness of China's carbon ETS. Due to the development of the European carbon market, the research on carbon trading has been concentrated on the EU market, while the literature on China's carbon market is relatively limited. Besides, most studies on China’s carbon markets are qualitative analysis. Hence, this thesis attempts to verify the impact of the ETS on carbon dioxide emissions and its mechanism of action, which can provide a quantitative analysis basis for policy evaluation and further deepen the construction of a nationwide environmental rights trading market.

2. Institutional background

Carbon emission trading is based on the economist Pigou's theory of externalities (Pigou, 1951) and Coase's theory of transaction costs (Coase, 1960). This theory was first applied to the regulation of carbon emissions by the Kyoto Protocol in 1997 —setting quantifiable emission reduction goals for developed nations and controlling carbon emissions through market mechanisms.

Shenzhen hosted the first carbon emission trading pilot in China in June 2013, representing a major milestone in the development of China's carbon trading market. Thereafter, Beijing, Tianjin, Shanghai, Guangdong, Hubei, and Chongqing have successively launched pilot work. Among all the pilot cities, Shanghai has the most extensive policy coverage and a relatively complete policy system. At the same time, Guangzhou, as the largest carbon trading pilot in China, has also made a great contribution to the total trading volume and trading scale. At present, the carbon trading market regulations in China's pilot regions are gradually improving. In July 2021, the nationwide carbon emission trading market has been officially established and put into operation. However, given China's special market regulation and features, can the execution of the carbon emission trading scheme effectively promote emission performance? To answer this question, further quantitative analysis and empirical support are needed.

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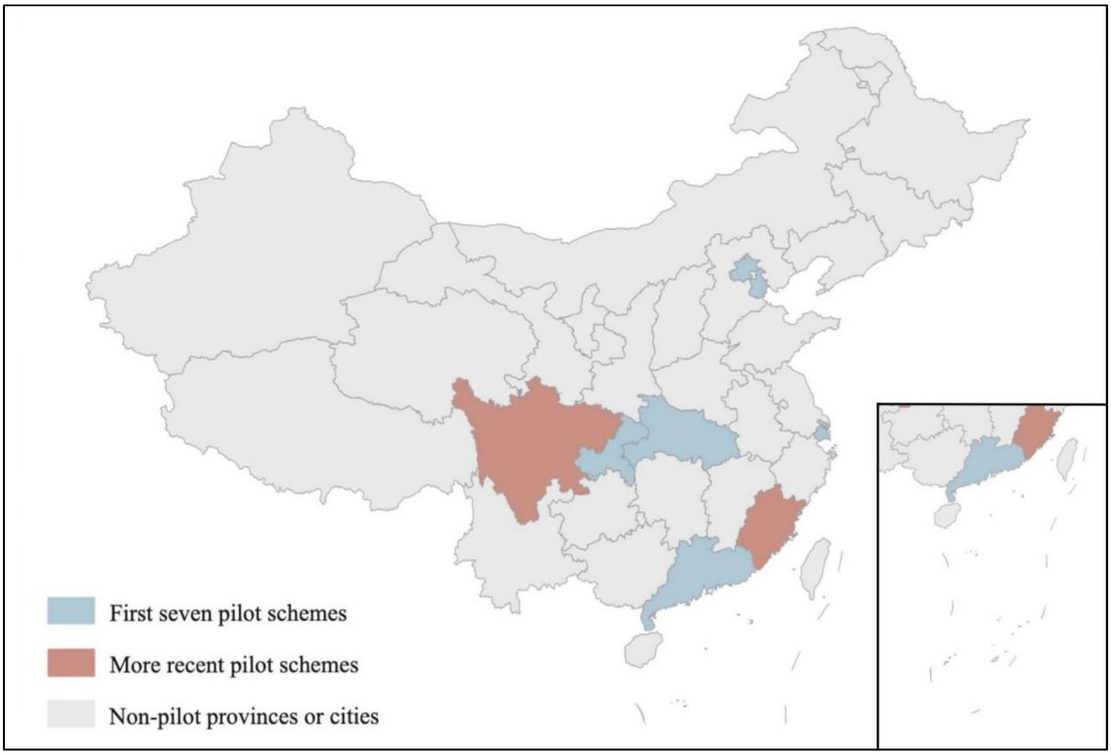

Figure 1: Carbon dioxide emission trading scheme pilot area distribution.

3. Literature Review

Emissions trading is a "market incentivized" environmental policy. In recent years, due to the intensification of global warming, scholars in the field of environmental economics are paying more and more attention to the emission mitigation effect of the ETS(Zhang et al., 2019; Zhang et al., 2020). The current research on the effectiveness of the carbon ETS is mainly based on the background of developed countries, especially the analysis of the EU-ETS (Lise et al., 2016).

Chinese scholars' empirical study on the validity of emission reduction in the environmental rights trading market mainly focuses on emissions trading, and most of the literature affirms the mitigation effect of emissions trading. However, the literature on the effectiveness of market based environmental regulations in reducing emissions has not come to a consensus. At the same time, the research on the effectiveness of China’s carbon ETS is insufficient, and most of them are qualitative discussions, empirical discussions, or the research focusing on a specific industry or region (Zheng et al., 2021), which lacks empirical analysis at the national level.

Xuan et al. (2020) established that the ETS play a key role in mitigating carbon emissions by using the DID method. Zheng et al. (2021) gain insights from the standpoints of micro enterprises, and through heterogeneity analysis, they proposed that the performance of listed enterprises’ carbon emissions in China’s eastern coastline regions was promoted noticeably, while those in the central and western pilot regions were not significantly improved. Fan et al. (2017) incorporated the Porter hypothesis and proved that technological innovation exerts a mediating effect on environmental performance during the adoption of the ETS.

At the same time, some thesis have demonstrated that carbon emissions trading schemes have not yet achieved significant emission reductions. Wang et al. (2004) adopted the quantitative method to compare the emissions of sulfur dioxide before and after the introduction of emission rights trading, and pointed out that after the adoption of the policy, the level of sulfur dioxide emissions did not significantly change. The reason is that China has not formed an adequate emission rights trading

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market. Cao et al. (2021) discovered that the emission trading policies did not considerably enhance coal-fired power stations' carbon efficiency, since the operations of power generation were highly regulated by the competent authorities.

4. Research design

4.1. Data source

Considering the completeness and authority of the data, the samples used in this paper were collected from the panel data of 29 provinces in China from 2004 to 2019. All the data were collected from the National Bureau of Statistics, China Statistical Yearbook, China Energy Statistical Yearbook and Carbon Emission Accounts and Datasets(CEADs).

4.2. The Difference-in-Difference model

To verify the influence of the ETS on carbon emission intensity, this thesis uses the DID model for the analysis. The adoption of DID model can effectively avoid the endogeneity problem of policy as an explanatory variable because the policy is exogenous, and the reverse causality does not exist. In addition, the use of DID model also alleviates the problem of omitted variable bias to some extent because it eliminates the unobservable time invariant factors. In the study, I use the DID method to compare the difference in carbon emission intensity between the pilot and non-pilot regions before and after the implementation of the regulation to evaluate the effect of the policy. This can be seen as a quasi-natural experiment, where subjects are divided into a treatment group that contains the pilot cities that have implemented the carbon emission trading policy, and a control group which involves the non-pilot areas. The carbon ETS in seven pilot regions in China was launched in 2013 (Shenzhen, Shanghai, Beijing, Guangzhou and Tianjin) and 2014 (Hubei and Chongqing). Considering that Guangzhou and Shenzhen are prefecture-level cities affiliated to Guangdong Province, and most of the remaining pilot areas are provincial level administrative regions, this paper uses provincial level data and excludes Guangdong Province to avoid non-pilot cities in Guangdong from being used as experimental groups to affect the results. Therefore, I set the time when policies in Shanghai, Beijing and Tianjin actually take effect as 2014, while Hubei and Chongqing as 2015. The DID model is set as follows:

$$lnce_{it} = \beta_1(treated_i \times T) + \sum \beta_j Control_i + \gamma_i + \lambda_t + \varepsilon_{it} \tag{1}$$

where lnceit refers to the logarithmic value of carbon dioxide emission intensity in the t year of province i. treatedi is a regional dummy variable, representing whether the province is implementing carbon emissions trading systems. If province i belongs to the treatment group, the corresponding treatedi value is 1; otherwise, it is 0. T is also a dummy variable which equals to 1 when the carbon emission trading policy takes effect, and 0 otherwise. Thus, (treatedi×T) is the core explanatory variable which indicates whether the region i has adopted the pilot policy in period t. Controli refers to the control variables. γi and λt represent the region fixed effect and the time fixed effect, respectively.

4.3. Variable measurement

According to the existing literature (Guo et al., 2021; Xuan et al., 2020), this thesis uses the carbon dioxide emission intensity and total carbon dioxide emissions as explained variables to evaluate the emission reduction effect of the ETS. In particular, the carbon intensity, which measures the correlation between a nation's economic development and carbon emissions, is defined as the quantity

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of carbon dioxide emissions per unit of GDP. If a nation's economic expansion is accompanied with a drop in carbon emission intensity, the nation has met a low-carbon development model. Hence, in this paper, I divide the total carbon emissions for each province by the GDP and take the logarithm of this value, then denote it as lce.

With reference to (Hu et al., 2020; Zhang et al., 2019; Li et al., 2020), this paper selects the economic development, industrial structure, education level, energy intensity and population size as the control variables that may have impacts on the carbon emission intensity. Specifically, I choose the real GDP per capita (pgdp) as the indicator to reflect the economic condition in each province, which is measured by the quotient of provincial GDP in a given year divided by population. Second, carbon dioxide emissions mainly come from the combustion of fossil fuels, so this thesis uses the added value of the secondary industry to reflect the impact of industrial structure (sgdp) on carbon dioxide emissions. Thirdly, to represent each province’s education level (school), the number of general higher education institutions is controlled. Besides, this study explores the influence of energy intensity (ei) on carbon dioxide emissions, which is quantified by the total energy usage to real GDP ratio. Finally, in addition to the production process that produces carbon dioxide, the concentration and size of the population are also one of the sources of carbon dioxide. Therefore, this study represents the population size (pop) of each province using the total population at the end of the year. The descriptive statistics for the variables are shown in Table 1.

Table 1: Descriptive statistics (N=454).

Variable	Variable meaning	Mean	Std. Dev.	Min	Max
ce	carbon dioxide emission intensity	2.713	2.176	0.438	12.162
treat	policy implementation	0.040	0.195	0	1
pgdp	economic development	38321.650	23620.260	4317	122398
sgdp	industrial structure	7019.956	6897.101	154.400	43507.500
school	education level	75.445	36.311	9	167
ei	energy intensity	1.086	0.637	0.324	4.323
pop	population size	4306.784	2500.847	539	10106

5. Empirical Results

5.1. Descriptive statistics

In Fig. 2, before the adoption of the policy in 2013, the average carbon emission intensity trends in pilot and non-pilot regions were roughly the same. However, the experimental group's carbon dioxide emission intensity exhibited a more significant downward trend than that of the control group from 2013 to 2020. This provides preliminary evidence for the conclusion that the ETS can improve carbon emission mitigation, but more rigorous regression analysis is still required.

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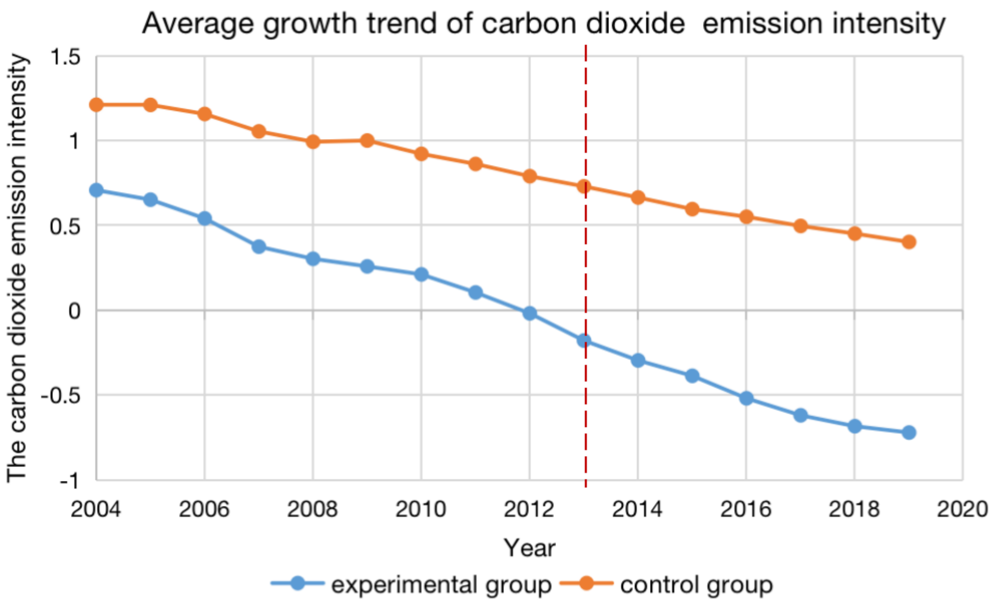

Figure 2: Average growth trend of the intensity of carbon emissions.

5.2. Analysis of empirical results

Table 2 represents the results of six regressions using the fixed effects model, in which the explained variable total carbon emissions (in log) in models (1), (2), (3) and the carbon emission intensity (in log) in models (4), (5), and (6) are both used to evaluate the impact of the ETS on carbon emissions. At the same time, models (1) and (4) do not add any control variables as reference groups; models (3) and (6) represent the overall reduction performance of the policy when the control variables including economic development, industrial structure, education level, energy intensity and population size are incorporated, and the effects of these six sets of control variables on carbon dioxide emissions were tested. In particular, models (3) and (6) and models (2) and (5) are compared to underscore the impact of energy intensity on carbon emission reduction.

Models (1) and (4) suggest that the coefficient of $\text{treated}_i \times T$ is always significant at the 1% level without the addition of control variables. Model (3) and (6) show that when control variables are included in the regression, the ETS can significantly mitigate carbon intensity and emission levels. Specifically, as can be seen from the coefficient results of model (6), the carbon dioxide emission intensity decreased by 12% in pilot regions after the implementation of the policy. Thus, the carbon ETS has a significant effect on the improvement of emission reduction performance.

The coefficient of the explanatory variable $\text{treated}_i \times T$ in model (6) is smaller than that in model (4), representing that control variables also exert an effect on carbon intensity. Regarding the control variables, the economic development, energy intensity and population size are positively correlated with carbon emissions. The rise in per capita GDP will increase carbon emissions, reflecting that China is still prioritizing economic expansion over environmental protection. Similarly, an increase in population size and density will hinder carbon reduction efforts as well. However, the impact of regional industrial structure on emission performance is not significant, indicating that the role of regional industrial structure upgrading on regional carbon emission reduction has not been thoroughly released, and it is necessary to strengthen the dominant role of industries with high technical level and production efficiency in regional industrial structure upgrading.

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Table 2: Impact of the carbon ETS on emission reduction performance.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	lco_2			lce		
$treated_i \times T$	-0.247***	-0.263***	-0.124*	-0.296***	-0.281***	-0.129**
	(0.057)	(0.074)	(0.051)	(0.101)	(0.071)	(0.044)
lpgdp		0.316*	1.183***		-0.537***	0.350**
		(0.166)	(0.154)		(0.176)	(0.150)
lsgdp		0.033	-0.155		-0.011	-0.203
		(0.206)	(0.210)		(0.209)	(0.210)
lschool		-0.394	-0.383		-0.355	-0.344
		(0.306)	(0.237)		(0.310)	(0.236)
lei			1.173***			1.200***
			(0.158)			(0.162)
lpop		0.202	0.144		-0.538	-0.598***
		(0.506)	(0.192)		(0.509)	(0.206)
Year fixed effect	Y	Y	Y	Y	Y	Y
Province fixed effect	Y	Y	Y	Y	Y	Y
Constant	4.814***	1.506	-5.344**	1.178***	12.020***	5.021**
	(0.052)	(4.184)	(2.017)	(0.046)	(4.179)	(2.059)
N	454	454	454	454	454	454
R^2	0.734	0.749	0.823	0.706	0.753	0.828

Note: the parenthesis are standard errors; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

It is also worth noting that the results of model (2) and model (5) show that the impact of energy intensity is significant at 1%, indicating that carbon emissions can be largely reduced by controlling energy demand and optimizing the proportion of coal consumption.

6. Robustness test

6.1. PSM-DID estimation

A crucial premise of adopting the DID model is to meet the assumption of the parallel trend — namely, there is no systematic difference in the trends of economic development and carbon emissions between the control group and the treatment group before the policy launches. However, the existence of selection bias may pose serious problems for the results. The regions selected as pilots generally have better economic development, so the energy consumption and carbon emissions are also higher than in other provinces and cities. Therefore, the premise of the DID model may not be satisfied. To solve this problem, this study adopts the propensity score matching (PSM) method to generate matched samples (Heckman et al., 1998).

The basic idea of the PSM-DID model is to match the pilot areas with the regions that have similar observable variables and are in the non-pilot provinces and cities based on the propensity scores. Thus, the new comparison groups can be established with the identical distribution for the

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covariates(Lu, 2016). Specifically, the covariates in the propensity score matching select the economic development, industrial structure, education level, energy intensity and population size mentioned above. Next, I used the DID model to re-estimate the panel data of the matched control group and the experimental group from 2004 to 2019. The results are shown in Table 3.

The empirical results of model (1) and model (2) indicate that after the policy was formally implemented, total carbon dioxide emissions and carbon intensity decreased by 10% and 11%, respectively. In addition, the results are still significant, further confirming the reliability of the conclusion that the carbon ETS has a positive influence on the emission performance.

6.2. Other robustness tests

The second robustness test changes the dependent variable to the carbon dioxide emissions per capita. Different from carbon intensity, the indicator of per capita carbon dioxide emissions has nothing to do with economic development and technological innovation, so it can purely reflect the effect of the ETS on carbon emission reductions. The results in model (3) in Table 4 show that carbon ETS can not only mitigate carbon intensity, but also effectively reduce per capita carbon dioxide emissions, which further confirms the robustness of the results.

Table 3: Impact of the ETS on emission reduction performance (PSM-DID).

	(1)	(2)
Variables	lco_2	lce
$treated_i \times T$	-0.097*	-0.110^{**}
	(0.051)	(0.044)
lpgdp	1.180^{***}	0.346^{**}
	(0.157)	(0.154)
lsgdp	-0.161	-0.210
	(0.214)	(0.215)
lschool	-0.377	-0.337
	(0.241)	(0.240)
lei	1.178^{***}	1.205^{***}
	(0.159)	(0.162)
lpop	0.118	-0.627^{***}
	(0.197)	(0.210)
Year fixed effect	yes	yes
Province fixed effect	yes	yes
Constant	-5.089^{**}	5.306^{**}
	(2.087)	(2.135)
N	451	451
R^2	0.822	0.826

Note: the parenthesis are standard errors; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

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Table 4: Other robustness tests.

	(1)	(2)	(3)
Variables	lco_2	lce	$lpco_2$
$treated_i \times T$	-0.097*	-0.110**	-0.097*
	(0.051)	(0.044)	(0.051)
lpgdp	1.180***	0.346**	1.180***
	(0.157)	(0.154)	(0.157)
lsgdp	-0.161	-0.210	-0.161
	(0.214)	(0.215)	(0.214)
lschool	-0.377	-0.337	-0.377
	(0.241)	(0.240)	(0.241)
lei	1.178***	1.205***	1.178***
	(0.159)	(0.162)	(0.159)
lpop	0.118	-0.627***	-0.882***
	(0.197)	(0.210)	(0.197)
Year fixed effect	Y	Y	Y
Province fixed effect	Y	Y	Y
Constant	-5.089**	5.306**	-0.484
	(2.087)	(2.135)	(2.087)
N	454	454	454
R^2	0.822	0.826	0.799

Note: the parenthesis are standard errors; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

7. Discussion and conclusion

This thesis explores whether the carbon ETS can improve the carbon emission performance based on data from 29 provinces from 2004 to 2019. The study uses the DID model and the PSM-DID model for quantitative regression analysis and found that the ETS can significantly mitigate regional carbon emissions (12%). In addition, the economic development, energy intensity and population size have a positive impact on the carbon dioxide emissions, so these factors may hinder the carbon reduction efforts. However, the regional industrial structure does not affect carbon emission performance significantly, indicating that China still needs to continuously upgrade the industrial structure and technological innovation to promote the implementation of emission reduction projects.

On the basis of the foregoing conclusions, this thesis proposes the following policy implications. Firstly, based on the actual effect of the ETS contributing to carbon emission reduction, China should give full play to the dominant role of carbon trading policies in efforts to mitigate emissions and save energy. Specifically, China ought to implement the emission reduction strategy that incorporates both government and market initiatives, improve the legal system of the carbon trading market and vigorously promote the establishment of the nationwide ETS.

Second, the study found that energy intensity played an inhibitory role in the process of carbon emission reduction. Therefore, China should actively boost the green transformation of the economy and reduce citizens' reliance on coal-based traditional energy. At the same time, the enterprises should strengthen technological innovation and energy efficiency elevation to realize the green production process and the low carbonization of the production terminal.

Overall, as a crucial market-based environmental regulation for reducing emissions, the carbon ETS has achieved satisfactory results at this stage in terms of carbon emission reduction performance.

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These experiences not only provide theoretical and empirical support and guidance for the promotion and strengthening of carbon trading policies in developing nations, but also serve as a powerful reference for China to use market-oriented environmental regulation to accomplish sustainable development of the economic growth and environmental protection.

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