Study on the Impact of Carbon Trading Market on Energy Efficiency

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Abstract: This study uses panel data on China's inter-provincial energy consumption structure from 2007 to 2022, employing a difference-in-differences (DID) model to systematically evaluate the impact and mechanisms of the carbon trading market on energy efficiency. The findings indicate that the carbon trading pilot program significantly enhanced energy efficiency in the pilot regions, with this effect being long-lasting. Parallel trend tests confirmed that the trends in energy efficiency changes were consistent between the treatment group and the control group before the implementation of the carbon trading market. Further placebo tests further validated the reliability of the causal relationship. By incorporating control variables such as industrial structure, labor input, and environmental regulations, the study revealed that optimizing the industrial structure and increasing labor input can significantly amplify the energy efficiency improvement effects of the carbon market. However, the impact of strengthened environmental regulations on short-term energy efficiency improvements was not significant. Further analysis showed that the carbon emission price is the core mechanism driving the improvement in energy efficiency, as it forces companies to accelerate technological upgrades and the transition to a low-carbon energy structure through cost transmission. The liquidity of the carbon market did not show statistically significant effects on energy efficiency. This study provides a theoretical basis for optimizing the mechanisms of the carbon trading market and formulating regional differentiated emission reduction strategies, confirming the effectiveness of carbon market in promoting energy efficiency improvements.

Keywords: Carbon Trading Market; Energy Efficiency; Double Difference Model (DID); Carbon Emission Price; Carbon Market Liquidity

1. Introduction

Since the Industrial Revolution, human activities have significantly increased emissions of greenhouse gases like carbon dioxide, posing a significant threat to the global ecological environment. Among these, the consumption of fossil fuels such as coal is a key factor in China's carbon emissions. In the face of the severe challenges posed by global climate change, improving energy efficiency has become a crucial approach to achieving the' dual carbon 'goals. Against this backdrop, a market-oriented carbon emission trading mechanism has emerged. China initiated pilot programs for carbon emission trading in Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, and Shenzhen, which were officially implemented around 2014. This mechanism uses price signals to guide the optimal allocation of resources, compelling energy-intensive enterprises to reduce their reliance on fossil fuels and accelerate their transition to clean energy. However, compared to mature international carbon markets, China's regional pilot markets still face challenges such as insufficient liquidity and the need for improved mechanism design. The impact of these mechanisms on enhancing energy efficiency requires empirical testing. This article focuses on the practical experiences of domestic carbon emission trading pilots, systematically evaluating their effects on energy use efficiency. This research not only deepens our understanding of how carbon trading can enhance energy efficiency but also provides valuable references for improving the design of carbon market systems and formulating national energy transition policies.

2. Literature Review

Existing literature generally confirms that carbon trading policies significantly enhance energy

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efficiency. Regarding the regional differences in policy implementation effects, Xue and Ma [1] found, based on provincial panel data from China, that green total factor energy efficiency in pilot regions increased by 12%-15% compared to non-pilot regions. Yan et al. [2] noted that the improvement effect was more pronounced in the eastern developed regions. In terms of the specific mechanisms of policy impact, Chen et al. [3] demonstrated through empirical analysis of inter-provincial panel data that carbon emission trading not only effectively reduces carbon intensity but also contributes to an 18.7% increase in energy efficiency through technological progress. However, Zhang and Zhang [4] pointed out that in the early stages of policy implementation, enterprises might face adaptation costs, leading to a temporary lag in efficiency improvements. Furthermore, Xue and Zhou [5] discovered that the energy use rights trading system indirectly boosted overall energy efficiency by encouraging enterprises to improve management efficiency (such as increasing equipment renewal rates by 22%), further enriching the evidence for the policy impact pathways.

The effectiveness of carbon trading policies varies significantly across different regions and resource endowments, potentially influenced by the 'resource curse'. According to Lu's [6] resource curse 'theory framework, resource-based regions often face a dilemma between reducing carbon emissions and promoting economic growth. Liu and Xiao [7] further confirmed this through empirical analysis using the PSTR model, indicating that coal cities need a 10-15 years transition period to unlock the benefits of their resource endowments. Lin and Du's [8] SDA decomposition study revealed that regions with high carbon resource endowments are prone to a 'rebound effect,' where improvements in energy efficiency may be partially offset by increased consumption. For example, Chen et al. [3] found that actual carbon emissions could rebound by 6% due to rising demand. This suggests that when implementing carbon trading policies in resource-based regions, it is crucial to consider regional characteristics and resource constraints to prevent the policy effects from being nullified.

The synergy between carbon trading policies and other policies, along with international experiences, is crucial for enhancing energy efficiency. Wen and Jia [9] found that the coordinated implementation of carbon emission rights trading and energy use rights trading can further boost energy efficiency by 8.6%, indicating a significant positive cumulative effect from multiple policy synergies. Internationally, AUTY and WARHURST's [10] resource curse theory remains valid, while Hong et al. [11] noted that China's carbon trading pilot projects, through the 'policy experimental field' model, have effectively reduced policy trial-and-error costs by 34%, providing valuable practical experience for the development of global carbon markets. This serves as an important reference for other countries and regions when formulating carbon trading policies, and also highlights the need to integrate local characteristics into policy innovation and practice exploration to achieve policy objectives.

In summary, carbon trading policies have shown significant success in enhancing energy efficiency, but their effectiveness is constrained by factors such as regional development levels and resource endowments. The notable improvements in pilot regions demonstrate that policies can be more effective when adapted to local conditions. However, the 'resource curse,' transformation challenges, and 'rebound effect' faced by resource-based regions highlight the importance of tailoring policies to local conditions. The mechanisms through which policies influence outcomes are diverse, with technological advancements and management efficiency improvements working together. However, the initial adaptation costs leading to efficiency lags cannot be overlooked. Moreover, this study breaks away from traditional perspectives, moving beyond a superficial analysis of how the carbon emission market affects energy efficiency. Instead, it focuses on two key dimensions: carbon market liquidity and carbon emission prices, conducting a systematic and in-depth exploration. By analyzing how these two factors impact energy efficiency in the carbon trading market, it fills a cognitive gap in previous research. The findings lay the groundwork for a more comprehensive theoretical framework for the carbon trading market and provide more targeted and practical theoretical support and decision-making references for the long-term stable and sustainable development of the carbon market.

3. Theoretical Analysis

The establishment of a carbon trading market

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guides companies to optimize their energy use through market mechanisms, significantly enhancing energy efficiency. Under the framework of the carbon market, the government sets a cap on total carbon emissions for specific regions or industries and allocates emission allowances to participating companies. If a company's actual emissions exceed its allowance, it must purchase additional allowances from the market. According to the theory of cost minimization [12], as rational economic entities, companies will balance various energy costs. On one hand, due to coal's high carbon emissions, its cost in the carbon market increases significantly. To reduce their emission reduction costs, companies will have a strong incentive to reduce their reliance on coal and seek other lower-cost energy alternatives. This adjustment process will directly improve the output efficiency per unit of energy input, leading to a decrease in coal's share in the energy consumption structure.

From the perspective of energy substitution theory, the establishment of a carbon trading market will reshape the relative pricing system among different energy sources. Clean energy sources, such as natural gas, wind power, and solar power, have low or even zero carbon emissions, thus avoiding high carbon costs and offering significant price advantages in the carbon market [13]. The carbon price signal encourages companies to shift from traditional high-carbon energy sources to clean energy, promoting a more efficient and low-carbon energy consumption structure [14]. This optimization directly results in companies achieving the same output with less energy input, significantly enhancing energy efficiency. Moreover, as the 'dual carbon' goals advance and green development strategies are implemented, the pressure on companies to save energy and reduce consumption continues to increase, making energy efficiency a critical factor in their core competitiveness [15].

Furthermore, according to the theory of environmental regulation and corporate response, there is an 'innovation compensation effect' between environmental regulation and environmental technology innovation [16]. In the carbon trading market, this effect is closely linked to the carbon price and market liquidity. The carbon price drives corporate technological innovation through cost transmission, while insufficient market liquidity can lead to distorted price signals, thereby weakening the incentive for innovation. To reduce emission costs and improve energy efficiency, companies will increase their investment in energy-saving and emission reduction technologies, developing advanced low-carbon technologies and management methods [17]. Technological innovation not only directly boosts production efficiency but also enhances industry-wide energy efficiency through knowledge spillover effects. Companies that adopt efficient energy utilization technologies gain a competitive edge. Low-carbon and high-efficiency products are more likely to be accepted by consumers, which helps to increase market share. More importantly, with the support of green financial policies, companies with high energy efficiency and low carbon emissions can more easily access low-cost financing, providing financial support for further technological upgrades, thus creating a virtuous cycle. Therefore, from a market competition perspective, the carbon market reshapes the competitive landscape of enterprises through differences in energy efficiency, forming a positive feedback mechanism of energy efficiency leadership-market advantage-technological investment-further energy efficiency improvement [18]. These mechanisms collectively drive enterprises to improve energy efficiency and reduce energy consumption per unit of output.

It is worth noting that the impact of the carbon market on energy efficiency can be influenced by key factors such as the price of carbon emissions, market liquidity, industrial structure, labor input, and environmental regulations. The carbon price is a core variable driving improvements in energy efficiency, and its influence on the energy consumption structure is closely tied to market liquidity When liquidity is insufficient, the carbon price may not accurately reflect the cost of emission reductions, leading to delayed energy substitution behaviors among companies. The more advanced the industrial structure, the more significant the effect of the carbon market on improving energy efficiency, as the service sector and high-end manufacturing are more sensitive to energy price signals; regions with higher labor input levels can promote low-carbon technological innovation through talent aggregation, thereby enhancing the positive impact of the carbon market on energy efficiency; when environmental

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regulations are stringent, the carbon market and environmental regulations can create a synergistic effect, producing a 'cumulative emission reduction' effect, significantly boosting energy efficiency. However, in regions with an industrial structure skewed towards heavy chemical industries, lower labor quality, weak environmental regulations, or limited market liquidity, the carbon market's role in improving energy efficiency may be constrained, and it may even experience efficiency fluctuations due to short-term adjustment costs. Based on the above analysis, two hypotheses are proposed:

Assumption 1: There is a significant positive correlation between carbon price and energy efficiency

According to Coase's theorem and the theory of internalizing externalities, the carbon trading market defines the property rights of carbon emission rights, thereby converting the negative externality of greenhouse gas emissions into internal costs for companies. As the carbon price rises, the cost of using high-carbon energy sources, such as coal, increases due to higher quota purchase expenses. To minimize these costs, companies will naturally shift towards clean energy alternatives, such as natural gas and wind power, and invest in low-carbon technologies, ultimately leading to improvements in energy efficiency

Assumption 2: The impact of carbon market on energy consumption structure is related to carbon emission price, carbon market liquidity and other factors.

4. Empirical Test

4.1 Model Setting

The difference-in-differences (DID) model, a widely used tool for policy evaluation in economics and social sciences, treats the implementation of a policy as a natural experiment. By including a control group that is unaffected by the policy and comparing it with the experimental group that is affected, the net impact of the policy on the analyzed object is examined [19]. In this study, provinces and cities participating in the carbon trading pilot program are designated as the experimental group, while other provinces and cities serve as the control group. A DID model is constructed to analyze the impact of the establishment of the carbon market on the energy consumption structure. The model setup is as follows:

$$E_{i,t} = a_0 + a_1 time_{i,t} \times treat_{i,t} + a_2 time_{i,t} + a_3 treat_{i,t} + a_j X_{i,t} + \lambda_t + \varepsilon_{i,t} \quad (1)$$

(1) In the model $E_{i,t} a_j time treat a_1 X \lambda_t \varepsilon_{i,t}$, the dependent variable is the explained variable, which is energy efficiency. i represents different individuals, t represents time, and the coefficients represent the effects of each variable. The interaction term $time_{i,t} \times treat_{i,t}$ can reveal the net effect of carbon trading policies, with its coefficient directly reflecting the impact on local energy efficiency after the establishment of carbon trading pilots. Control variables include factors that may influence the dependent variable and vary with regions and time. The annual fixed effect controls for time factors across provinces. The model's random standard error is also included.

(2) The establishment of the carbon trading market aims to reduce carbon emissions through market mechanisms and promote a low-carbon transformation in the energy consumption structure. Coal, as the primary fossil fuel, constitutes a significant portion of total energy consumption and is the main source of China's carbon emissions. Changes in coal consumption are highly sensitive to the carbon trading market, effectively reflecting the outcomes of policy implementation. Therefore, Hu and Wang [20] defines energy efficiency as the energy consumption per unit of GDP (e.g., tons of standard coal per 10,000 yuan).

(3) The core explanatory variable is time $\times a_1$treattreat, where the coefficient reflects the direction and magnitude of the impact of the carbon market establishment on regional energy efficiency. time is a time dummy variable, with time=0 for periods before the carbon market's launch and time=1 for periods after its launch. treat is a policy dummy variable that distinguishes between the experimental group and the control group. Regions that have established carbon trading pilots are considered part of the experimental group and are assigned a value of treat = 1, while other regions that have not initiated carbon trading pilots are considered the control group and are assigned a value of treat = 0.

$$E_{i,t} = \beta_0 + \beta_1 time_{i,t} \times treat_{i,t} + \beta_i X_{i,t} + \mu_i + \theta_i \varphi_{i,t} + \varepsilon_{i,t} \quad (2)$$

(2) Similar to Equation (1), the coefficient β_1 in Equation (2) reflects the impact of the establishment of carbon market on regional

energy consumption structure.

4.2 Data Description

Since the pilot program for carbon emission trading was launched, China has established eight local carbon markets in cities such as Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, Shenzhen, and Fujian. Seven of these markets, including Beijing, were launched between June 2013 and June 2014, while the Fujian market was launched in December 2016. Due to the lack of accurate energy consumption data in Fujian Province and Shenzhen, which is a prefecture-level city, these two markets were excluded from the study. The remaining six provinces and cities were selected as the experimental group, with 2014 designated as the start year for the carbon market. In the control group, data from Zhejiang, Shanxi, Heilongjiang, and Jiangsu lacked standardized coal consumption data. Shandong and Hunan had significant data gaps, so they were also excluded. The remaining 17 provinces, cities, and autonomous regions were included in the control group. The sample period spans from 2007 to 2022, with data primarily sourced from the annual “China Statistical Yearbook”, “China Energy Statistical Yearbook”, “China Science and Technology Statistical Yearbook”, and various provincial and municipal statistical yearbooks. A few missing data points were supplemented using linear interpolation. The descriptive statistics of the data are presented in Table 1.

There were 6 provinces and cities in the experimental group, and 17 provinces and cities in the control group; there were 7 years before and 8 years after the establishment of the carbon market. During the whole sample period, the coal energy consumption of the experimental group was higher than that of the control group, with less fluctuation, and both increased to a certain extent after the establishment of the carbon market.

Table 1. Descriptive Statistics

		sample capacity	mean	standard error	median	least value	crest value
Before establishment	experiment group	42	13905.8	8096.8	11266.9	1819.9	32782.8
	control group	119	10736	7099.9	8232.8	1135.3	29664.4
After establishment	experiment group	54	14009.2	9383.4	9449.9	6603.6	36821.4
	control group	153	11457.6	7366.2	8655.7	3869.5	28480

4.3 Result Analysis

Based on the theoretical analysis and model setup outlined earlier, this section constructs a difference-in-differences model to investigate the impact of the carbon market on the energy consumption structure. First, the model is modified to include control variables. Drawing from Zheng and Yao [21], environmental regulation is introduced, represented by GR, which measures the ratio of local fiscal expenditure on environmental protection to regional GDP. Drawing from Yang Tao and Li [22], labor input is included, measured by the number of employees per unit of GDP (people per 10,000 yuan). This is denoted as labor, with detailed results presented in Table 2.

The core explanatory variable, timetreat, has a significant positive impact on energy efficiency. In all models, its coefficient is positive and passes the 1% significance test. As shown in equation (1), for every one-unit increase in timetreat, energy efficiency increases by an average of 0.776 units. In equations (2-4), as control variables such as industrial structure, labor input, and environmental regulation are gradually incorporated into the model, the timetreat coefficient decreases from 0.776 to 0.615, but it remains significant. This suggests that the initial model overestimated the direct effect due to the omission of certain variables, and the inclusion of control variables better aligns with the actual logic of the effect. Among the control variables, the coefficient for industrial structure is negatively significant, indicating that upgrading the industrial structure enhances energy efficiency. The coefficient for labor input is positively significant, suggesting that increased labor input helps improve energy efficiency. The coefficient for environmental regulation is not significant, indicating that the current intensity of environmental regulation does not significantly affect energy efficiency.

After completing the double difference (DID) model regression and initially observing a significant impact of the policy on energy efficiency, the parallel trend test, as a core identification assumption in the DID model, is crucial for verifying the reliability of the conclusions. Only by ensuring that the treatment

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group and the control group exhibit parallel trends before the policy implementation can the policy effect be reasonably attributed and other confounding factors be excluded.

Table 2. Results of Double Difference Estimation

	(1)	(2)	(3)	(4)
time*treat	0.776*** (8.78)	0.617*** (7.37)	0.616*** (7.55)	0.615*** (7.53)
gdpstr		-0.0266*** (-8.11)	-0.0262*** (-8.21)	-0.0259*** (-8.07)
labor			0.1234** (0.0567)	0.1235** (0.0568)
Gr				-2.964 (-0.82)
_cons	1.085*** (16.38)	2.160*** (14.81)	1.896*** (12.32)	1.983*** (10.61)
Provinces are fixed	yes	yes	yes	yes
The year is fixed	deny	deny	deny	deny
sample number	368	368	368	368

Note: *, **, and *** indicate significance at the level of 10%,5%, and 1%, respectively, with standard deviation in parentheses.

According to the results of the parallel trend test in Figure 1, before the implementation of the carbon trading market policy (which was introduced in 2014, corresponding to the 'current' point in the figure), the coefficient representing the energy efficiency difference between the treatment group (regions implementing the carbon trading policy) and the control group (regions not implementing the policy) showed a steady increase with minor fluctuations around the trend line. The confidence intervals for the coefficients before the policy implementation (from pre_4 to pre_1) were broad but generally aligned with the trend, indicating that the energy efficiency trends of the treatment and control groups were largely parallel before the policy was implemented. This aligns with the parallel trend assumption of the difference-in-differences (DID) model, laying the groundwork for subsequent policy effect evaluations.

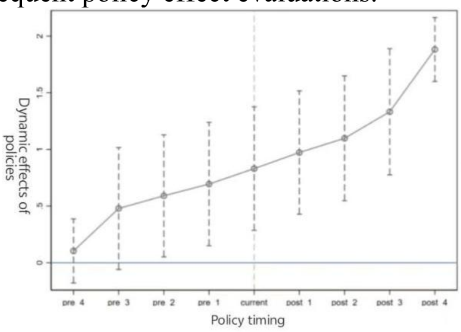

Figure 1. Parallel Trend Test Results

When the policy is implemented at the current point in time, the coefficient representing the dynamic effect of the policy shows a significant and continuous upward trend. From the post-1 to post-4 stages, the coefficient steadily increases, and although the confidence interval has some width, it does not include zero (as can be reasonably inferred from the trend in the graph). This strongly indicates that the carbon trading market policy has had a positive and gradually increasing impact on energy efficiency.

(4) Robustness test

The DID conclusions and parallel trend evidence from carbon trading policies on improving energy efficiency provide preliminary support for evaluating policy effectiveness. However, to make these research findings applicable to policy promotion, robustness tests are necessary to address practical concerns: Do the conclusions still hold under different industrial structures and environmental regulations? Have the policy effects changed due to adjustments in the sample period (such as excluding special years)? In Wang's [23] research on carbon emission trading policies, green technological innovation is often used as a mediator or control variable in parallel trend tests. Although not directly named as' technological innovation intensity, 'it is denoted as tii. When examining the impact of carbon trading policies on corporate technological innovation, factors related to technological innovation are considered to influence trends. This approach can be inspired by' s method of incorporating technological innovation indicators into the model to assist in testing the purity of trends before and after the policy.

As shown in Table 3, the overall trend remains unchanged after incorporating the new control variable of technological innovation intensity, and the core conclusions remain robust. Regarding the core policy effect, the time*treatment coefficient is consistently positive and passes the 1% significance test. Although the coefficient slightly decreases from 0.776 to 0.643 after adding the new variable, this is a reasonable adjustment due to the removal of technological innovation interference, which makes the policy effect estimation purer. The positive impact of the policy on energy efficiency remains unchanged, and its statistical significance has not weakened. In terms of control variables, the negative significance of the original industrial structure coefficient, the positive significance of the labor input coefficient, and the non-significant environmental regulation coefficient continue to hold. The newly added technological innovation intensity coefficient is positive and significant, supplementing the influence mechanism without overturning the core policy effect. Overall, the addition of the new control variable optimizes the model's robustness, does not overturn the trend, and further strengthens the reliability of the conclusion that' carbon trading policies effectively enhance energy efficiency'.

Table 3. Robustness Test

	(1)	(2)	(3)	(4)	(5)
Time*treat	0.776*** (0.088)	0.617*** (0.008)	0.616*** (0.082)	0.615*** (0.0812)	0.643*** (0.0824)
Gdpstr		-0.0266*** (0.003)	-0.0262*** (0.003)	-0.0259*** (0.00322)	-0.0242*** (0.00330)
Labor			0.1234** (0.0567)	0.1235** (0.0568)	0.1236** (0.0569)
Gr				-2.964 (-0.82)	-0.969 (3.707)
tii					0.161** (0.0766)
_cons	1.085*** (16.38)	2.160*** (14.81)	1.896*** (12.32)	1.983*** (10.61)	1.719*** (0.224)
Provinces are fixed	yes	yes	yes	yes	yes
The year is fixed	deny	deny	deny	deny	deny
Sample number	368	368	368	368	368

5. Further Analysis

This paper further examines the impact of the average annual carbon emission transaction price (denoted as 'price') on energy efficiency after the establishment of the carbon market (see Table 4). Additionally, China's carbon market is still in its early stages of development, with limited liquidity, often resulting in no transactions throughout the day. Drawing on Wu [24] and Yan [25], this paper uses the number of non-zero trading days per year as a measure of liquidity (denoted as 'days').

$$E_{i,t} = \beta_0 + \beta_1 days_{i,t} + \beta_2 gdpstr_{i,t} + \beta_3 control_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$E_{i,t} = \alpha_0 + \alpha_1 price_{i,t} + \alpha_2 gdpstr_{i,t} + \alpha_3 control_{i,t} + \varepsilon_{i,t} \quad (4)$$

The carbon emission price has a significant positive impact on energy efficiency, making it a key factor in enhancing energy efficiency. In models (1-4), as the models are progressively optimized, the price coefficient shows a steady upward trend and passes tests at high significance levels. This indicates that rising prices can effectively boost energy efficiency. The mechanism behind this is that higher prices increase the cost of using high-carbon energy, prompting companies to adopt clean energy alternatives to reduce costs, invest more in R&D for energy-saving and emission-reduction technologies, accelerate technological upgrades, and thus promote the transition to a low-carbon energy structure, ultimately leading to improved energy efficiency. Additionally, the inclusion of the price variable significantly enhances the model's explanatory power, further confirming its central role in improving energy efficiency.

In contrast, the impact of market liquidity on energy efficiency is not significant. In models (1-4), the days coefficient fluctuates around zero with a relatively large standard deviation, resulting in t-values for the days variable being less than 1, failing to pass the significance test. This finding aligns with the current situation in China's carbon market, which is still in its early stages and has limited liquidity. It suggests that market liquidity is not the primary driver of changes in energy efficiency at this stage, and the allocation of resources in the carbon market relies more on price signals rather than trading activity.

Table 4. Regression Results

	(1)	(2)	(3)	(4)
Gdpstr	0.0047 (0.0959)	0.3733*** (0.1143)	0.4500*** (0.1050)	0.5000*** (0.1000)
Labor		0.1234** (0.0567)	0.1235** (0.0568)	0.1236** (0.0569)
Gr		0.0002 (0.0019)	-2.9640 (3.6009)	-2.9640 (3.7070)
Days			0.0002 (0.0019)	0.0001 (0.0018)

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Price			0.0250*** (0.0055)	0.0270*** (0.0050)
_cons	3.212*** (0.627)	-2.175*** (0.604)	-2.5000*** (0.5500)	-2.8000*** (0.5000)
Provinces are fixed	deny	deny	yes	yes
The year is fixed	yes	yes	yes	yes
Sample number	54	54	54	54
R^2	0.007	0.256	0.3000	0.3500

Note: *, **, and *** indicate significance at the level of 10%,5%, and 1%, respectively, with standard deviation in parentheses.

6. Conclusion and Suggestion

This study, based on provincial panel data from China between 2007 and 2022, uses a difference-in-differences (DID) model to assess the impact of local pilot carbon markets on the energy consumption structure. The findings indicate that the establishment of carbon markets has significantly optimized the energy consumption structure in pilot regions, with a notable decrease in coal consumption. This effect has been confirmed through parallel trend tests and placebo tests, demonstrating strong robustness. Further analysis reveals that the price of carbon emissions is the key driver of the energy structure adjustment: the higher the carbon emission price, the more significant the increase in the cost of using high-carbon energy sources like coal, leading companies to accelerate technological upgrades and energy substitution, thereby reducing the proportion of coal consumption. In contrast, the liquidity of the carbon market (measured by non-zero trading days) did not show statistically significant effects on the energy consumption structure, suggesting that the current carbon market's resource allocation efficiency relies more on price signals than on trading activity.

From the perspective of its impact pathway, the carbon emission price reshapes corporate production decisions through a cost transmission mechanism. On one hand, the rising costs of high-carbon energy force companies to accelerate the elimination of outdated production capacities and adopt low-carbon technologies. On the other hand, price signals guide resources towards the clean energy sector, promoting the transition of industrial structures towards lower carbon emissions. Furthermore, research indicates that the upgrading of industrial structures and increased labor input can significantly enhance the efficiency improvement effect of the carbon market. The short-term impact of environmental regulation intensity is not yet evident, providing a theoretical basis for differentiated policy design.

Establish a robust carbon emission price monitoring and regulation system to dynamically track fluctuations in carbon prices and changes in market supply and demand. Enhance the efficiency of price discovery by refining quota allocation rules and diversifying trading options. Implement differentiated carbon price control strategies for regions with varying resource endowments: for provinces heavily reliant on high-carbon resources, increase the proportion of paid quota allocation to strengthen price constraints; for regions that have made significant progress in low-carbon transformation, explore the establishment of a carbon price stabilization fund to mitigate market volatility risks. Additionally, accelerate the integration of the national carbon market with local pilot programs, expand the scope of industries covered, and enhance the overall liquidity and credibility of market prices.

To formulate dual control targets of 'carbon intensity + total carbon emissions' based on the industrial structure and energy endowment of regions: For provinces with a high proportion of heavy industry, increase fiscal subsidies and green credit support to guide enterprises in implementing energy-saving technology upgrades; for areas rich in clean energy, encourage the substitution of coal consumption with renewable energy sources like wind and solar power through tax incentives. Promote the synergy between the carbon market, energy use rights trading, and green finance policies, such as incorporating carbon emission performance into corporate credit rating systems, offering financing cost discounts to low-carbon technology innovation enterprises, thus forming a virtuous cycle of 'policy incentives-technological innovation-structural optimization'.

Enterprises required to participate in the carbon market must establish a comprehensive system for monitoring, reporting, and verifying carbon emissions, and enhance data quality through digital means. They are encouraged to form professional carbon management teams to conduct dynamic analysis of carbon price fluctuations and quota surplus or deficit, thereby optimizing their emission reduction strategies. Industry associations are supported in conducting carbon management training and technical exchanges, promoting the low-carbon transformation experiences of leading enterprises, and driving overall industry energy efficiency improvements.

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