EXPLORING THE INFLUENCE OF CHINA'S CARBON TRADING MARKET ON CARBON EMISSION REDUCTION AND FIRM-LEVEL TOTAL FACTOR PRODUCTIVITY

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Abstract. This paper investigates firms in China's carbon trading market from the viewpoint of production efficiency. It is found that the carbon emission trading mechanism significantly improves the total factor productivity (TFP) of carbon emission control firms, but this mechanism has no positive spillover effect, and the TFP of non-carbon emission control firms does not change significantly. The positive effect of the carbon emission trading mechanism on TFP is more evident when initial carbon quotas are partially auctioned, the benchmark method is used, non-contractual parties trade actively, product market competition is high, and the market pricing power of firms is relatively low. In addition, the carbon emission trading mechanism significantly reduces the degree of resource misallocation in carbon emission control firms and improves the green production input and technological innovation output. This paper reveals the microeconomic effects of the development of China's carbon trading market from the perspective of firm production efficiency. The research conclusions are significant for constructing a national unified carbon trading market and advancing the green development strategy.
Keywords: *carbon quotas, technological innovation, carbon transaction cost, industrial spillover effect, sustainable economic transition*

Introduction

China is currently the world's largest developing country and one of the countries with the highest total carbon emissions. To transform the mode of economic development and alleviate environmental pollution, the Chinese government has adopted green development as an economic and social development strategy. To deepen the green development strategy, the Chinese government has adopted effective policies and measures to reach peak carbon dioxide emissions before 2030 and strive to achieve carbon neutrality before 2060. From the perspective of China's practical path to deepening the green and low-carbon development strategy, the carbon emission trading mechanism is an important measure. In 2011, the Chinese government launched a pilot carbon trading market. Since 2013, eight regions, including Shenzhen, Shanghai, Beijing, Guangdong, Hubei, Tianjin, Chongqing, and Fujian, have established carbon trading markets to carry out carbon emission trading. In 2017, the National Development and Reform Commission issued a plan to establish a carbon emission trading market in China's power generation industry, creating a unified national carbon trading market that began trading in July 2021. In the first compliance period, 2200 power generation firms entered the carbon emission trading market, all of which were key emitters in the power generation industry, with carbon emissions exceeding 4 billion tons. As a result, China has established the world's largest carbon emissions trading market.

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The continuous improvement of the carbon emission trading mechanism reflects China's strong will to develop a green and low-carbon economy. However, there is still no clear conclusion on whether the carbon trading market can balance low-carbon emissions and economic development, achieving a win-win situation for the environment and economy. According to the "Porter effect" hypothesis, appropriate environmental regulations can not only solve the pollution problem, but also help promote the technological innovation of firms, and the first-mover advantage of innovation can partially or even completely offset the cost of environmental regulations, to achieve a win-win situation for both environment and economy (Wei et al., 2022). New Keynesian scholars also proposed that environmental regulations can help reduce managers' rent occupation and current preference, etc, encourage firms' managers to invest in innovation, and improve production efficiency (Zhang et al., 2024a; Li and Wu, 2024). From the analysis of the operation effect of China's carbon trading market, the implementation of carbon emission regulation has achieved a better emission reduction effect (Wang and Guo, 2023; Zhang et al., 2024a,b). For the development of a low-carbon economy, relevant studies have not reached a consistent conclusion. Despite the constraint of firms' cost transfer and market liquidity, the carbon trading market has a positive impact on the technological innovation of pollutant emission control firms (Gan et al., 2024; Tian et al., 2024). However, China's carbon trading market has achieved a good emission reduction effect, the carbon trading mechanism mainly reduces the production scale of firms, rather than improving production efficiency (Pan and Yu, 2024; Jia, 2024).

Green and low-carbon development is not at the expense of slowing down economic growth, social wealth accumulation, and improvement of people's living standards, but to transform the mode of economic development, and improve the TFP of firms to promote sustainable economic growth. Formulating environmental protection policies to promote the improvement of firms' TFP is an inevitable choice to achieve green and low-carbon development of China's economy (Sun et al., 2024; Tian et al., 2024). Improving the efficiency of resource allocation through institutional reform is the key path to improve the TFP of firms (Zhang et al., 2023a; Huang et al., 2024). The development process of China's carbon trading market is first piloted, then improved, and then promoted to the whole country, and its effect on the actual operation is expected by the government and the public. Although the existing literature conducted many discussions on the environmental consequences of China's carbon trading market and provided evidence conducive to energy conservation and emission reduction, there is no consensus on whether environmental regulations can help guide firms to green low-carbon transformation and improve TFP. Therefore, based on existing research, this paper tries to focus on the total factor productivity of firms and discuss it.

Since 2013, the pilot carbon trading markets in Shenzhen, Shanghai, Beijing, Guangdong, Hubei, Tianjin, Chongqing, Fujian, etc. eight regions have provided conditions to study the above issues. Therefore, this paper uses the difference-in-difference method to investigate how the carbon trading market affects the TFP of firms. This paper found that the carbon emission trading market significantly improves the TFP of firms, but the above effect only exists in the carbon emission control firms and has not produced regional and industrial spillover effects. The emission reduction incentive and constraint generated by the carbon emission trading mechanism for carbon emission control firms are important reasons for promoting the improvement of TFP. The effect of the carbon emission trading mechanism on the TFP of firms will be more obvious when

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the carbon emission control firms need to pay consideration for emission allowances in the carbon trading market, carbon emission control firms use the benchmark method to calculate carbon allowances, the non-contractual parties are more active in market trading, and the product market is more competitive and firms have less ability to set prices in the market. In addition, the resource misallocation of carbon emission control firms in the carbon trading market is low, and the output of green production input and technological innovation is relatively higher, indicating that environmental regulation is conducive to the optimal allocation of resources.

The contribution of this paper is mainly from three aspects. First, can environmental regulations promote a win-win situation between environmental protection and economic development in China? This paper analyzes China's carbon emission trading mechanism from the perspective of TFP, expands the research on the policies effect of environmental regulations, and provides evidences for whether Porter's hypothesis can be realized in China's carbon trading market. Second, it reveals the microeconomic effect of the carbon emission trading mechanism. China's carbon trading market has defined the carbon emission control firms to perform the convention, but most of the existing literature on the carbon trading market focuses on regions or industries, which may lead to biased estimates of the economic effect of the carbon trading market. Through the study of carbon emission control firms, it is found that the carbon emission trading mechanism has played a positive role in improving the production efficiency of carbon emission control firms, but there is no spillover effect in the regions or industries. Thirdly, it reveals the important role of carbon market mechanism design. The design of the carbon trading market mechanism will affect the emission reduction incentives and constraints of carbon emission control firms, but there is little relevant literature. This paper analyzes the differences of initial quota accounting, allocation methods, and non-contractual main market transactions in China's carbon trading markets, and reveals the impact of carbon trading market mechanism design on its operation effect, which has reference significance for the design and optimization of carbon trading market mechanism in eight regions and the power industry.

Development history and mechanism design of China's carbon trading market

Development history of China's carbon trading market

To combat global warming and reduce greenhouse gas emissions, 155 countries of the United Nations signed the "United Nations Framework Convention on Climate Change" in 1992, and adopted the "Kyoto Protocol" in 1997. The "Kyoto Protocol" establishes three emission reduction compliance mechanisms: international emissions trading (IET), joint implementation (JI) and clean development (CD). In 2005, the European Union, as one of the main parties to the Kyoto Protocol, launched the international carbon emissions trading system under the IET and implemented it in the EU countries, which was the world's first international and largest carbon emissions trading market at that time.

China is one of the major signatories to the Kyoto Protocol. In 2009, the Chinese premier proposed at the Copenhagen Climate Conference that by 2020 China's carbon dioxide emissions per unit of GDP should be reduced by 40-45% compared with 2005. To achieve the emission reduction goals, the Chinese government launched a pilot carbon emission trading in 2011 in seven regions, including Shenzhen, Beijing, Shanghai, Tianjin, Chongqing, Guangdong, and Hubei. In 2013, China's first carbon emission trading market opened in Shenzhen. After the first trial and then improvement, in 2021,

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a unified national carbon emission trading market was established. The power generation firms have large carbon emissions and become one of the first carbon emission control firms in the market. At present, the carbon emission coverage scale of China's carbon emission trading market has surpassed that of the European Union, becoming the largest carbon emission trading market in the world.

Mechanism design of China's carbon trading market

China's carbon emissions trading market is similar to that of the European Union. First, implement total carbon emission control, and set a cap on total carbon dioxide emissions. Second, the list of carbon emission control firms included in the carbon trading market is determined according to their previous carbon dioxide emission intensity. Third, allocate the initial carbon emission quota of each carbon emission control firm by using the historical or the benchmark method, and decide the distribution method of the initial carbon emission quota (paid or free). Finally, carbon emission control firms can be bought and sold in the carbon trading market based on the initial quota and the amount of carbon emissions, as long as they do not exceed the total carbon emission control. Finally, carbon emission control firms can buy and sell the remaining carbon allowances in the carbon trading market according to their initial quotas and carbon emission quantity, and the transaction quantity cannot exceed the total carbon emission control amount.

Although the overall framework is similar, there are also some differences in the mechanism design between China and the EU carbon emissions trading market. First, there are different methods to determine the total amount of carbon emissions. In China, firm report respective amount of carbon emissions to gather the total amount of carbon emissions, but in the European Union, the European Commission sets the total amount of carbon emissions, and distributes them to member states. Second, the initial carbon quotas accounting methods are different. The EU uses the benchmark method to calculate the average carbon emissions per unit product, while China uses a combination of historical and benchmark methods to calculate the initial carbon emission quota. The benchmark method establishes a benchmark for the carbon emission reduction of firms, avoids the shortcomings of the historical method to allocate more quotas to firms with high historical carbon emissions, and has a stronger incentive effect on improving the production efficiency of firms to save energy and reduce emission (Du et al., 2022; Chen et al., 2023). Third, the distribution methods of the initial carbon emission quotas are different. In the European Union since 2013, firms have mainly obtained their initial carbon emission quotas through auction. At present, China's carbon emission quotas are mainly distributed free, and although carbon trading markets such as Guangdong, Shenzhen, Beijing, and Tianjin have auctioned carbon emission quotas, their proportion is very low relative to the total amount of carbon emission quotas.

Literature review

Economic analysis of the carbon trading market

Under the constraint of total carbon emissions, firms with higher carbon emissions can buy the necessary quotas from the carbon trading market, which increases the production cost of firms. While firms with lower carbon emissions can sell the remaining quotas in the carbon trading market, which increases the income of firms. It is helpful for carbon

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emission control firms in the carbon trading market to reduce emissions, and achieve the reduction of total carbon emissions and emission intensity.

The mechanism of the carbon trading market still has certain limitations to mitigate carbon emissions. The first is transaction costs. Coase's property right theory assumes that the market is perfectly competitive, that is, the transaction cost of the carbon trading market is zero. However, this assumption is difficult to realize in reality, because the carbon trading market has the transaction search cost of firms and the market supervision cost of the government (Zhang and Zheng, 2024). The second is the definition of property right. Which method is used to define the carbon emission quotas of firms, and how to distribute firms' initial carbon emission quotas, different definitions and distribution methods will have an important impact on encouraging firms to reduce emissions (Song et al., 2023; Liu et al., 2023). The third is the balance of social welfare. Environment protection has obvious externality and publicity, and the definition of carbon emission right increases the firms' income of low-carbon emission. Government departments need to distribute the income twice, otherwise, it will lead to an imbalance of social welfare.

Although there are some limitations in the theory of carbon emission, in practice, carbon emission reduction mechanism has a positive effect on emission reduction. Scholars have studied some countries or regions, and found that the carbon emissions of firms in the carbon emission trading market have decreased significantly (Rontard and Hernández, 2022; Akinlo et al., 2023; Mandaroux et al., 2023; Adamolekun et al., 2024).

From the perspective of the carbon emission reduction path, even in the same country or region, different firms may choose different ways of carbon emission reduction. Therefore, scholars have explored the impact of the carbon emission reduction path on firms' performance. According to the "Porter effect" hypothesis, the study on whether the operation of the carbon trading market can promote the technological innovation of firms, and affect the performance of firms which has attracted the attention of scholars, but their research conclusions are inconsistent. The EU carbon trading market has no positive impact on firms' technological innovation and even has a negative impact on some industries (Nadiri et al., 2024). The emission reduction effect in the carbon trading market is mainly due to the production reduction of firms (Niu et al., 2024). The carbon emission intensity of the pilot carbon trading regions has not been significantly reduced, and the emission reduction is achieved by reducing firms' production, rather than improving firms' production efficiency (Pan and Yu, 2024). The emission reduction effect achieved by the carbon trading market mainly depends on the administrative intervention of the government, and the market mechanism represented by the carbon quota trading volume is limited (Pan et al., 2022). However, some studies show that the EU carbon trading market has a significant positive impact on firms' technological innovation (Mandaroux et al., 2023; Adamolekun et al., 2024). The carbon market reduces the total factor productivity of firms, mainly because it increases the operating cost (Kuosmanen and Maczulskij, 2024).

From the perspective of relevant studies on the carbon trading market, the differences in the selection of research objects in the current literature may be the reason for the inconsistent conclusions. The contractual parties in China's carbon trading market are firms that should perform the treaty, namely, carbon emission control firms. The other is a non-contractual parties, mainly for investment institutions and individuals. At present, institutional investors are allowed to participate in carbon trading markets in eight regions of China, individual investors are also allowed to participate in trading except the Shanghai carbon market. Since eight carbon markets have lists of firms that control

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carbon emissions, not all firms in regions or particular industries have to participate in carbon trading. If the regions or industries are taken as the research objects, it is likely to amplify or underestimate the economic effect of the carbon trading market, resulting in biased conclusions.

To sum up, there are many differences in the research conclusions of the carbon trading market, and the selection of research objects in the carbon trading market is also insufficient. Therefore, this paper takes the list of carbon emission control firms in the pilot regions of the carbon trading market as the research object to explore the impact of China's carbon emission rights trading mechanism on the production efficiency of firms, to demonstrate whether the implementation of environmental regulations can help guide firms to achieve green and low-carbon development.

Research hypothesis

As mentioned above, the carbon emission trading mechanism creates incentives and constraints for firms to reduce emissions through total carbon emission control and carbon emission market trading. Total carbon emission control is mainly reflected in that carbon emission control firms can obtain a certain amount of carbon emission. The governments determine initial emission quotas based on baseline or historical methods, the initial quotas are lower than the actual carbon emissions produced by the firms, to promote the emission reduction of the firms. Market trading is mainly reflected in the reduction of total carbon emissions by firms through resource allocation or technological transformation, or the buying of carbon emission quotas in the carbon market to meet the total carbon emission control. If the firms' carbon emissions are lower than the emissions quota, the firms can trade the difference on the carbon market for additional revenue.

Therefore, the emission trading mechanism may affect the production efficiency of firms from the following two aspects. On the one hand, the cost pressure under the total carbon emission control will encourage firms to optimize resource allocation or upgrade technology to improve production efficiency. Carbon emission rights are no longer free public resources, if a firm exceeds a given carbon quota, it needs to buy the emission difference from the carbon trading market, otherwise, it will be punished by the government. The carbon emission trading mechanism internalizes the externality cost of carbon emissions and increases pressure on firms to reduce emissions. Under the pressure of environmental costs in the carbon trading market firms usually have three options. The first is to maintain the production capacity and purchase excess emission quotas in the carbon trading market. The second is to reduce the production capacity to meet the requirements of total carbon emission control. The third is to optimize the allocation of resources to improve the production process, reduce the carbon emissions per unit output by improving production efficiency, and achieve the carbon emission reduction goals (Xu et al., 2023; Li et al., 2023).

On the other hand, the emission reduction benefits under the carbon emission trading mechanism encourage firms to optimize resource allocation or upgrade processes to improve production efficiency. The carbon emission trading mechanism is conducive to total carbon emission control and the reduction of carbon emission costs. The remaining carbon emission quotas of firms can also be sold to obtain additional benefits (Niu et al., 2024). The increased revenue is conducive to reducing the positive externalities of firms' emission reduction, to match the cost of reducing emissions with the benefit (Pan et al., 2022). Firms effectively allocate resources based on the goal of maximizing value,

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improving production efficiency to reduce carbon emissions per unit and selling surplus carbon emission quotas in the carbon emission trading market to obtain additional profits. Firms can obtain emission reduction benefits under the carbon emission trading mechanism, which depends on the liquidity of the carbon trading market.

Based on the analysis of the above two aspects, the carbon emission trading mechanism can generate emission reduction incentives and emission constraints for firms, and play a positive role in improving production efficiency. Therefore, this paper proposes the following hypothesis:

H1: The implementation of the carbon emission trading mechanism helps to improve the production efficiency of firms.

Material and methods

Samples selection and data

Since 2013, eight Chinese regions such as Shenzhen, Shanghai, Beijing, Guangdong, Hubei, Tianjin, Chongqing, and Fujian successively launched carbon trading markets, and the national unified carbon market for the power generation industry also was traded online in 2022. As the data for 2022 and subsequent years have not yet been updated, and the policy observation window remains relatively short, this paper primarily focuses on the carbon markets of eight regions. This paper takes all listed companies on the Shanghai and Shenzhen A-share markets as the initial samples and selects the period from 2012 to 2022 as the sample interval. This can ensure that there is at least A three-year window period before and after the implementation of each carbon market. The data involved in this article include whether listed companies are classified as carbon market emission control firms and other financial-related data. The former is mainly compiled by the authors based on carbon market information, while the latter mainly come from the Guotai’an (CSMAR) and Wind databases.

The initial samples are screened according to the following principles. (1) Excluding financial and insurance kinds of listed firms, the financial data structure and regulatory system of these firms are very different from other firms. (2) Excluding listed firms marked with ST, which are marked with ST due to continuous financial losses. (3) Eliminate firms with missing financial data. After the above treatment, the observed values of 29310 firms are obtained. To avoid the bias of the extreme values of the data on the estimated results, all continuous variables are winsorized at 1% and 99%, respectively.

Model and variables

Hypothesis testing

China’s carbon emission trading mechanism has adopted a pilot approach, the governments of the pilot regions determine the firms participating in the carbon market trading according to their carbon emissions, which provides a scenario for this paper to analyze the impact of carbon emission trading mechanism on the production efficiency of firms. By comparing the differences in results before and after the implementation of the policy between the treatment group (affected by the policy) and the control group (not affected by the policy), and eliminating the influence of common trends, the true effect of the policy can be identified. Therefore, this paper adopts the difference-difference method for hypothesis testing, and the model is set as follows:

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$$TFP_{it} = \alpha_0 + \alpha_1 CECF_i + \alpha_2 CECF\_Post_{it} + \alpha Controls_{it} + FixedEffect + \boldsymbol{\varepsilon}_{it} \quad \text{(Eq.1)}$$

where TFP is the total factor productivity of the firm, and represents the production efficiency of firm i in year t.

Firm total factor productivity calculated

At present, the *Cobb-Douglas* production function is mainly used to estimate the fitting value through a two-step method and quantify the residual to calculate TFP, such as *OP*, *LP*, and *OLS* methods. In the study of regions, industries, or firms, the factor of low-productivity firms exiting the market is used as a parameter in *OP* and *LP* methods, which reduces the sample selectivity bias, so *OP* and *LP* methods are widely used (Sun and Liao, 2021). Because listed firms in China are rarely delisted, the calculation of TFP by *OP* and *LP* methods will be limited to some extent, while the *OLS* method is not subject to the above limitation (Huang and Li, 2024). Lin and Zhang (2023) improved the traditional *OLS* method when calculating the TFP of listed firms. First, by using *OP* and *LP* methods, the intermediate input parameter M is added to the equation, that is, it is assumed that firms will make investment decisions based on productivity to mitigate the simultaneity bias when estimating TFP. Second, based on the annual and industry differences, the samples are regression by industries and years to mitigate the consistency bias of estimated TFP. Since the samples in this paper are listed firms, so Lin and Zhang (2023) is referred. *OLS* method is used to measure firms' TFP to test the hypothesis, and *OP* and *LP* methods are used to test the sensitivity of TFP measurement in the robustness test. The regression equation of firm total factor productivity calculated by the improved *OLS* method is as follows:

$$Y_{it} = X_0 + \gamma_1 L_{it} + \gamma_2 K_{it} + \gamma_3 M_{it} + \varepsilon_{it} \quad \text{(Eq.2)}$$

where Y represents the natural logarithm of the firm i sales revenue in year t. L is the natural logarithm of the number of employees in year t of firm i. K represents the natural logarithm of the total assets of firm i in year t. M is the natural logarithm of goods purchased and services received etc by firm i in year t. Model (2) is a regression by year and industry, and the residual term of each equation is obtained. The larger the residual term value, the higher the TFP of the firm. In this paper, the residual term is used to describe the production efficiency of the firm, which is represented by *TFP_GLY*.

Parallel trend model

This paper uses the difference-in-difference method to test whether the carbon emission trading mechanism can promote the total factor productivity growth of firms. The difference-in-difference method assumes that there should be parallel changes trend between the treatment group and the control group before the policy implementation, otherwise, the conclusion is biased. Refer to Guo et al. (2024), this paper uses the following model to test whether the benchmark regression model meets the parallel trend:

$$TFP\_GLY_{it} = \alpha_0 + \sum_{-4}^{-2} \alpha_i CECF\_Before_{it} + \sum_{1}^{4} \alpha_i CECF\_Post_{it} + \alpha Controls_{it} + FixedEffect_{it} + \varepsilon_{it} \quad \text{(Eq.3)}$$

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where the explanatory variable *CECF_Before* indicates whether the firms are included in the emission control list of the carbon trading market. The dummy variable *CECF_Post* is the interaction term of four years before and after the firms' inclusion in the carbon trading market, that is, *CECF_Post*1 indicates the year in which the carbon trading market is launched, and so on. When the time is greater than 4 years or less than -4 years, which is represented by *CECF_Before* -4 and *CECF_Post* 4. The other variables are defined as above. In addition, the model does not include the -1 phase, that is, the year before the firms entered the carbon emission control list as the base period, to test whether the production efficiency of the treatment group and the control group conforms to the parallel trend.

Variables

Explanatory variable *CECF* indicates whether the listed firm is a carbon emission control firm in the carbon trading market. Referring to Hu et al. (2023), if the listed firm is a carbon emission control firm, it is defined as the treatment group, and the value of *CECF* is 1; the other firms are classified as the control group, and the value of *CECF* is 0. *CECF_Post* is the interaction term, the year in which a firm is included in the carbon trading market to limit carbon emissions is assigned a value of 1, the year before inclusion, and other firms that are not included in the carbon emission control list are assigned a value of 0. The *CECF_Post* coefficients reflect the impact of the carbon emission trading mechanism on the production efficiency of firms. If the coefficient of *CECF_Post* is significantly greater than 0, it indicates that the production efficiency of the *CECF* is significantly higher than that of other firms during the period before and after the implementation of the carbon emission trading mechanism, which is consistent with the research hypothesis of this paper.

Controls indicate the control variables, referring to Zhang and Zheng (2024), control variables in the model (1) are as follows: firm size, financial leverage, return on assets, nature of property rights, the share proportion of major shareholders, the shareholding ratio of institutional investors, the time from the initial public offering, net cash flow generated from operating activities, the chairman is also the general manager, product market competition, fixed asset investment, firm R&D expenditure, analyst attention, and financing constraints, etc. In addition, to avoid the impact of time-varying and time-invariant differences in business cycles, industries, and regions on the productivity of firms, the model controls for interactive fixed effects by years, industries, and regions. Finally, to make the firm not affected by time-varying, the fixed effect is added to the model.

Results

Benchmark regression results

The benchmark regression results of the carbon emission trading mechanism on firms' productivities are shown in *Table 1*. In column (1), no control variables are added to the model, and the productivity change of carbon emission control firms and other ones are compared before and after the implementation of the carbon trading market. The coefficient of *CECF* is -0.0301, and that of *CECF_Post* is 0.0368, both of which are significant at 1% level, indicating that the implementation of the carbon trading market improves the productivity of firms, which supports the research hypothesis of this paper.

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In column (2), the regression model controls the control variables mentioned above and also adds year, industry, region, and the fixed effect of year interaction with industry and region, respectively. The coefficient of *CECF_Post* is 0.0461, which is significant at 1% level. After considering the time-varying and time-invariant differences of industries and regions in which different firms are located, the hypothesis of this paper is still hold. In column (3), the model further controls the firm's fixed effect, and the coefficient of *CECF_Post* is consistent with the first two columns, which is significantly positive at the 1% level, indicating that the benchmark regression results do not ignore the influence of firm-level non-time-varying factor.

Table 1. *The spillover effect of improving firm production efficiency*

	(1)	(2)	(3)	(4)	(5)
	TFP_GLY	***TFP_GLY***	***TFP_GLY***	***TFP_GLY***	***TFP_GLY***
CTCF	0.0301*** (0.00919)	-0.0389*** (0.0105)			
CECF_Post	0.0368*** (0.0111)	0.0461*** (0.0121)	0.0319*** (0.00851)	0.0369*** (0.0141)	0. 0322*** (0.00871)
Pro_Spillover				0.00851 (0.0161)	
Ind_Spillover					-0.00278 (0.0211)
Controls	No	Yes	Yes	Yes	Yes
Year & Indcd & Province	No	Yes	Yes	Yes	Yes
Year×Indcd &Year Province	No	Yes	Yes	Yes	Yes
Firms	No	No	Yes	Yes	Yes
N	29310	29310	29310	29310	29310
Adj. R^2	0.000411	0.114	0. 507	0. 507	0. 507

Note: Annual and cluster-adjusted standard deviations are shown in parentheses, *,**, and *** are significant at the level of 10%, 5%, and 1%, respectively

Spillover effect of regions and industries

When investigating the micro-environment of China's carbon trading market, many studies take all firms or specific industries in the region where the carbon trading market is located as the processing group for analysis (Xu et al., 2023; Huang and Li, 2024). This paper uses carbon emission control firms as the treatment group, does this design underestimate the impact of carbon emission trading market? The existing relevant literature analyzed the regions where the carbon trading markets are located or the specific industries as the treatment groups. Does this amplify the economic effect of the carbon trading market? Therefore, this paper analyzes whether there is regional or industrial spillover effect of the carbon emission trading mechanism.

First, to investigate whether there is a regional spillover effect of the carbon market on the productivity of firms. Setting a variable *Pro_Spillover* based on the geographical distribution of all control group firms in the research samples. The control group of firms located in the pilot region are assigned a value of 1 to *Pro_Spillover* when after the launch of the carbon trading market, and earlier years and non-control firms are assigned a value of 0. The benchmark model test for *Pro_Spillover* is conducted, and the regression results

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are shown in column (4) of *Table 1*. The coefficient of *CECF_Post* is 0.0368, which is significant at 1% level and consistent with the above benchmark regression results. The coefficient of *Pro_Spillover* is only 0.00851, and there is no statistical significance, which indicates that before and after the implementation of the carbon trading market, the difference in productivity between non-controlled firms in the pilot regions and ones in other regions are not obvious.

Secondly, to investigate whether the impact of the carbon trading market on the productivity of firms has a spillover effect in the industries. Similar to *Pro_Spillover*, setting the *Ind_Spillover* variable. By analyzing the industries distribution of carbon emission control firms, *Ind_Spillover* value to 1 is set for firms that should control carbon emission but do not control carbon emission when after the launch of carbon emission market trading, and 0 for earlier years and other firms. Then, *Ind_Spillover* is tested on the benchmark model, and the regression results are shown in column (5) of *Table 1*. The coefficient of *CECF_Post* in column (5) is 0.0322, which is significant at the level of 1%, consistent with the benchmark results above, but the coefficient of *Ind_Spillover* is -0.000278, which is not significant, indicating that there is no positive spillover effect on non-emission control firms. The regression results in *Table 1* show that the implementation of China's carbon emission trading mechanism has significantly improved the productivity of carbon emission control firms, which supports the theoretical expectation of this paper. However, the spillover effect of carbon emission trading mechanism on the regions or industries is not positive. It shows that if the pilot regions or industries are taken as the treatment groups, the average output of the actual treatment group (i.e. carbon emission control firms) may be lowered, and the conclusion is biased.

Robustness test

The benchmark regression results in this paper confirm the research hypothesis, but the potential endogeneity problems such as missing variables may also lead to bias in the estimation of regression results. Therefore, to test whether the benchmark regression results are robust and effective, the robustness of the benchmark regression results is tested by parallel trend analysis, placebo test, matching samples, etc.

Parallel trend test

The regression results of model (3) are shown in *Table 2*. It can be seen from column (1) that the coefficients of variables in each period of *CECF_Before* are not significant, indicating that before the launch of the carbon trading market, the differences in productivity between carbon emission control firms and other ones are similar to that in the base period ($CECF\_before_{-1}$), consistenting the parallel trend hypothesis. However, the coefficient of *CECF_Post* is still significant at 5% level, which is consistent with the conclusions above. In column (2) of *Table 2*, the decomposition of *CECF_Post* shows that the coefficients of each period of *CECF_Before* are not significant, while the coefficients of each period of *CECF_Post* are significant at least at the level of 10%, which also indicates that before the implementation of the carbon emission trading mechanism, there are no significant differences between the productivity of carbon emission control firms and other ones in the base period, but in the following years, the productivity of carbon emission control firms has been significantly increased.

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Table 2. *The impact of the carbon emission trading mechanism on TFP*

Variables	(1)	(2)
	TFP_GLY	***TFP_GLY***
CECF_Before $_{-4}$	0.000319 (0.0161)	0.000831 (0.0161)
CECF_Before $_{-3}$	-0.00201 (0.0151)	-0.00211 (0.0151)
CECF_Before $_{-2}$	-0.00591 (0.0121)	-0.00601 (0.0121)
CECF_Post	0.0312** (0.0112)	
CECF_Post $_1$		0.0302* (0.0181)
CECF_Post $_2$		0.0309* (0.0159)
CECF_Post $_3$		0.0369*** (0.0119)
CECF_Post $_4$		0.0281*** (0.0112)
Controls	Yes	Yes
Fixed Effect	Yes	Yes
N	29310	29310
Adj. R^2	0. 502	0. 503

Note: *Controls* indicate the control variable. *Fixed Effect* includes years, industries, provinces, and firms, and interaction term of years with industries and provinces, respectively

Other robustness test

In addition to the above tests, this paper also conducts a variety of robustness tests on the benchmark regression results. (1) Constructing a false treatment group through random sampling to conduct a placebo test on the benchmark regression results. (2) Using the event study method and the two-stage difference method to revise the benchmark estimation results. (3) Propensity score matching and entropy balance matching methods are used to construct control samples with similar characteristics to emission control firms in the carbon trading market. (4) Referring to Yin and Ding (2023), standard errors are doubly clustered in individual and time to mitigate the effect of autocorrelation and heteroscedasticity on statistical inference. (5) Manufacturing firms and ones in the region where the carbon trading market are respectively used as samples for regression. (6) The *OP* and *LP* methods are used to estimate the total factor productivity of firms, and the sensitivity of the regression results to the measurement of variables are tested. The above robustness test results are consistent with the benchmark regression results in this paper.

Further analysis

The previous section verified the impact of the carbon emission trading mechanism on firms' production efficiency and tested the robustness and reliability of the benchmark regression through methods such as balanced trend tests, placebo tests, PSM (Propensity Score Matching) and EBM (Entropy Balance Method) samples, etc. To further analyze the impact of the carbon emission trading mechanism on the firms' production efficiency of firms and reveal the internal transmission mechanism between the two, this paper

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follows the theoretical analysis part of the previous section and analyzes and tests the relationship between the carbon emission trading mechanism and the production efficiency of around the design of the carbon market mechanism, product market competition and resource allocation, etc.

Carbon trading market mechanism design and firms productivity

Different from the carbon trading markets of other countries or regions, the Chinese government implements the policy of "pilot first, then popularization". Pilot regions can design the carbon emission trading mechanism according to the actual situation, and summarize the experience, and promote it to the national unified carbon trading market. Carbon emission quota allocation method, accounting method, and the participation degree of non-emission control firms, etc are not only related to the enthusiasm of emission control firms to reduce emissions, but also directly affect the liquidity of the carbon market, which is crucial to the implementation effect of the carbon emission trading mechanism.

Therefore, this paper further examines the impact of the carbon emission trading mechanism on the firms' productivity of by combining the differences in the above mechanisms of eight carbon markets in China. In terms of the allocation of initial emission quotas in the carbon markets, which can be divided into two types: free and paid allocation. At present, carbon emission quotas in China's carbon trading markets are mainly allocated free of charge, and supplemented by paid allocation. Among them, the carbon trading markets of Shanghai, Chongqing, Hubei, and Fujian adopted the policy of free allocation of carbon emission quotas, but Guangdong, Shenzhen, Beijing, and Tianjin adopted the policy of partial free and partial paid allocation. For example, Shenzhen's carbon trading market through the auction of carbon quotas should not be less than 3% of the annual carbon quotas.

The differences in the mechanism design of the initial carbon emission quota in the carbon trading markets may affect the emission reduction incentives and constraints of carbon emission control firms. Compared to the free acquisition of initial carbon emission quotas, obtaining carbon emission quotas through paid which can create greater carbon emission cost constraints for carbon emission control firms, and the incentive effect of improving production efficiency to obtain emission reduction benefits will also be greater. Therefore, it is expected that when carbon emission control firms need to pay for the initial carbon emission quotas, the carbon emission trading mechanism will be more effective in improving the production efficiency of firms than when the initial carbon emission quotas are obtained free of charge.

To test the above expectation, based on the mechanism design of China's eight carbon trading markets, the carbon emission control firms in Shanghai, Chongqing, Hubei and Fujian carbon trading markets are defined as the quota free group, the carbon emission control firms in the remaining four carbon trading markets are defined as the quota paying group, and all other non-carbon emission control firms are compared. The first two columns of *Table 3* report the corresponding grouped regression results.

To test the above expectation, based on the mechanism design of eight carbon trading markets in China, this paper defines the carbon emission control firms in the carbon trading markets of Shanghai, Chongqing, Hubei, and Fujian as the quota free group, the carbon emission control firms in the remaining four carbon trading markets as the quota-paying group, and all other non-carbon emission control firms as the comparison group. The first two columns of *Table 3* show the corresponding grouped regression results. In

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column (1), the regression results of the quota-free group and non-carbon emission control firms are taken as samples. It can be seen that the coefficient of *CECF_Post* is 0.0210, which is significant at the level of 10%. In column (2), the quota-paying group and non-carbon emission control firms are taken as samples, and the regression results show that the coefficient of *CECF_Post* is 0.0511, which is significant at the 1% level. The differences test of the two columns of regression coefficients show that when carbon emission control firms need to pay for the initial emission quotas, the coefficient increase of *CECF_Post* is significant, which indicates that when the carbon trading market adopts the mechanism design of partially paid allocation for the initial emission quotas, the production efficiency of carbon emission control firms can be better improved.

Table 3. *The impact of carbon market mechanism design on TFP*

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	TFP_GLY	***TFP_GLY***	***TFP_GLY***	***TFP_GLY***	***TFP_GLY***	***TFP_GLY***
	Initial emission quotas are free	Pay for initial emission quotas	Historical method of accounting emission quotas	Benchmark method for calculating emission quotas	Participation of non-contractual parties is low	Participation of non-contractual parties is high
CECF_Post	0.0210^{*} (0.0111)	0.0511^{***} (0.0151)	0.0181^{*} (0.0112)	0.0589^{***} (0.0131)	0.0262^{**} (0.00991)	0.0531^{***} (0.0151)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	28513	27158	28209	27129	28407	27654
Adj.R^2	0.489	0.501	0.502	0.503	0.502	0.502
CECF_Post difference	P-value = 0.0809^{*}		P-value = 0.0317^{**}		P-value = 0.0881^{*}	

According to the accounting method of the initial carbon emission quotas in the carbon trading market designed by the mechanism, it is divided into historical and benchmark methods. The historical method mainly determines the current quota based on the historical carbon emission data of the firms, while the benchmark method determines the carbon emission per unit output based on the industry benchmark, and then determines the emission quota according to the total production volume of the firms.

At present, the eight carbon trading markets in China have different accounting methods for carbon quotas. Even in the same carbon trading market, the accounting methods of different industries are also different. For example, in the Shanghai carbon trading market, the benchmark method is applied to the power, aviation, airport, and port industries, while the historical method is applied to manufacturing and commercial industries. Guangdong carbon trading market adopts benchmark method for heat supply firms and thermal power generation ones and adopts historical method for others.

The differences in the accounting methods of the initial carbon emission quota in the carbon trading market may also affect the emission reduction incentives and constraints of carbon emission control firms. Compared with the historical method, the benchmark method determines the carbon emission per unit output based on the industry benchmark. Under the constraint of the established carbon emission quota, if the firms maintain the original production technology, it will bear relatively greater pressure on carbon emission cost, and the firms may obtain the emission reduction income from the carbon trading markets by improving the production efficiency and reducing the carbon emission

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intensity of the unit product. Therefore, it is expected that compared with the historical method, when the carbon trading market adopts the benchmark method to calculate the initial emission quota for carbon emission control firms, the carbon emission trading mechanism will have a more obvious effect on the production efficiency of firms.

Similar to the test of carbon emission quotas allocation, according to carbon emission control firms belong to the carbon trading markets and industries, these firms are divided into two groups of historical and benchmark method accounting, and then regression test is conducted with non-carbon emission control firms, respectively. Column (3) of *Table 3* shows the regression results of the historical method accounting group and non-carbon emission control firms as samples. The coefficient of *CECF_Post* is 0.0181, which is significant at the 10% level. Column (4) shows the regression results using the benchmark method accounting group and non-carbon emission control firms as samples, and the coefficient of *CECF_Post* is 0.0589, which is significant at the 1% level. Comparing the differences test between the two columns of coefficients show that when the carbon emission control firms obtain the initial carbon emission quotas through the benchmark method, their coefficient of *CECF_Post* is larger, which is consistent with the expectation, indicating that when the carbon trading markets adopt the benchmark method to calculate the initial carbon emission quotas, it has a more obvious effect on the improvement of the production efficiency of carbon emission control firms.

In the carbon trading market, in addition to carbon emission control firms, there are also non-contractual parties such as institutional and individual investors. Non-contractual parties invest in the carbon trading market for the purpose of making profit by buying carbon quotas at low prices and selling carbon quotas at high prices. Their trading will not affect the total amount of carbon quotas in circulation but will promote the flow of carbon quotas in the market. Flowability is an important factor for the positive effect of the carbon trading market. China's carbon emission trading policies implemented in 2002 failed to achieve the "Porter effect", mainly due to the inefficient operation of the emission trading market (Sun et al., 2024). When non-contractual parties trade actively, the market flowability increase, which enhances the value discovery function of the carbon trading market, reduces the uncertainty of the income of firms, reduces the transaction cost of information search, and increases the income of firms in energy conservation and emission reduction. Therefore, it is expected that the higher the degree of participation of non-contractual parties, the greater the impact of the carbon emission trading mechanism on the production efficiency of firms.

According to the information disclosure of carbon trading markets, this research collects the carbon quotas trading data of non-contractual parties (institutions and individuals) in eight carbon trading markets. In terms of trading volume data, non-contractual parties in Hubei, Guangdong, Shenzhen, and Beijing are more active, with their average volume of quotas trading higher than the median of the eight carbon trading markets. Based on the above, these four carbon markets are classified as the group with higher participation, and the other four carbon markets are classified as the group with lower participation. Then, these two groups are respectively combined with samples of non-carbon emission control firms for regression tests. The regression results in the last two columns of *Table 3* show that the coefficients of *CECF_Post* in the two columns are 0.0262 and 0.0531, respectively, and both of which are significant at the 5% level. However, the differences test of the coefficients between the two groups shows that when non-contractual parties in the carbon trading markets are more active, the coefficient of *CECF_Post* is larger. The results of these two columns show that the carbon trading

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markets can help improve the production efficiency of firms regardless of the degree of participation of non-contractual parties. However, when the degree of the participation of non-contractual parties in the carbon markets is relatively higher, the positive role of the carbon markets will be more obvious.

Market competition and productivity effect of carbon trading markets

The emission reduction incentives and constraints of firms are affected by the carbon trading market mechanism, and the degree of competition in the product market may also indirectly affect the emission reduction motivation of firms. In China, power firms have a monopoly position in the market, and these firms pass on most of the carbon emission costs to users by raising product prices (Zhang et al., 2023b). The study of the Chinese power system also found that when the level of industry competition is low, there are fewer alternative products in the market, and firms are more likely to pass on carbon emission costs to consumers (Lan et al., 2023). The above researches indicate that the operational effect of the carbon emission trading mechanism will be affected by the degree of market competition in the industries where carbon emission control firms are located. Based on the previous assumptions in this article, the reason why the carbon emission trading mechanism promotes the improvement of production efficiency is the emission costs and emission reduction benefits under the carbon quotas.

Considering the degree of competition in the product market, if firms pass the cost of carbon emissions onto consumers who have no alternative products, the incentive and constraint of emission reduction will be reduced, which will affect the motivation of firms to improve production efficiency. Although firms can reduce the cost of carbon emissions through cost pass-through, when the product market competition becomes more intense, firms will increase the price of products, which will lead consumers to choose alternatives or other brands, which will affect the product competitiveness and market share of firms. Therefore, it is expected that when the product market competition is more intense, the carbon emission trading mechanism will have a more significant effect on the production efficiency of firms.

This paper analyzes the product market competition from the two levels of industry and firm and tests the above analyses and expectations. The industry level is determined by calculating the Herfindahl-Hirschman Index (HHI) for each industry in each year based on the sales revenue of the firms, and then grouped tests against the annual-industry median of the HHI.

As can be seen from the first two columns of *Table 4*, the coefficient of *CECF_Post* in the group with a high degree of product market competition (HHI is less than the annual median) is 0.0469, and is significant at 1% level, but in the group with a low degree of competition (HHI is greater than the annual median), the coefficient of *CECF_Post* is not significant.

Referring to Xie et al. (2023) to determine the level of the firm, this paper describes the firm's pricing power in the product market by calculating the Lerner index (*LI*). L= (business income-business cost- selling cost-management cost)/business income. The last two columns of *Table 4* show the industry-annual median in terms of the firm's Lerner index, and then grouped regression against the annual-industry median of the LI. It can be seen that in the group of firms with lower product pricing power, the coefficient of *CECF_Post* is significantly positive. While in the group of firms with higher pricing power, the coefficient of *CECF_Pos*t is positive but not significant. The grouped regression results in *Table 4* are consistent with expectations. When the degree of industry competition is higher or the market pricing power of the firms is lower, the carbon emission trading mechanism has a more obvious promoting effect on production efficiency.

Table 4. *The influence of the degree of product market competition on TFP*

Variables	**(1)**	**(2)**	**(3)**	**(4)**
	TFP_GLY	***TFP_GLY***	***TFP_GLY***	***TFP_GLY***
	Product market competition is low	Product market competition is high	The pricing power of firms is low	The pricing power of firms is high
CECF_Post	0.0171 (0.0110)	0.0469*** (0.0141)	0.0391** (0.0161)	0.0151 (0.0112)
Controls	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes
N	17132	13124	15117	14028
Adj.R^2	0. 569	0. 443	0. 542	0. 583
CECF_Post difference	P-value = 0.000209***		P-value = 0. 000408***	

Carbon emission trading mechanism and firms resource allocation

According to the hypothesis in this paper, the carbon emission trading mechanism can alleviate the mismatch between the cost and benefit of firms' emission reduction, and firms have stronger motivation to optimize internal resource allocation, such as green upgrading of production processes or strengthening technological innovation, and reduce the carbon emission intensity per unit product by improving production efficiency. Based on the perspective of firm resource allocation, this paper examines the transmission mechanism of production efficiency improvement under the influence of the carbon emission trading mechanism from three aspects: green upgrading of production process, technological innovation, and capital misallocation.

Table 5 shows the results of a regression test of the above mechanisms. Among them, the explained variable *Env_invest* represents the green upgrading of the production process. Referring to Hu et al. (2023), *Env_invest* is measured by dividing the current investment increment related to the environment by the total assets at the end of the period. The patent represents technological innovation, referring to Liu et al. (2024), this article measures technological innovation by taking the natural logarithm of the total number of patent applications made by firms in the current year plus one. CMS represents capital misallocation, referring to Shen (2023), capital misallocation is measured by comparing the unit risk-return rate with the invested capital. The higher the value of *CMS*, the lower the degree of capital misallocation in the firms. From *Table 5*, it can be observed that the coefficients of the explanatory variable *CECF_Post* are significantly positive at least at the 1% level, which indicates that the implementation of the carbon emissions trading mechanism significantly promotes the upgrading of production processes and technological innovation in carbon emissions control firms, while significantly reduce the degree of resource misallocation.

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Table 5. *The impact of the carbon emission trading mechanism on resource allocation*

Variables	(1)	(2)	(3)
	Env_invest	***Patent***	***CMS***
CECF_Post	0.000931*** (0.000321)	0.129*** (0.0431)	0.539*** (0.211)
Controls	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes
N	29310	29310	29310
Adj.R^2	0. 249	0. 781	0. 261

Discussion

The paper examines the impact of China’s carbon emission trading mechanism on firms’ total factor productivity (TFP), revealing several critical insights.

First, the carbon emission trading mechanism has significantly enhanced TFP among carbon emission control firms, aligning with the Porter effect hypothesis that environmental regulations can drive technological innovation and efficiency gains. This effect is driven by emission reduction incentives and constraints, as firms optimize resource allocation or upgrade technologies to meet quota requirements or profit from surplus allowances.

Second, the design of the carbon emission trading market profoundly influences its effectiveness. Paid allocation of initial quotas and benchmark-based accounting methods outperform free allocation and historical methods, as they impose stronger cost pressures and incentivize efficiency improvements. Active participation from non-contractual parties (e.g., investors) also amplifies these effects by enhancing market liquidity and value discovery, reducing transaction costs, and stabilizing emission reduction revenues.

Third, market competition moderates the impact of the carbon emission trading mechanism. In more competitive markets or among firms with lower pricing power, cost pass-through is difficult, forcing firms to improve TFP to mitigate carbon costs. Conversely, monopolistic firms can transfer costs to consumers, blunting incentives for efficiency.

Notably, the carbon emission trading mechanism shows no significant regional or industrial spillover effects, indicating that its benefits are confined to regulated firms. This highlights the need to expand the coverage of the carbon emission trading mechanism and optimize its design to foster broader diffusion. Mechanistic analyses confirm that the carbon emission trading mechanism drives green production upgrades, technological innovation, and reduced resource misallocation, underscoring its role in facilitating sustainable economic transitions.

From a policy perspective, lowering entry barriers for both regulated firms and non-contractual participants, expanding paid quota allocation, and strengthening market competition can maximize the carbon emission trading mechanism’s potential to balance environmental protection and economic growth. These findings offer critical guidance for refining China’s carbon emission trading mechanism and scaling its green development strategy globally.

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Conclusions and policy implications

The carbon emission trading mechanism is an important means for China to deepen its green development strategy. Whether this environmental regulation can guide the transformation of China's economic development momentum, and achieve a win-win situation of environmental protection and economic development has attracted much attention from the Chinese government and society.

Based on the above, this paper classifies carbon emission control firms in eight carbon trading markets across China and analyzes the impact of the trading mechanism in the carbon emission trading market on production efficiency. The ultimate goal is to facilitate the green and low-carbon transformation and achieve sustainable economic growth.

The conclusions of this study are as follows.

(1) Carbon emission trading mechanism can form incentives and constraints on carbon emission control firms, and promote the growth of TFP. (2) The design of the carbon trading market mechanism will affect the incentives and constraints of carbon emission control firms. When the initial carbon emission quota is allocated with compensation or benchmark method, and non-contractual parties participate actively, the carbon emission trading mechanism has a significant effect on the improvement of firms' TFP. (3) When the product market competition is fierce, and the market pricing power of firms is lower, the carbon emission trading mechanism can effectively improve the TFP. (4) Under the incentives and constraints of the carbon emission market trading mechanism, carbon emission control firms carried out green upgrading of production processes and technological innovation, and resource allocation optimization is an important transmission mechanism for environmental regulation to promote the improvement of production efficiency.

The policy implications of this study are as follows.

First, lower the entry criteria for carbon emission control firms in the carbon trading market. The market management department can appropriately reduce the entry standards of carbon emission control firms in the carbon trading market, increase the number of firms, and form emission reduction incentives and constraints for more firms, to play the role of environmental regulation in promoting the high-quality development of firms.

Second, continuously optimize the mechanism design of the carbon trading market. At present, the carbon trading market allocates the initial quota free of charge, and a part of the carbon emission quota can be allocated by bidding to expand the influence of the carbon trading market.

Third, lower the entry threshold for non-contractual parties in the carbon market. The carbon market management authorities can appropriately reduce the entry threshold for non-contractual parties such as institutions and individuals, to further activate the incentive and constraint functions of the carbon trading market.

Fourth, the development of carbon trading markets cannot ignore the impact of the product markets. The government management departments should adopt strict measures to control the abuse of market dominance by monopolies, to give full play to the positive role of carbon market in promoting the low-carbon transformation of firms.

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