

Impact mechanism of carbon emission trading pilot policy on green total factor productivity——Empirical research based on the double difference model

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Abstract. This paper uses the panel data of 30 provinces and cities in China from 2008 to 2018, adopts the double-difference method and the mediation effect model to empirically evaluate the carbon emission reduction effect of the carbon emission trading pilot policy, and demonstrates that the specific impact mechanism of carbon emission trading pilot policy to improve green total factor productivity. The study found that the carbon emission trading pilot policy promotes carbon emission reduction in regional industries through cost-benefit mechanisms, market mechanisms, and technological innovation mechanisms, thereby improving green total factor productivity; Corporate green technology innovation is the key way to promote carbon emission reduction and low-carbon development. , and the introduction of high-quality human capital can enhance the concept of green development for enterprises; the role of financial products such as green credit and green finance in serving green development has yet to be explored, and the foreign investment in the field of green development needs to be guided. Finally, it is concluded that the implementation of the pilot policy should uphold the principle of combining the government's macro-control and market-determining mechanism, play the key role of technological innovation, and formulate differentiated policies.

Keywords: carbon emission trading, carbon emission reduction, green total factor productivity, mediation mechanism.

1. Introduction

In the context of the current global low-carbon economy and green finance, the "dual carbon goal" has become the trend of the times. The 2021 Central Economic Work Conference and the 2022 Two Sessions made a solemn commitment to advance the carbon peaking and carbon neutrality process in an orderly manner, strive to achieve the Paris Agreement's climate target of 2°C or 1.5°C, and contribute Chinese wisdom to the green transformation of the world economy. Carbon emissions are an important factor restricting green development and climate improvement. Countries around the world have formulated the "Kyoto Protocol", the Clean Development Mechanism (CDE) and a series of related institutional documents on carbon emissions, which have established an institutional framework for global carbon emission reduction actions and an integrated market for emission rights. It also lays the foundation for large-scale and standardized transactions. In 2011, China promulgated the "Notice on Launching the Pilot Work of Carbon Emissions Trading", and from 2013 to 2016, it approved seven provinces and cities in Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Guangdong and Fujian to carry out the pilot work of carbon emissions trading. In 2021, the total transaction volume of national carbon emission allowances (CEA) will reach 179 million tons, and the cumulative transaction value will be 7.661 billion yuan, showing the healthy development trend of China's carbon market. In addition, the Minister of Ecology and Environment pointed out in February 2022 that it is necessary to make preparations for the second cycle of the carbon emissions trading market, further deepen carbon emissions trading, and play an important role in the development of the green economy.

With the in-depth development of carbon emission trading, industrial development will inevitably face the economic pressure of internalizing external environmental costs, so it is particularly important to integrate green and low-carbon indicators into the measurement of total factor productivity of enterprises, thus introducing green total factors productivity. Green total factor productivity not only includes the input-output ratio measurement of traditional industrial total factor

productivity, but also includes green indicators such as energy utilization and pollution emissions, which can effectively measure the production efficiency of enterprises under the current green development trend. Therefore, can the pilot policy of carbon emission trading promote the improvement of green total factor productivity of regional industries? What is the specific impact mechanism? What is the reference for the subsequent construction of a unified carbon trading market? Research on the above problems can summarize the experience and shortcomings of the pilot practice of trading. It can not only provide suggestions for the construction of a unified national carbon emission rights market, but also provide valuable Chinese experience for the policy construction of carbon emission trading markets in many developing countries, and contribute to the green transition and low-carbon development of the global industries.

2. Literature review

This paper reviews the literature from two aspects: the impact of carbon emission trading pilot policies on carbon emission reduction, and the construction of green total factor productivity and related research on influencing factors.

First, regarding the relationship between the carbon emission rights trading pilot policy and carbon emission reduction, most of the existing literature has demonstrated the commercialization of carbon emission rights and the effective reduction of carbon emissions through market mechanisms^[1]. According to the research methods, it can be divided into three categories: the first category, the single-difference method, compares the actual carbon dioxide emissions after the implementation of the policy and before the implementation, so as to explain the impact of the carbon emission trading pilot policy on carbon emission reduction^[2-3]. The single-difference method can directly compare the changes in carbon emissions between the treatment group and the control group before and after the implementation of the policy, but it cannot effectively eliminate the influence of unobservable heterogeneity factors on carbon emissions during the implementation of the policy, resulting in large errors. The second type, the double-difference method (DID), on the premise of ensuring that the treatment group and the control group have the same development trend before the implementation of the policy, compares whether there is a significant difference in carbon emissions before and after the implementation of the policy, so as to verify the promotion effect of carbon emission trading pilot policy on carbon emission reduction, such as Liu Chuanming and other scholars^[1, 5]. Some scholars combined the DID model with the mediation effect to evaluate the effect of the carbon emission trading pilot policy, and found that one of the most important factors to promote carbon emission reduction is technological innovation^[4]. Due to the heterogeneity of the pilot areas, the parallel trend assumption of the differences-in-differences method is difficult to satisfy in most cases, and scholars have spawned a third type of method: the PSM-DID method, which is a common method used by most scholars to study the effect of carbon emission trading pilot policy.^[6-8] However, this method has certain limitations: First, the preconditions of PSM-DID are very strict, and its test effect is the best under large samples. However, since there are only 7 provinces and cities in the pilot area of carbon emission rights, the research sample does not meet the conditions of large sample. Second, PSM-DID regards all provinces and cities in the carbon emission trading policy experiment as a whole for analysis, and the conclusions drawn from the study are more holistic. However, there are great differences in the economic development, industrial structure, technological innovation and other aspects of the pilot regions, and the results of the policies are likely to be different. Therefore, how to explore the policy heterogeneity caused by factors such as the implementation of supporting measures in various places has become a hot research topic in the current academic circles.

Second, related research on the construction and influencing factors of green total factor productivity. In view of the proposed goal of carbon neutrality and carbon peaking, the green total factor productivity plays an increasingly important role in the evaluation of economic growth. In recent years, there have been abundant research achievements in this field. Green total factor productivity (GTFP) is an indicator to evaluate the coordinated development between development

and environment in a developed country or region. The estimation methods generally include parametric and non-parametric methods, among which the more representative methods include distance function model and non-radial model, non-radial and non-angular SBM model, Malmquist exponential model, SBM-GML model, etc. ^[9-12]. Based on the above models, there are also some differences in the results of estimating green total factor productivity. Regarding the influencing factors of green total factor productivity, Gong Mengqi et al. (2020) explored the inverted "U"-shaped relationship between environmental protection regulations and industrial green total factor productivity by systematically sorting out strict regulatory policies for industrial environmental protection ^[10]. Summarizing the existing research results in the field of green total factor productivity, the main problems are as follows: First, most of the current literature focuses on in-depth research on the overall total factor productivity of China's industrial and agricultural sectors ^[13], but there is a lack of in-depth research and analysis of green total factor productivity. Secondly, most of the literature use non-parametric methods to calculate, and the calculation methods are relatively simple, and the results calculated based on different models also have a certain gap, and the error is large. Thirdly, there are relatively few literatures on the influencing factors of industrial green TFP from an empirical perspective.

To sum up, previous studies by scholars have provide a reference research ideas and theoretical cornerstones for this paper. Based on this, this paper adopts the double-difference method and the mediation effect model to empirically analyze the impact mechanism of the carbon emission trading pilot policy on green total factor productivity. Considering that this paper selects carbon emission reduction as an intermediary variable, it is necessary to explore whether the carbon emission trading pilot policy affects green total factor productivity through carbon emission reduction. The possible marginal contributions of this paper are as follows: (1) Using the double-difference model, From the regional level, this paper studies the impact of carbon emissions trading pilot policies on green total factor productivity, and provides direct empirical evidence for carbon trading policies on green total factor productivity and industrial green development. (2) The previous research was limited by the short-term implementation of the policy, resulting in a small sample size. At present, the policy has been implemented for 9 years, and the long-term effect of the policy can be fully demonstrated, which is an effective supplement to the previous short-term research by many scholars. (3) Using the mediation effect model to study the specific mechanism of carbon emissions trading pilot policies on green total factor productivity, enriching the relevant research on the influencing factors of green total factor productivity, making the mechanism of action in this field more specific and detailed, which can provide a reference for the green and low-carbon transformation of the industry

3. Theoretical mechanism

Environmental pollution such as carbon emissions are public goods. The carbon emission rights trading mechanism was first proposed by foreign scholar Dales ^[14]. On the premise that the total amount of pollutant discharge does not exceed the specified total amount, the market means is used to give the pollutant emission right a commodity attribute, so that it can be reasonably allocated among enterprises to achieve carbon emission reduction. This principle can be traced back to the property rights theory of new institutional economics, that is, resources with clear property rights can minimize costs and optimize resource allocation through market mechanisms such as cost-benefit, competition, and price, and internalize the external effects of public goods ^[15]. The way of carbon emission trading pilot policy to promote carbon emission reduction is mainly carried out through the purchaser and the seller of carbon emission rights ^[1].

For buyers, carbon emission rights trading promotes carbon emission reduction through cost pressure mechanism, competition-driven mechanism, and green transition mechanism. Buyer enterprises not only face the tax pressure of carbon emissions, but the commercialization of carbon emission rights also internalizes their external environmental costs. The increase in taxation and production costs compresses their profit margins, and the funds used for expansion and reproduction

of enterprises are correspondingly reduced. In order to maintain industry status, control costs and reduce environmental taxes, the buyers will focus on reducing the demand for carbon permits through the development of green technologies, thereby reducing carbon emissions. For sellers, carbon emissions trading promotes carbon emission reduction through revenue-driven mechanisms, technological innovation mechanisms, and policy incentives. The market transaction of carbon emission rights makes the sellers, motivated by the pursuit of profits and tax subsidies, reduce the use of carbon emission credits and increase the balance of carbon emission rights through technological innovation, and then sell emission rights through market supply and demand and price mechanisms to make profits, providing impetus for its further technological innovation and green development. Based on this, this paper proposes the following hypothesis:

Hypothesis 1: The carbon emission trading pilot policy can effectively promote the carbon emission reduction of regional industries through the market mechanism.

Green total factor productivity is mainly used to measure the relationship between economic development and environmental protection. On the basis of traditional industrial total factor productivity, it considers undesired output, that is, the degree of environmental pollution, which makes industrial efficiency not only reflect economic efficiency but also reflects the green production and pollution control efficiency of the industry^[9,10]. Carbon emission reduction is mainly achieved through the carbon emission side and the carbon absorption side^[16]. On the emission side, in order to reduce the cost of pollution treatment such as carbon trading, enterprises develop energy-saving and emission reduction technologies, thereby reducing carbon emissions from the source; on the absorption side, improve the terminal carbon treatment technology and play the role of natural vegetation in carbon absorption, so as to curb carbon emissions at the end. The reduction of carbon emissions leads to the reduction of environmental pollution output in green total factor productivity, which reduces the environmental pollution caused by the same production input and output, thereby improving green total factor productivity. Based on this, this paper proposes the following hypothesis: Hypothesis 2: The strengthening of carbon emission reduction in regional industries can improve green total factor productivity.

Hypothesis 3: The carbon emission trading pilot policy further contributes to the improvement of green total factor productivity by promoting carbon emission reduction.

4. Research Design

4.1 Benchmark DID Model

When assessing the effect of a policy, most of the literature use the difference-in-difference (DID) method. The difference-in-difference method mainly measures the causal effect of the policy by comparing the changes in the mean value of the variables in the experimental group and the control group before and after the implementation of the policy, which can effectively avoid the endogeneity problem. There are two policy time points for the carbon trading pilot policy in this paper, so the benchmark DID model is used to measure its impact on regional green total factor productivity. The benchmark DID model is as follows:

$$GTFP_{it} = \alpha_0 + \alpha_1 treat_i \times post_t + \alpha_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Among them, i represents the i th province and city, and t represents the t period. The explained variable $GTFP_{it}$ is the green total factor productivity level of each province and city, which $treat_i$ reflects the dummy variable of the carbon trading pilot. $post_t$ represents the time dummy variable, which represents the implementation time of the carbon trading pilot policy. This paper takes 2013 as the policy implementation node, the value is 0 before the policy is implemented, and the value is 1 after the policy is implemented. X_{it} represents control variables that may affect green total factor

productivity. μ_i represents the individual fixed effects, λ_t represents time fixed effects, and ε_{it} represents random disturbance terms. Therefore, the impact of the carbon trading pilot policy on the regional green total factor productivity is the coefficient of the multiplication term α_1 .

4.2 Parallel trend test

In order to ensure the robustness and accuracy of the estimated results of the DID model, it is necessary to conduct parallel trend test and dynamic effect estimation for the treatment group and the control group. The model is set as follows: The premise of using the double difference model is that the treatment group and the control group meet the parallel trend assumptions that the time trend of green total factor productivity in the treatment group and the control group is consistent even if in the absence of the impact of the carbon trading pilot policy. Therefore, in order to carry out the parallel trend test, this paper sets the following model:

$$GTFP_{it} = \alpha_0 + \sum_{\tau=1}^m \theta_{-\tau} D_{i,t-\tau} + \theta D_{i,t} + \sum_{\tau=1}^p \theta_{+\tau} D_{i,t+\tau} + \alpha_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Among them, $D_{i,t}$ is the policy variable, which is equivalent to $treat_i \times post_t$. $\sum_{\tau=1}^{-5} \theta_{-\tau}$, $\sum_{\tau=1}^4 \theta_{+\tau}$ are the effects of the τ phase before and after the implementation of policy. If the policy effect is significant, $\sum_{\tau=1}^{-5} \theta_{-\tau}$, $\sum_{\tau=1}^4 \theta_{+\tau}$ should not be significant in theory.

4.3 The mediation effect model

The theoretical hypothesis part of this paper analyzes that the carbon trading pilot policy affects the green total factor productivity by the process of the regional carbon emission reduction.

Therefore, this paper constructs the following model to verify whether this mediating effect is significant.

$$GTFP_{it} = \alpha_0 + \alpha_1 treat_i \times post_t + \alpha_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

$$cer_{it} = \alpha_0 + \beta_1 treat_i \times post_t + \beta_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$$GTFP_{it} = \alpha_0 + \lambda_1 treat_i \times post_t + \lambda_2 cer_{it} + \lambda_3 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

Among them, formula (3) is the benchmark DID model, which directly measures the policy effect; the explained variable of formula (4) is carbon emission reduction cer_{it} (CER, carbon emission reduction), which measures the effect of carbon trading pilot policies on regional carbon emission reduction. (5) means adding the explanatory variable of carbon emission reduction on the basis of formula (3). This paper uses the stepwise regression method to test the mediation effect. The first step is to regress equation (3), if it is not significant, it means α_1 that the causal relationship between α_1 carbon trading policy and green total factor productivity is very weak, and the mediation effect test stopped; if it is significant, continue to regress equation (4). If β_1 it is not significant, it means that there is no significant causal relationship between the carbon trading policy and the regional carbon emission reduction, and the mediation effect test is stopped; if it is significant, continue to regress formula (5). If λ_1 , λ_2 both are significant, and λ_1 the value is smaller α_1 , it means that there is a partial mediation effect; if it is not significant or λ_1 , λ_2 significant, it means that the carbon trading

policy affects green total factor productivity completely through carbon emission reduction , and there is a complete mediation effect.

4.4 Sample selection and index selection

4.4.1 Sample selection

This paper selects 30 provinces and cities in China (excluding areas with missing data such as Tibet, Hong Kong, Macao and Taiwan) as the research object, takes Beijing, Shanghai, Tianjin, Chongqing, Guangdong, Hubei as the treatment group, and other provinces as the control group. By using panel data from 2008 to 2018 to empirically test the impact mechanism of carbon emissions trading pilot policies on green total factor productivity. The data comes from China Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Statistical Yearbook, etc. Some missing data are filled by interpolation.

4.4.2 Indicator selection

(1) Core variables

Green total factor productivity ($GTFP_{it}$): Most of the existing scholars' calculation methods for green total factor productivity use SBM, Malmquist index, ML index, etc. This paper adopts the SBM-GML model, taking 2008 as the base period, its GTFP value is 1, and calculating Green total factor productivity from 2008 to 2018. Since the descriptions in the previous literature are very detailed, this paper will not repeat them. The calculation content mainly includes three parts: input elements, expected output and undesired output. The input indicators mainly include labor, capital and energy, which are measured by the total employment population of the province, the stock of fixed capital, and the total energy consumption. The main reference indicator for expected output is real GDP, with 2008 as the base period. Undesirable output mainly refers to the output of industrial pollutants, which is mainly characterized by chemical oxygen demand in industrial wastewater and total sulfur dioxide emission in industrial waste gas.

(2) Mediating variable

Carbon emission reduction index (cer_{it}): This paper draws on the construction method of carbon emission reduction index of Wang Tingting (2021)^[16], and constructs a carbon emission reduction index from the level of energy consumption structure , which mainly includes the consumption proportion of high-carbon, low-carbon and zero-carbon energy. The first one is a negative indicator, the last two are positive indicators, and finally the coefficient of variation method is used to synthesize. The larger the carbon emission reduction index , the more significant the regional carbon emission reduction effect is. Table 1 shows the composition of the carbon emission reduction index .

Table 1 Construction of carbon emission reduction index

first-level indicator	Secondary indicators	The meaning of variable	category	Weights
Carbon emissions	Proportion of high carbon energy	Proportion of coal, oil, etc. in energy consumption	negative	0.22
	Proportion of low carbon energy	Natural gas as a share of energy consumption	positive	0.61
	Proportion of zero carbon energy	The proportion of primary electricity and other energy in energy consumption	positive	0.17

(3) Control variables

In order to accurately capture the impact of carbon emissions trading pilot policies on green total factor productivity, this paper controls other variables that may affect green total factor productivity, including: financial development level (FIN), loan balance of financial institutions and regional production ratio of total value; scientific research investment (TECH), which is the ratio of government spending on scientific and technological innovation to general budget expenditure; foreign direct investment (FDI), which is the ratio of foreign direct investment measured in RMB to regional GDP; human capital Level (HC) is the ratio of the employed population with a high school education or above to the total employed population; Industrial Structure Advanced (ISA): is the ratio of the output value of the tertiary industry to the output value of the secondary industry.

The descriptive statistics of the main variables are shown in Table 2.

Table 2 Descriptive statistics of main variables

VARIABLES	Obs	Mean	Std. Dev.	Min	Max
GTFP	330	1.2506	0.3313	0.8186	3.6141
CER	330	0.2792	0.1552	0.0380	0.8266
FIN	330	1.3280	0.4430	0.5846	2.5507
TECH	330	0.0198	0.0140	0.0039	0.0720
FDI	330	0.0544	0.1201	0.00001	1.3779
HC	330	0.1628	0.0992	0.0301	0.5894
ISA	330	1.0587	0.6012	0.4996	4.3476

5. Empirical Analysis

5.1 DID regression results

Based on Equation (1), this paper empirically tests the impact of carbon trading policies on green total factor productivity by using the multi-dimensional fixed-effects linear regression method. The regression results are shown in Table 3. The coefficient of the policy variable is 0.204, which has passed the 1% significance test, which fully demonstrates the effect of the pilot carbon emissions trading policy on the improvement of regional green total factor productivity. In addition, the effects of control variables on green total factor productivity also show significant differences. The positive effect of financial development level on regional green total factor productivity is not significant. This may be because the proportion of loans issued by financial institutions to support the green transformation of industries and the development of green projects is relatively low, and the strength of green credit to support the green development of industries is relatively low. Therefore, it needs to be further strengthened. The investment in scientific and technological innovation is significantly positively correlated with green total factor productivity. It can effectively reduce pollution emissions represented by carbon emissions through promoting the development of enterprise green technology and the improvement of production efficiency, thereby improving green total factor productivity, which is consistent with expectations^[1, 10]. The positive promotion effect of foreign direct investment on green total factor productivity is not significant. This may be because foreign investment tends to be low-cost and high-profit industries. Enterprises pursuing green development may face the situation of pursuing environmental effects at the expense of economic interests in the short term. Therefore, the short-term foreign investment support for the green transformation of enterprises is not high. The level of human capital can significantly improve green total factor productivity. This is because the education level of the employed population with a high school degree or above is relatively high, and the awareness of environmental protection is strong. Lower environmental costs in exchange for higher economic benefits^[17]. The advanced industrial structure has an insignificant negative effect on green total factor productivity. This may be because the increase in the proportion of the tertiary industry reduces the proportion of investment in the secondary industry, and industries with high carbon emissions are mostly secondary industries. The decline in capital investment has led to

insufficient green and low-carbon development momentum, which is not conducive to the improvement of green total factor productivity.

Table 3 Effects of carbon emissions trading pilot policies on regional GTFP

VARIABLES	GTFP
$post_t \times treat_t$	0.2039*** (0.0523)
FIN	0.0129 (0.0822)
TECH	7.4102*** (2.5026)
FDI	0.0597 (0.1026)
HC	1.2259** (0.5333)
ISA	-0.1066 (0.0810)
Constant	0.9747*** (0.1601)
Observations	330
R-squared	0.781

Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

5.2 Robustness test

5.2.1 Parallel trend test

The parallel trend test is the premise of using the DID model, and the test content is to judge whether there is no significant difference between the treatment group and the control group before the implementation of the policy. If the change trend of the two groups of samples before the policy implementation is the same, then the regression result of the double difference is credible; if this assumption cannot be satisfied, the regression result of the double difference is not credible. For the carbon trading pilot policy, the economic development level, industrial structure and green development technology of the pilot area are generally higher than those of other areas. If the green total factor productivity of the treatment group and the control group is quite different before the policy is implemented Then the difference between the two after the policy time point is not necessarily caused by policy factors, but may be caused by heterogeneity factors that cannot be captured outside the policy. The parallel trend test is shown in formula (2). The results are shown in Figure 1. The blue solid line represents the treatment group, and the red dotted line represents the control group. It can be seen that before 2013, the change trends of the treatment group and the control group were basically the same , the policy effect is not significant until the third year after the policy is introduced, and the policy effect has a hysteresis phenomenon, so it passed the parallel trend test. The reasons for the lag in policy effects may be as follows: Firstly, there is a time lag between the release of the policy and the formulation and implementation of specific implementation measures in each pilot region. Secondly, it is the fact that it takes a certain amount of time for regional industries to develop green transformation technologies and promote carbon emission reduction .

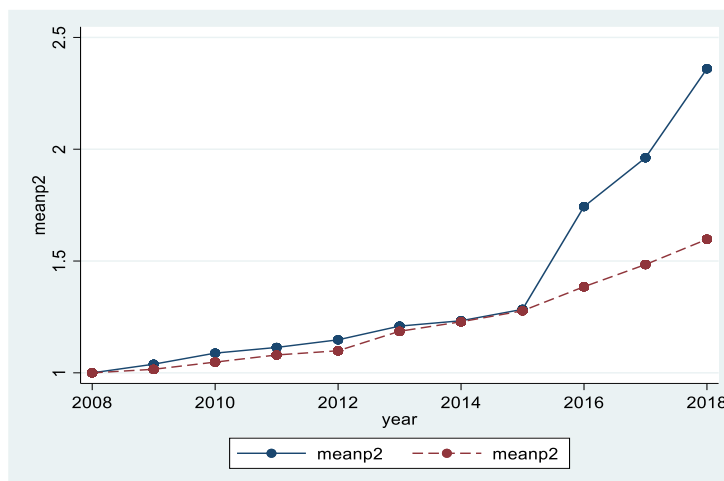


Figure 1 Parallel trend test chart

5.2.2 Placebo Test - Advance Policy Time

In order to ensure the robustness of the regression results of the DID benchmark, this paper adopts a placebo test to advance the policy implementation time point to 2010. If the change trend of green TFP between the treatment group and the control group is inconsistent between the time point in advance of the policy and the actual implementation of the policy, it means that there is an error in the DID regression results, and other factors other than policy effects have an impact on the green TFP of the two groups. . The regression results show that the coefficient of advance policy time is not significant, and the placebo test is passed.

5.3 Analysis of mediation effect

The above benchmark regression results have proved the significant improvement effect of the pilot emission trading policy on regional green total factor productivity, so how is the specific impact mechanism transmitted? Equations{ (3), (4) and (5) }are regressed by stepwise regression method, and the results are shown in Table 4. It can be found that carbon emission reduction has a significant partial mediation effect on the improvement of the regional green total factor productivity by the carbon emission trading pilot policy. Through the cost-benefit mechanism and the market mechanism, the carbon trading pilot policy can effectively act on the green technology innovation of enterprises and the adjustment of the industrial structure ^[1], thereby promoting the regional carbon emission reduction, and finally achieving the goal of improving the regional green total factor productivity ^[8].

Table 4 The mediating effect mechanism of carbon emissions trading pilot policies on regional green total factor productivity

VARIABLES	GTFP	CER	GTFP
$post_t \times treat_t$	0.4279 *** (0.0536)	0.1162 *** (0.0267)	0.4025 *** (0.0549)
CER			0.2188 ** (0.1105)
individual effect	YES	YES	YES
time effect	YES	YES	YES
Observations	330	330	330
R-square	0.1627	0.0547	0.1726

Standard errors in parentheses

***p<0.01, **p<0.05, *p<0.1

6. Conclusions and Recommendations

This paper uses the panel data of 30 provinces and cities in China from 2008 to 2018, adopts the double-difference method and the mediation effect model to empirically evaluate the carbon emission reduction effect of the carbon emission trading pilot policy, and demonstrates the specific impact mechanism of carbon emissions trading pilot policies to improve green total factor productivity. The research results show that: (1) The carbon emission trading pilot policy promotes carbon emission reduction in regional industries through cost-benefit mechanisms, market mechanisms, and technological innovation mechanisms, thereby improving green total factor productivity; (2) The key way to promote carbon emission reduction and low-carbon development is enterprise green technology innovation. The introduction of high-quality human capital can enhance the concept of green development of enterprises; (3) The role of financial products such as green credit and green finance in serving green development has yet to be explored, and foreign investment in the field of green development needs to be guided; the development of the tertiary industry has absorbed the capital investment of the secondary industry to a certain extent, hindering its green transformation. Based on the above conclusions, this paper makes the following policy recommendations:

First, the implementation of the carbon emissions trading pilot policy should uphold to the principle of combining government macro-control and market-determined mechanisms. On the one hand, the market plays a decisive role in the allocation of carbon emission rights, and promotes the rational distribution of carbon emission rights among different enterprises through market mechanisms such as supply and demand, price, and competition, so as to achieve the purpose of minimizing costs and maximizing economic benefits. On the other hand, to give full play to the macro-control role of the government in the pilot process of carbon emissions trading, carbon emissions are essentially public goods, and relying solely on market mechanisms may breed market chaos. At this time, the government needs to use the "visible hand" to control and adjust the market failure phenomenon and maintain the rational operation of the market.

Second, giving full play to the key role of technological innovation in improving green total factor productivity, guide domestic and foreign capital flows to green innovation and low-carbon development through green finance and policy support, and provide fundamental impetus for the green transformation of enterprises; at the same time, cultivate high-quality human capital with environmental awareness, form a green development concept within the enterprise, and enhance the endogenous development momentum.

Third, formulating differentiated regional carbon emission trading pilot policies according to the level of economic development, industrial structure, and energy structure. At present, most of the pilot areas are high-level economic areas, and the relevant supporting measures have certain regional characteristics. In the future, in the process of promoting the marketization of carbon emission rights, it will inevitably face different external conditions in different regions. Therefore, differentiated green development strategies should be formulated based on the combination between existing measures and regional characteristics.

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