

Study on the Impact of Carbon Trading Pilot policy on Green Total Factor Productivity

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Received: 9 March 2024; Accepted: 25 March 2024; Published: 11 April 2024

Abstract:

Based on the panel data of 30 provinces (autonomous regions and municipalities) in China from 2007 to 2020, we adopt the EBM model with non-expected output to measure the green total factor productivity, and empirically examines the impact effect of the carbon trading pilot policy on the green total factor productivity by using the multi-temporal DID model. The baseline results show that the carbon trading pilot policy significantly enhances the green total factor productivity in the pilot regions; the results of the heterogeneity analysis show that the carbon trading pilot policy is unable to effectively enhance the green total factor productivity in regions with high energy-consuming industries as the pillar industries, and that the positive impact of the carbon trading pilot policy on the green total factor productivity is more significant in the regions with higher scientific and technological expenditures. Finally, we provide reference suggestions for building a unified national carbon market and realizing the green development of Chinese economy.

Keywords:

Carbon Trading Pilot Policy, Green Total Factor Productivity, DID Model

1. Introduction

Since the introduction of the concept of green development, China's social development has been aimed at maximizing economic benefits at the least environmental cost, emphasizing the win-win path of economic growth and environmental protection. Therefore, how to accelerate the formation of a green development approach has become a pressing issue for the Chinese economy. In fact, the carbon trading pilot policy (hereinafter referred to as the "carbon trading policy"), as an important tool to realize energy saving and emission reduction by using the market mechanism, is regarded as a major institutional innovation in environmental protection. Green Total Factor Productivity (TFP), which incorporates factors such as energy consumption and environmental pollution within the traditional TFP measurement framework, can more truly and comprehensively reflect the degree of coordination between the economy and the environment, and is an effective indicator

for measuring the level of green development in a region. So, is there an effective impact of carbon trading policy on it? The purpose of this paper is to study these issues and provide decision-making references for further improving carbon trading policies and realizing green development.

Scholars have done a lot of useful research on the impact effect of carbon trading policy implementation, this paper mainly from the environmental effect, economic effect and the impact effect on the green total factor productivity of the three aspects of the existing literature to sort out. In terms of environmental effects, carbon trading policy can realize the control of carbon emissions by consuming less social cost [1]. Some scholars [2] found that carbon trading policy has a significant carbon emission reduction effect. Some scholars [3] point out that the policy can also inhibit carbon emissions in neighboring regions through spillover effects. In terms of economic effect, carbon trading policy can make up for part of the economic loss caused by carbon emission reduction [4]. ZHANG [5] found that since the implementation of the policy, the total industrial output value of the pilot area has been significantly improved. The above studies have revealed the logical relationship between carbon trading policy and the environment and economy, but failed to highlight its important impact on green development. For this reason, the effect of green total factor productivity has gradually received academic attention in recent years. Research findings are mixed on the impact of carbon trading policy implementation on green total factor productivity. Some scholars [6] found that the carbon trading policy has a certain impact on the economy while realizing emission reduction, and it has a negative effect on the enhancement of green total factor productivity. LI et al. [7] suggested that the impact of the policy on the green total factor productivity in the short term is not significant. ZHOU and QI [8] came to a different conclusion from the above point of view, and concluded that the policy can significantly enhance the green total factor productivity, of which the Beijing carbon trading market promotes the effect of the green total factor productivity, and the policy has a significant effect on the green total factor productivity. Among them, the promotion effect of the Beijing carbon market is the most prominent. Some scholars [9] found that the implementation of this policy helps to enhance the green total factor productivity of the region, which is more significant in the eastern region and large-scale cities. With the depth of research, scholars have studied this effect from the perspective of different industries, including the promotion effect on the green total factor productivity of industry [10], agriculture [11], manufacturing [12] and other industries.

The contributions of this paper mainly lie in the following: firstly, this paper adopts a multi-temporal double-difference (DID) model to examine the effect of carbon trading policy on green total factor productivity, so as to provide more empirical support for the implementation of the policy; secondly, this paper tries to examine the heterogeneity characteristics of the effect from the dimensions of pillar industries and science and technology expenditures, so as to make a useful addition to the existing literature.

2. Materials and Methods

2.1. Theoretical Hypothesis

Carbon trading policy realizes carbon emission reduction in a way that improves rather than hinders economic efficiency, and the impact of this market incentive-based policy on green total factor productivity is mainly reflected in the following two

aspects. Firstly, low-carbon subsidies given by the government make the participating subjects reduce certain cost pressure, so that they will focus more on technological transformation and industrial upgrading. At the same time, the economic incentives of market trading will bring positive signals to low-emission subjects, forcing them to take the initiative to internalize environmental costs, carry out innovative activities of green technologies, processes or products, thereby improving productivity and resource utilization, reducing or offsetting the cost of emission reduction, or even increasing the surplus quota to obtain higher profits, and improving the overall green productivity of society. Secondly, the pressure of emission reduction compliance motivates participating entities to look for other clean energy sources to replace fossil energy sources, and to shift from mainly relying on inputs of large amounts of energy factors to relying more on other factors such as human capital and technological innovation. And, the subjects with lower productivity and high emissions may fall into a production dilemma, and a large number of production factors flow to low-emission subjects. In turn, it realizes the optimal allocation of factor resources and the advanced industrial structure, which contributes to the improvement of overall energy efficiency and economic efficiency. Therefore, we propose the following hypotheses:

H1: The implementation of carbon trading policy can enhance green total factor productivity.

2.2. Modeling

(1) Measurement Model

In 2013, Shenzhen, Shanghai, Beijing, Guangdong and Tianjin formally launched the carbon trading pilot work; in 2014, Hubei and Chongqing carbon trading pilot market opened; in 2016, Fujian became the nation's eighth carbon trading pilot region. This paper selects the time when each pilot region officially starts carbon trading respectively as the time point of policy implementation for research, and constructs a multi-temporal DID model to examine the impact of carbon trading policy on green total factor productivity. The corresponding model is set as follows:

$$TFP_{it} = \beta_0 + \beta_1 treat_i \times post_t + \beta_2 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

The subscripts i and t represent the region and year, respectively. TFP_{it} denotes the green total factor productivity of each province (region, city); $treat_i$ denotes the dummy variable of carbon trading pilot region, taking 1 for pilot region as the treatment group, and 0 for non-pilot region as the control group; $Post_t$ denotes the dummy variable of carbon trading pilot year, taking 1 in the year of implementation and the subsequent years, and 0 otherwise; X_{it} is the control variable of the influence of green total factor productivity; μ_i and γ_t are the region and year fixed effects, respectively; ε_{it} denotes the random perturbation term. control variables. β_1 is the core coefficient, which measures the average difference in green total factor productivity before and after the implementation of the carbon trading policy.

(2) Variable Selection

Explained variable: green total factor productivity (TFP). In this paper, we draw on related research ^[14] to measure the change of green total factor productivity by using the EBM model-GML index that includes non-expected outputs. For n decision units with m inputs and s outputs, the specific model is constructed as follows:

$$\gamma^* = \min \theta - \varepsilon_x \sum_{i=1}^m \frac{w_i s_i}{x_{i0}} \quad (2)$$

$$s. t. \quad \theta x_0 - X\lambda - s = 0, \lambda Y \geq y_0, \lambda \geq 0, s \geq 0$$

$$\begin{aligned} GML^{t,t+1}(x^t, y^t, b^t, x^{t+1}, y^{t+1}, b^{t+1}) \\ = \frac{1 + D^G(x^t, y^t, b^t)}{1 + D^G(x^{t+1}, y^{t+1}, b^{t+1})} \end{aligned} \quad (3)$$

where $i = 1, 2, 3, \dots, m$ denotes the input indicator; γ^* denotes the optimal efficiency value; θ denotes the radial efficiency value; w_i denotes the weight of the i th input factor, which satisfies $\sum_{i=1}^m w_i = 1$; s_i denotes the relaxation variable of the non-radial input factor; ε_x denotes the core parameter that contains both radial changes and changes in the non-radial relaxation variable; and λ denotes the relative importance of input factors. x and y denote input and output factors respectively, X and Y denote input and output matrices respectively, and $X > 0, Y > 0$. b^t and b^{t+1} denote the non-expected outputs of the decision unit in period t and period $t+1$ respectively, and $GML^{t,t+1}$ denotes the change of TFP from period t to period $t+1$; if $GML^{t,t+1} = 1$, it indicates that there is no change of TFP; if $GML^{t,t+1} < 1$, it indicates that TFP decreases; if $GML^{t,t+1} > 1$, it indicates that TFP increases.

The input and output indicators involved in this paper are set as follows. Input indicators include labor, capital, and energy, of which the labor input indicator is specifically the number of employed persons in urban units; the capital input is specifically the capital stock; and the energy input is specifically the total energy consumption. Desired output indicators refer to beneficial outputs in line with expectations, specifically gross domestic product (GDP), and are converted to a constant 2000-based level through the GDP price index using the deflator method. Non-expected output indicators refer to unproductive outputs that do not meet expectations, specifically carbon emissions, and are measured with reference to the accounting standards of the United Nations Intergovernmental Panel on Climate Change (IPCC). The green total factor productivity of each province (autonomous regions and municipalities) is further processed by taking 2007 as the base period and setting its green total factor productivity as 1, and the green total factor productivity of 2008 as 1 multiplied by the GML index of 2007-2008, and so on, and the green total factor productivity of each region for the period of 2008-2020 is obtained by multiplying by the method of chain comparison.

Explanatory variables: interaction term ($treat \times post$): specifically the interaction term of the dummy variables for carbon trading pilot regions and pilot years, whose coefficients reflect the treatment effect of carbon trading policy implementation on green total factor productivity in the multi-temporal DID model. Since the pilot regions launched carbon trading in batches during 2013-2016, the time dummy variables of different pilot regions are not consistent.

Control variables: considering that the heterogeneous factors related to green total factor productivity in each province (region and city) may interfere with the net effect of the policy, this paper controls the following variables. Industrial structure (str): the proportion of the secondary industry is used to measure the industrial structure. Degree of technological innovation (rd): the number of authorized patent applications per capita is used to characterize the degree of technological innovation. Human capital level (hum): the human capital level is measured by the proportion of the

number of students enrolled in higher education institutions in terms of the total number of students in the region. Information level (*inf*): we use the number of Internet ports accessed per capita to measure the level of informatization. Level of foreign investment (*lnopen*): the level of foreign investment is measured by the logarithm of the total investment of foreign-invested enterprises. Highway facilities (*lnroad*): we characterize the scale of highway facilities construction by the logarithm of the number of highway miles.

(3) Data Sources

We select the balanced panel data of 30 provinces (autonomous regions and municipalities) (except Tibet Autonomous Region, Hong Kong, Macao and Taiwan) from 2008 to 2020 for the study. The data are derived from China Energy Statistics Yearbook, China Science and Technology Statistics Yearbook, China Education Statistics Yearbook, China Trade and Foreign Economic Statistics Yearbook, China Statistics Yearbook, and statistical yearbooks of provinces and cities. The descriptive statistics of relevant variables are shown in Table 1.

Table 1. Descriptive statistics.

Variable	Pilot Area			Non-Pilot Area		
	Observations	Average	Standard deviation	Observations	Average	Standard deviation
<i>TFP</i>	91	1.099	0.152	299	1.016	0.115
<i>treat × post</i>	91	0.560	0.499	299	0	0
<i>str</i>	91	0.416	0.107	299	0.444	0.088
<i>rd</i>	91	3.444	2.584	299	1.704	2.034
<i>hum</i>	91	2.363	0.661	299	1.922	0.564
<i>inf</i>	91	0.451	0.248	299	0.370	0.240
<i>lnopen</i>	91	9.516	1.016	299	8.370	1.441
<i>lnroad</i>	91	11.001	1.183	299	11.640	0.852

3. Results and Discussion

3.1. Benchmark regression and analysis

We conduct regression analysis of green total factor productivity of 30 provinces (autonomous regions and municipalities) in China from 2008 to 2020 based on equation (1), and control variables, region and year fixed effects are selectively controlled to minimize the impact of omitted variables, and the results are shown in Table 2. From the results, it can be seen that the regression coefficients of the core explanatory variable *treat × post* are significantly positive regardless of the scenario, implying that the carbon trading policy significantly enhances the green total factor productivity, and hypothesis H1 is verified.

Table 2. Benchmark regression of the impact of carbon trading pilot policies on green total factor productivity.

Variable	TFP			
	(1)	(2)	(3)	(4)
<i>treat × post</i>	0.131*** (0.019)	0.067*** (0.015)	0.044** (0.019)	0.063*** (0.017)
<i>str</i>			-0.005*** (0.001)	-0.003** (0.001)
<i>rd</i>			0.010* (0.006)	0.009 (0.006)

hum			0.087*** (0.027)	0.067** (0.031)
inf			0.079 (0.052)	0.051 (0.069)
lnopen			0.029** (0.011)	-0.012 (0.012)
lnroad			-0.300*** (0.067)	-0.130* (0.066)
Control Variable	NO	NO	YES	YES
Area Fixed Effect	YES	YES	YES	YES
Time Fixed Effect	NO	YES	NO	YES
Constant	1.018*** (0.005)	1.026*** (0.004)	4.275*** (0.734)	2.609*** (0.741)
Observations	390	390	390	390
R ²	0.522	0.761	0.716	0.771

3.2. Robustness Tests

(1) Parallel Trend Test

Satisfying the parallel trend assumption is the prerequisite for adopting the multi-temporal DID model in the empirical analysis, i.e., the green total factor productivity in the pilot regions and the non-pilot regions maintains the trend of change without significant difference before the carbon trading policy takes place. Since different batches of pilot regions start to implement the policy at different times, it is necessary to set relative time dummy variables for policy implementation for different batches of pilot regions. This paper draws on the practice of Bai et al [15] to conduct the parallel trend test, and the corresponding model is set as follows:

$$TFP_{it} = \alpha + \beta_1 Pre4_{it} + \beta_2 Pre3_{it} + \beta_3 Pre2_{it} + \beta_4 Pre1_{it} + \beta_5 Current_{it} + \beta_6 After1_{it} + \beta_7 After2_{it} + \beta_8 After3_{it} + \beta_9 After4_{it} + \beta_{10} After5_{it} + \beta_{11} After6_{it} + \beta_{12} After7_{it} + \gamma X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (4)$$

The time dummy variable represents observations in the n years before, during and after the implementation of the policy in the pilot regions, and 0 in the non-pilot regions, as 2013 was the year when the first pilot regions officially implemented the carbon trading pilot work, and thus some pilot regions did not have more than a -5 period of the sample value. In view of this, it is necessary to aggregate the time before the -5 period in other regions and exclude this time dummy variable as a benchmark to avoid multicollinearity. In this paper, the 95% confidence intervals of the regression coefficients of the relative time dummy variables are plotted using periods -1, -2, -3 and -4 before the implementation of the policy as the reference years for the parallel trend test before the policy occurred, as shown in Figure 1. As can be seen from Figure 1, the regression coefficients of the dummy variables for periods -1 to -4 before the implementation of the carbon trading policy are not significant, which can indicate that there is no significant difference in the green total factor productivity between the pilot and non-pilot regions before the policy occurs, and satisfy the parallel trend assumption.

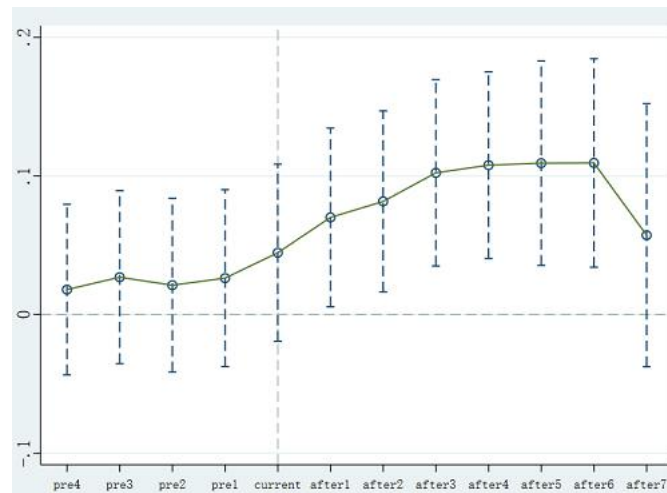


Figure 1. Parallel trend test.

(2) Placebo test

Considering that the improvement of green total factor productivity may be affected by some exogenous factors that are not related to the carbon trading policy, this paper conducts a placebo test by fictionalizing the case of no policy in the treatment group. Due to the differences in the time when different batches of pilot regions start to implement the policy, it is necessary to randomly select the pseudo-pilot region dummy variable and the pseudo-pilot year dummy variable at the same time, and the specific steps are as follows: randomly select 7 provinces (districts and municipalities) out of the 30 provinces (districts and municipalities) to generate the pilot region, and the year of the pilot is given randomly; this random sampling process is repeated 500 times, and we get 500 sets of interaction terms ($treat^{random} \times post^{random}$); Plot the distribution of interaction term coefficients and their P-values. As can be seen from Figure 2, the coefficients of the interaction terms are mostly concentrated around the value of 0, which is different from the estimated coefficient of 0.063 of the actual policy, and the p-values are mostly higher than 0.1, indicating that the effect of the carbon trading pilot policy on the green total factor productivity is not obviously affected by other stochastic factors, and the results are robust.

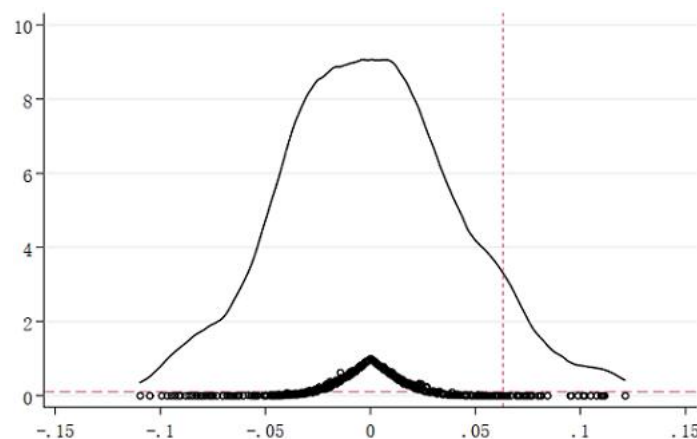


Figure 2. Distribution of coefficient estimates after stochastic treatment.

Note: The X-axis is the estimated coefficients of the 500 randomly generated interaction terms, the empty circles are the p-values of the estimated coefficients, and the solid line is the kernel density distribution of the estimated coefficients; the right vertical line is the estimated coefficients of the actual policy.

3.3. Further discussion

(1) Heterogeneity Analysis Based on Pillar Industries

Considering the fact that when facing the emission reduction constraints of carbon trading policy, the production mode and development path of regions with high-pollution industries as pillar industries are difficult to be easily improved in a short period of time, which largely restricts the effect of carbon trading policy on green total factor productivity. In order to test the differences in implementation effects brought about by different pillar industries in various regions, this paper selects the A-share market value ratio of enterprises in the six major energy-consuming industries as a measure of pillar industries, and divides the samples by calculating the median of the A-share market value ratio of enterprises in the six major energy-consuming industries in various provinces (autonomous regions and municipalities) in the three years before the implementation of the carbon trading pilot policy (2010-2012), and defines the provinces (autonomous regions and municipalities) with a ratio higher than the median as For the region with high-pollution industry as the pillar industry, the provinces (autonomous regions and municipalities) below the median are defined as the region with non-pillar industry of high-pollution industry, and group regression is carried out, and the results are shown in Table 3, columns (1)-columns (2).

(2) Heterogeneity Analysis Based on Science and Technology Expenditure

Since S&T expenditure is the basic guarantee and condition support for regional S&T progress, regions with more financial S&T funds will fully drive the enthusiasm of technological innovation, and also inject strong momentum for economic growth and environmental protection, which in turn will affect the implementation effect of the carbon trading policy. In order to test the differences in the implementation effect of different regions due to different S&T expenditures, this paper takes the proportion of fiscal S&T expenditures to fiscal general budget expenditures as a S&T expenditure indicator, and divides the samples by calculating the median ratio of fiscal S&T expenditures of provinces (autonomous regions and municipalities) in the three years before the implementation of the carbon trading pilot policy (2010-2012), and defines the provinces (autonomous regions and municipalities) with higher than median expenditures as regions with high S&T expenditures, and those with lower than median expenditures as regions with high S&T expenditures. The provinces (autonomous regions and municipalities) with high and lower than median expenditure on science and technology are defined as regions with lower expenditure on science and technology, and group regression is carried out, and the results are shown in columns (3)-columns (4) of Table 3.

Table 3. Heterogeneity Analysis.

Variable	TFP			
	(1)	(2)	(3)	(4)
<i>treat × post</i>	0.028 (0.036)	0.090*** (0.022)	0.122*** (0.038)	0.031 (0.021)
Fixed Effect	YES	YES	YES	YES
Control Variable	YES	YES	YES	YES
Constant	3.722*** (1.155)	2.938*** (1.091)	1.299 (1.075)	5.000*** (1.025)
Observations	195	195	195	195
R ²	0.793	0.767	0.790	0.784

4. Conclusions

Based on the panel data of 30 provinces (autonomous regions and municipalities) in China from 2007 to 2020, this paper examines the effect of carbon trading policy on regional green total factor productivity through a multi-temporal DID model. The results show that the implementation of carbon trading policy significantly enhances the green total factor productivity, which is of great significance in promoting the green development of China's economy. After conducting robustness tests, the above conclusions remain valid. Heterogeneity analysis based on pillar industries and science and technology expenditures shows that in regions with high energy-consuming industries as pillar industries, the carbon trading pilot policy cannot effectively enhance green total factor productivity, while in regions with higher science and technology expenditures, the positive impact of the carbon trading policy on green total factor productivity is more significant.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

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