The influence and mechanism of carbon emission trading policy on green total factor productivity— An empirical study based on difference-in -difference model

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Abstract. Based on the panel data of 30 provinces and cities in China from 2008 to 2018, this paper empirically-analyzes the impact of carbon emission trading on green total factor productivity by using differential and intermediary effect models, and demonstrates the specific mechanism from the perspective of carbon emission reduction effect. The study found that carbon emission trading significantly improved green total factor productivity. From the perspective of influence mechanism, carbon emission trading improves green total factor productivity through marketization effect and technological innovation effect. Finally, it is concluded that the implementation of pilot policies should adhere to the principle of the combination of government macro-control and market decision, play the key role of technological innovation and formulate differentiated policies.

Key words: Carbon emission trading; Double difference; Green total factor productivity; Mediating effect

1. Introduction

In the current global low-carbon economy and green finance in the background, "double carbon goal" has become the trend of The Times. In 2011, China promulgated the "Notice on the Pilot Program of Carbon Emission Trading", and from 2013 to 2016, seven provinces and municipalities -- Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Guangdong and Fujian -- successively approved the pilot program of carbon emission trading. In 2021, the total transaction volume of the national carbon emission quota (CEA) reached 179 million tons, and the cumulative transaction volume was 7.661 billion yuan, showing the healthy development trend of the Chinese carbon market.

Under the above background, with the in-depth development of carbon emission rights trading, industrial development will certainly face the economic pressure of internalization of external environmental costs. It is particularly important to integrate green and low-carbon indicators into the measurement of enterprise total factor productivity. Therefore, green total factor productivity is introduced. 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 use and pollution emission, which can effectively measure the production efficiency of enterprises under the current situation of green development. In view of the reflection on green total factor productivity introduced by carbon emission trading, this paper puts forward the following questions: Can carbon emission trading pilot policies promote the improvement of regional industrial green total factor productivity? What are the specific influencing mechanisms? What is the reference significance for the subsequent construction of the carbon trading unified market?

2. Model establishment and variable description

2.1 Research hypothesis

Carbon emission trading can affect green total factor productivity through market mechanism, technological innovation effect and carbon emission reduction effect.

First of all, carbon emission trading was first proposed by foreign scholar Dales [1], which means that the emission right is given commodity property under the premise that the total emission does not exceed the prescribed total amount, and the optimal allocation of carbon emission right is achieved among enterprises through market mechanisms such as supply and demand, price and competition,

forcing enterprises to develop energy saving and emission reduction technologies and reduce environmental pollution based on cost-benefit considerations. To achieve the goal of improving green total factor productivity. This principle can be traced back to the property rights theory of new institutional economics, that is, resources with clear property rights can be optimally allocated at the lowest cost through the market mechanism, so as to internalize the externalities of public goods. Based on this, we conclude the following hypothesis:

Hypothesis 1: Carbon emission trading improves green total factor productivity through marketization effect.

Secondly, carbon emission trading allows carbon emission quota to be allocated independently by the market supply and demand parties, who are faced with the motivation of technological innovation. In order to gain gains from quota sales, suppliers devote themselves to increasing investment in green research and development, developing energy-saving and emission reduction technologies, and promoting technological innovation of enterprises, which directly affects the improvement of green total factor productivity. At the same time, the cost of carbon emission quota purchase forces the demanders to reduce environmental pollution through technological innovation, maintain their profit space and industrial competitive position, and provide technical support for their transformation from carbon emission right demander to supplier and the adjustment and upgrading of industrial structure. Enterprise green technology innovation significantly improves production efficiency and green level, and improves green total factor productivity. Based on this, we conclude the following hypothesis:

Hypothesis 2: Carbon emission trading improves green total factor productivity through technological innovation effect.

2.2 Model building

2.2.1 SBM model

In terms of the measurement method of green total factor productivity, most of the existing studies, based on the measurement method of total factor productivity, consider adding the undesirable output under the assumption of constant return to scale to generate the SBM super efficiency model, which to some extent avoids the simultaneous effectiveness of multiple decision units when there are a large number of input and output indicators and affects the evaluation results. Based on the research and measurement methods of Yin Lihui and Wang Zhi, this paper uses SBM super efficiency model to measure green total factor productivity under carbon emission trading rights.

2.2.2 Benchmark DID model

In assessing the effect of a particular policy, most literature uses the difference in difference (DID) method. By comparing the changes of variables in the experimental group and the control group before and after the implementation of the policy, the difference in difference method measures the causal effect of the policy, which can effectively avoid the endogeneity problem. In this paper, there are two policy timing points in the carbon emission trading pilot policy. Therefore, the multi-period DID model is adopted to measure its impact mechanism on the regional green total factor productivity. The multi-period DID model is as follows:

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

2.2.3 Mediation effect model

The theoretical assumption of this paper is to analyze the effect of carbon emission permit trading on green total factor productivity by influencing technological innovation and marketization level. Therefore, the following model is constructed to verify whether the intermediary effect is significant.

$$GTFP_{it} = \alpha_0 + \alpha_1 treat_i \times post_t + \alpha_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$$inv_{it} = \gamma_0 + \gamma_1 treat_i \times post_t + \gamma_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

$$mar_{it} = \varphi_0 + \varphi_1 treat_i \times post_t + \varphi_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$$GTFP_{it} = \lambda_0 + \lambda_1 treat_i \times post_t + \lambda_2 cer_{it} + \lambda_3 inv_{it} + \lambda_4 mar_{it} + \lambda_5 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

2.3 Data source and description

2.3.1 Core variable

Green total factor productivity ($GTFP_{it}$) : This paper adopts the SBM-GML model, taking 2008 as the base period and its GTFP value being 1, to calculate the green total factor productivity from 2008 to 2019.

2.3.2 Mediating variable

Marketization level: reflects the extent to which market mechanism plays a role in resource allocation. This paper takes Fan Gang Marketization Index as a measure of regional marketization level.

Technological innovation: The number of provincial green patent applications is used as a measure of regional technological innovation level.

2.3.3 Control variable

In order to more accurately capture the impact of carbon emission permit trading on green total factor productivity, this paper controls other variables that may affect green total factor productivity, including financial development level (FIN), the ratio of loan balance of financial institutions to gross regional product; Scientific research input (TECH) is the ratio of government expenditure on science and technology innovation to general budget expenditure; The level of foreign direct investment (FDI), which is the proportion of the amount of foreign direct investment measured in RMB to the gross regional product; Human capital level (HC), is the ratio of the employed population with high school education or above to the total employed population; Green upgrading of industrial structure (ISA) : is the ratio of output value of tertiary industry to output value of secondary industry; Government intervention degree (GOV) : refers to the proportion of the government's general public budget expenditure in the GDP; The descriptive statistics of the main variables are shown in Table 2.

Table 1 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

3. Regression result

3.1 Baseline regression result

Based on Equation (1), this paper uses multidimensional fixed effects linear regression method to empirically test the impact of carbon emission trading on the green total factor productivity. The regression results are shown in Table 3. The coefficient of policy variable is 0.204, passing the

significance test of 1%, which fully explains the effect of carbon emission trading on the improvement of regional green total factor productivity.

Table 2 Results of baseline regression

	GTFP	GTFP	GTFP	GTFP
$post_i \times treated_t$	0.0993***	0.1248***	0.1562***	0.2131***
	(0.0963)	(0.1486)	(0.0421)	(0.0562)
FIN			0.0245	0.0136
			(0.1471)	(0.1961)
TECH			6.4251***	7.3214***
			(1.9624)	(2.5924)
FDI				0.0562
				(0.1359)
HC				1.2365**
				(0.4963)
ISA				-0.2317
				(0.0834)
Year fixed effects		containment	containment	containment
individual fixed effect		containment	containment	containment
_cons	0.7493***	0.5681***	0.3968***	0.9642***
	(0.3562)	(0.1635)	(1.5624)	(0.1731)
N	360	360	360	360
R-square	0.752	0.696	0.731	0.785

3.2 Examination of the mechanism of mediation effect

The above benchmark regression results have proved the significant improvement effect of carbon emission permit trading on regional green total factor productivity. Then how do the specific influencing mechanisms between the two be transmitted? In this paper, stepwise regression method is adopted to regression equations (2), (3), (4) and (5), and the results are shown in Table 4. It can be found that carbon emission reduction, technological innovation and marketization level have significant partial mediating effect on the improvement of regional green total factor productivity by carbon emission permit trading. Through carbon emission reduction effect, technological innovation effect and marketization effect, carbon emission trading can effectively affect the adjustment of enterprises' industrial structure[1] and ultimately achieve the purpose of improving regional green total factor productivity[2].

Table 4 Test of the mediation effect mechanism of carbon emission trading policy on green total factor productivity

	(1) GTFP	(2) INV	(3) GTFP	(4) MAR	(5) GTFP
policy	0.2131***	1.0162***	0.9325***	0.1042**	0.1054***
	(0.0562)	(0.2621)	(0.4059)	(0.1580)	(0.5699)
FIN	0.0136	0.9444***	0.6362**	0.8756**	1.1689***
	(0.8423)	(0.3621)	(0.4758)	(0.8138)	(0.3499)
TECH	7.3214***	3.7246***	2.6465***	0.8161**	0.9142***
	(0.7418)	(0.5473)	(0.2062)	(0.7150)	(0.8529)
FDI	0.0562	0.3717***	0.2160**	0.3604**	0.9879***
	(0.6251)	(0.7246)	(0.4386)	(0.9249)	(0.8187)
HC	1.2365***	0.6469**	1.3622***	0.9004**	0.3604*
	(0.4772)	(0.1981)	(0.2608)	(0.8420)	(0.7039)
ISA	-0.2317	0.3925**	0.7587**	0.1689*	0.2317**
	(0.4651)	(0.6779)	(0.5042)	(0.9753)	(0.8047)
particular year	containment	containment	containment	containment	containment
self-employed	containment	containment	containment	containment	containment
_cons	0.9642***	0.4036***	1.0984***	0.2569***	0.6281***
N	360	360	360	360	360
R-square	0.7521	0.8134	0.6523	0.7231	0.6742

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

4. Conclusion and suggestion

This paper uses the differential method and the intermediary effect model to evaluate the carbon emission reduction effect of carbon emission trading, and demonstrates the specific influencing mechanism of carbon emission trading to improve green total factor productivity. The results show that: (1) technological innovation effect and marketization effect of carbon emission trading improve green total factor productivity; (2) Corporate green technology innovation is a key way to promote low-carbon development, and the introduction of high-quality human capital can enhance the concept of corporate green development; (3) The role of green financial products represented by green credit in serving green development needs to be explored. Foreign investment in 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 gives the following policy recommendations:

First, the implementation of pilot carbon emission trading policies should adhere to the principle of combining government macro-control and market decision mechanism. On the one hand, the market should play a decisive role in the allocation of carbon emission permits, and promote the reasonable allocation of carbon emission permits 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, given the government's macro-control role in the pilot process of carbon emission trading, carbon emission is essentially a public good, and market chaos may be generated only by relying on the market mechanism. In this case, the government needs to use the "visible hand" to control and regulate the market failure and maintain the reasonable operation of the market.

Second, give play to the key role of technological innovation in improving green total factor productivity, and guide domestic and foreign capital to green innovation and low-carbon development through green finance and policy support, so as to provide fundamental impetus for enterprises' green transformation. At the same time, we should cultivate high-quality human capital with environmental protection awareness, form green development concept inside enterprises, and enhance internal development power.

Third, we should give full play to the leading role of pilot areas in the development of carbon emission trading in pilot areas and promote the common development of more provinces and regions. Differentiated regional carbon emission trading pilot policies shall be formulated according to the level of economic development, industrial structure and energy structure. At present, most of the pilot areas are regions with high economic level, and relevant supporting measures have certain regional characteristics. In the future, in the process of promoting the unification of the carbon emission rights market, different external conditions will inevitably be faced in different regions. Therefore, it is necessary to make continuous adjustment based on the existing measures and regional characteristics, and formulate differentiated green development strategies.

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