

*Original Research*

# The Impact of China's Carbon Emission Trading Policy on Green Total Factor Productivity – Influence Analysis Based on Super-EBM and Multiple Mediators

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## Abstract

Can China's carbon trading policy promote regional green total factor productivity? What are the specific influencing processes and mechanisms between the two? In this paper, we construct an indicator framework for China's green total factor productivity from the perspective of green development, which comprehensively considers various inputs and outputs. This paper uses a more scientific Super-EBM model considering the mixed distance to accurately measure the regional green total factor productivity in China. The static and dynamic effects and multiple mediating effects of carbon trading policy on green total factor productivity were studied by using DID model combined with stepwise regression method. The robustness of the results was tested by parallel trend test and placebo test. The mediating effects of total energy consumption, energy consumption structure, technological innovation and the moderating effects of financial development level and intellectual property protection degree are studied. The results show that carbon trading policy significantly improves China's regional green total factor productivity. The effect of carbon trading policy on green total factor productivity in pilot areas increased to decreased; Total energy consumption and energy consumption structure have a partial intermediary effect on the relationship between carbon emission trading policy and regional green total factor productivity in China, while technological innovation has a masking effect. Regional financial development level and intellectual property protection intensity play a moderating role in the relationship between carbon emission trading policy and regional total factor productivity. Based on the above conclusions, some suggestions are put forward for the improvement of China's carbon trading policy system.

**Keywords:** carbon emission trading, green total factor productivity, Super-EBM, DID model, the masking effect

## Introduction

Since the Western Industrial Revolution, human society has made more and more progress with the development of science and technology and industry, which corresponds to a series of problems such as over-exploitation of natural resources, rapid increase in the consumption of reserved fossil fuels, increasingly severe environmental pollution and global warming. In order to solve the common problem of sustainable future survival and development of mankind, the international community is increasingly committed to developing a low-carbon economy and reducing greenhouse gas emissions generated by energy consumption. The Kyoto Treaty, which came into effect in 2005, gave birth to the first international carbon trading market, the European Union Carbon Trading System (EU ETS), which aims to use the market economy to intervene in enterprises' pollution emissions, so as to reduce the greenhouse gas emissions of EU countries [1]. The establishment of the international carbon trading market is dominated by the European Union, the United States, Japan and other developed countries. After nearly 20 years of development, the European Union carbon trading market has grown into a mature representative of the international carbon emission trading market, and has become the object of learning and reference for developing countries. On September 22, 2020, at the 75th Session of the United Nations General Assembly, China proposed that it would enhance its nationally determined contribution, adopt more effective policies and measures, strive to peak carbon dioxide emissions by 2030, and strive to achieve carbon neutrality by 2060. The implementation of carbon emission trading policy is a key step towards achieving the dual carbon goal. In November 2011, the National Development and Reform Commission (NDRC) issued a Notice on pilot carbon emission trading, and since 2013, carbon emission trading has been piloted in seven regions: Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Hubei and Shenzhen. The pilot area covers about 1.2 billion tons of carbon dioxide emissions from different industries, with plans to gradually expand nationwide, and is expected to surpass the European Union as the world's largest carbon trading system.

The Porter hypothesis holds that the environment and the economy can achieve a win-win situation. The right environmental regulation can promote the technological innovation of enterprises, so as to enhance the competitiveness of enterprises and improve their performance. The effect of environmental regulation has positive innovation compensation effect and negative innovation offset effect. When the compensation effect of environmental regulation on enterprise innovation exceeds the offset effect caused by the internalization of environmental cost, it provides sustainable conditions for enterprise innovation activities, forming the so-called "Porter hypothesis" effect. The carbon emission trading system is a typical way of environmental

regulation. To some extent, the carbon quota and the price of carbon emission trading reflect the intensity of environmental regulation.

The positive impact of carbon emission trading policy on carbon dioxide emissions has been unanimously concluded by scholars, that is, carbon emission trading policy significantly reduces carbon emissions [2-4], and the mediating effect of energy consumption structure, technological innovation level and industrial structure on carbon emission reduction has also been confirmed [5-7]. Other scholars have tested the environmental effects of carbon emission trading policies from the perspectives of low-carbon innovation, carbon efficiency or carbon performance [8-10]. In terms of the empirical impact on energy utilization, the paper [11] use the DID model to investigate the specific impact of carbon emission trading scheme (ETS) on energy efficiency and its mechanism, and the results show that CARBON ETS can improve energy efficiency by promoting technological innovation of enterprises. The marketization level enhanced the promoting effect of CARBON ETS on energy efficiency. Literature [12] finds that both carbon trading scheme and green certificate trading scheme can increase installed capacity of renewable energy and reduce carbon emissions. When both mechanisms are introduced, the proportion of renewable energy installed will be the highest and carbon emissions will be the lowest. The paper [13] evaluated the ETS effect of non-fossil energy development in China by using the DID model, and found that ETS significantly promoted the development of non-fossil energy in China, and the higher the carbon price, the more ETS promotes the development of non-fossil fuels. In terms of the empirical impact on economy, scholars at home and abroad have carried out research from different perspectives of economic development, especially the direct impact of carbon emission trading policy on economic growth, the research conclusions are still controversial. Scholars [14-16] found that carbon emission permits significantly reduced carbon emissions, but did not significantly improve the growth of local economy, mainly because they failed to form effective incentives for technological breakthroughs. The other [17] found that the carbon emission trading policy did not produce porter effect, because the pollution paradise effect induced by the carbon emission trading pilot policy offset the Porter effect to some extent. In other aspects of economic impact, Scholars had verified the different impacts of carbon trading on urban-rural income equality [18] and labor demand [19].

Through literature review, it can be found that although the international research on carbon trading is relatively mature, the relevant research on carbon market in China is more focused on some aspects of its impact on economy or energy. Studies on the effects of carbon trading on green total factor productivity in China are scarce. The measurement index of productivity including green total factor is one-sided. Only carbon

dioxide and a few major types of air pollutants are often considered in terms of environmental negative outputs. Measurement tools are also relatively backward. Most scholars use SBM model, super-efficiency SBM model or non-parametric DEA-Malmquist index model (non-radial relaxation variables are ignored). Moreover, there is a lack of analysis on the multiple intermediate influence mechanisms of carbon trading on China's green total factor productivity.

Based on the above analysis, the main contributions of this paper are as follows:

First, we construct an indicator framework for China's green total factor productivity from the perspective of green development, which comprehensively considers various inputs and outputs, as well as the relationship between resources, economy and environment. The fixed capital stock, employment number and total energy consumption of each province in China are taken as input variables. In this paper, five major environmental pollutants related to industry are taken into account comprehensively as far as possible, including carbon dioxide, sulfur dioxide, industrial smoke (powder) dust, industrial waste water discharge, industrial solid waste production as the adverse output of environmental pollution. Gross regional product is expected output. So we can measure the green total factor productivity of each province in China comprehensively.

Secondly, based on the deficiency of traditional SBM model and super-SBM model (non-radial relaxation variables are ignored), this paper applies the mixed distance model EBM proposed by Tone and Tsutsui [20], which includes both radial and SBM distances. EBM model retains the original proportion of the front projection value well, and at the same time solves the problem of the dimension difference of input-output factors, which can measure the green development efficiency of decision making units more scientifically and effectively. By combining EBM model with super-efficiency model, the super-EBM model can combine the advantages of the two models and further distinguish frontier efficiency with efficiency value greater than 1 more accurately. In recent years, its effectiveness in measuring green development efficiency has been verified [21, 22]. In this paper, super-EBM model is used for the first time to calculate green total factor productivity of 30 provinces in China from 2005 to 2019, which effectively improves the scientific nature and accuracy of efficiency measurement.

Finally, what is the specific way that carbon trading policy promotes China's green total factor productivity, and what is the specific influence process and mechanism between the two? The deep mechanism research of this aspect is very scarce. By introducing multiple mediating and moderating factors, including total energy consumption, energy consumption structure, technological innovation, financial development level and intellectual property protection level, this paper makes up for the research

gap in this area. The static and dynamic effects of carbon trading policy on China's regional green total factor productivity are analyzed by using the DID model combined with stepwise regression method, and the mediating effects of total energy consumption, energy consumption structure, technological innovation and the moderating effects of financial development level and intellectual property protection degree are studied. The influence process and mechanism of carbon trading and green total factor productivity (GTFP) are further analyzed, and based on the empirical results, policy suggestions for improving carbon trading and promoting regional green total factor productivity are put forward.

### **Influence Mechanism**

Based on the existing studies, combined with Property Rights theory, Economic Growth theory, Cost-Benefit theory and Porter hypothesis, it can be concluded that the impact of carbon emission trading policy on regional green total factor productivity mainly comes from three ways: total energy consumption, energy consumption structure and technological innovation. In this process, the level of financial development and the intensity of intellectual property protection play a moderating role.

First of all, in terms of energy consumption, the implementation of carbon emission trading policy forces enterprises to reduce carbon emissions, so as to reduce carbon emission costs or gain profits by selling carbon emission rights. The goal of carbon emission reduction makes enterprises start to reduce the consumption of high carbon emitting energy such as oil and coal, and improve energy utilization efficiency through new technology introduction and internal technological innovation of enterprises, so as to reduce the overall energy consumption while ensuring the scale of production capacity. In this process, the growth rate of energy and resource input required by economic growth slows down, and resource utilization efficiency is greatly improved. The double improvement of economic benefit and environmental effect can fundamentally improve green total factor productivity.

In terms of energy consumption structure, in the long run, as the consumption of high carbon emission products such as oil and coal decreases, enterprises must continuously increase the investment in technology research and development and try to develop and use alternative energy such as natural gas, shale gas and shale oil in order to survive and develop in the highly competitive market. Therefore, the energy consumption structure can be constantly optimized, and the economic growth mode of China is gradually transformed from unsustainable to sustainable. As China is still in the stage of rapid economic development, the total energy consumption is increasing. In this context, the optimization of energy structure can improve

the bottleneck of China's economic development in the future and promote the improvement of the regional green total factor productivity.

Based on Porter hypothesis and Schumpeter's "innovation theory", it can be concluded that technological innovation will become the main way for carbon emission trading policy to promote regional green total factor productivity growth, and amplify the effect of the policy, including environmental effect and economic effect. Specifically, when the compensation effect of carbon emission restriction on enterprise innovation exceeds the offset effect caused by the internalization of carbon emission cost, technological innovation will become the first choice of enterprises. "Offset effect" means that enterprises can produce technological innovation effect through technological innovation, which can improve production technology and optimize production process. It can give full play to the effect of green technology, improve production efficiency and reduce environmental pollution emissions in the process of industrial production, so as to get rewards from the government's carbon emission reduction policy. Specifically, it includes reducing its potential carbon emission cost and obtaining excess income by selling additional carbon emission rights. This excess revenue can "offset" the r&d costs of technological innovation by industrial enterprises. From the practical point of view, with the gradual strengthening of the carbon quota limit and the gradual rise of the carbon emission trading price, the green technology innovation of enterprises will become the general trend, and then drive the green technology level of the whole society, so as to promote the growth of the green total factor productivity.

However, financial development can improve the level and efficiency of investment and financing, and promote regional economic development by increasing the total amount of factors and playing the agglomeration effect of factors. Promote economic development by improving factor productivity, such as capital production efficiency, investment and financing efficiency. The intensity of intellectual property protection is the decision-making basis for enterprises to invest in innovation, which can bring huge economic benefits to enterprises and enhance their economic strength. Both of them have different moderating effects on total energy consumption, energy consumption structure and technological innovation. This paper will carry out further empirical analysis. The influence mechanism of carbon emission trading policy on the green total factor productivity is shown in Fig. 1.

### Material and Methods

#### Super-EBM Model

Most scholars at home and abroad use traditional or improved DEA model to measure green development efficiency or total factor productivity. The paper [20] put forward a hybrid Epsilon-based Measure (EBM) model that can consider both radial and non-radial distance functions. It can not only consider the undesired output, but also deal with the situation where input and output variables have both radial and non-radial characteristics. Since the efficiency value obtained by EBM model is 1 at most, multiple DMU are often rated as effective, and the efficiency of these effective DMU cannot be

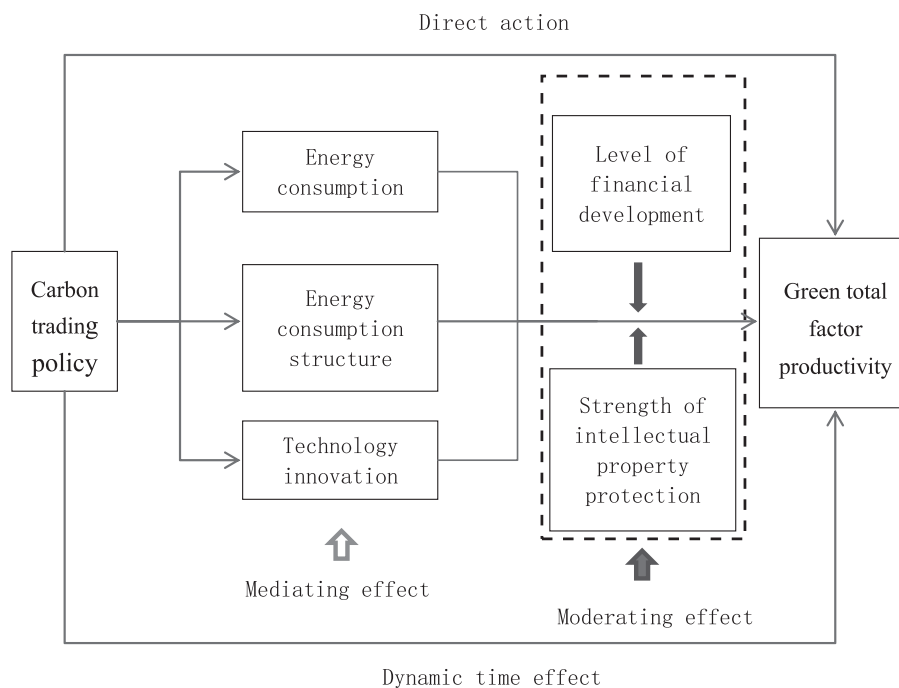


Fig. 1. Influence mechanism of carbon emission trading policy on the green total factor productivity.

further distinguished. In order to solve this problem, the paper [23] proposed a super-efficiency DEA model for further distinguishing effective DMU. In this model, the evaluated DMU is removed from the unit set and the efficiency of this decision-making unit is obtained based on the front surface composed by other DMU. In this way, the efficiency value obtained generally exceeds 1, which is called super-efficiency value. And the larger the efficiency value is, the higher the efficiency is.

Combining the advantages of super-efficiency DEA model and EBM model, this paper uses Super-EBM model to calculate China's regional green total factor productivity. The model can consider both radial and non-radial relaxation variables and further compare and distinguish the efficiency values of effective decision making units. Taken together, the Super-EBM model can more scientifically and accurately measure the green total factor productivity of 30 provinces in China. Assuming that there are n DMU, the Super-EBM model based on the non-expected super-efficiency is defined as follows:

$$r^* = \min \frac{\theta - \varepsilon \sum_{i=1}^m \frac{\omega_i^- s_i^-}{x_{i0}}}{\varphi + \varepsilon^+ \left( \sum_{r=1}^s \frac{\omega_r^+ s_r^+}{y_{r0}} + \sum_{p=1}^q \frac{\omega_p^{u-} s_p^{u-}}{u_{p0}} \right)} \quad (1)$$

$$\text{s.t.} \begin{cases} \sum_{j=1}^n x_{ij} \lambda_j + s_i^- = \theta x_{i0} & (i = 1, 2, \dots, m) \\ \sum_{j=1}^n y_{rj} \lambda_j - s_r^+ = \phi y_{r0} & (r = 1, 2, \dots, s) \\ \sum_{j=1}^n u_{pj} \lambda_j + s_p^- = \phi u_{p0} & (p = 1, 2, \dots, q) \\ \lambda_j \geq 0, s_i^-, s_r^+, s_p^- \geq 0 \end{cases} \quad (2)$$

In Formula (1),  $\gamma^*$  is the optimal efficiency value of green total factor productivity measured by super-EBM model,  $x_{i0}$ ,  $y_{r0}$ ,  $u_{p0}$  represent the input, expected output and unexpected output of DMU0 respectively,  $s^-$  represents the input relaxation vector,  $\theta$  is the radial efficiency value. There are m+1 parameter in the model.  $\omega_i^-$  represents the relative importance of each input index, and  $\varepsilon$  is the core parameter that determines the importance of the non-radial part of the calculation of  $\gamma^*$  efficiency value. The value range is [0,1]. When the value is 0, it is equivalent to the radial model, and when the value is 1, it is equivalent to the SBM model. In Formula (2),  $x_{ij}$ ,  $y_{rj}$ ,  $u_{pj}$  represent input, output and weight coefficients respectively.  $s_i^-$ ,  $s_r^+$ ,  $s_p^{u-}$  represent input relaxation, expected output relaxation and unexpected output relaxation respectively.  $\omega_i^-$ ,  $\omega_r^+$ ,  $\omega_p^{u-}$  represents the relative importance of each input index, expected output and non-expected output.

### Difference-in-Differences Model (DID Model)

In this paper, the DID model is constructed to explore the impact of carbon emission trading policies on regional green total factor productivity. Since 7 carbon emission trading pilot projects correspond to 6

provinces, 6 experimental groups and 24 control groups are set up in the model. The specific form of DID model is as follows:

$$y_{it} = \beta_0 + \beta_1 \text{time} \times \text{treated} + \beta_2 \text{time} + \beta_3 \text{treated} + \beta_4 \text{control} + \varphi_t + \mu_i + \varepsilon_{it} \quad (3)$$

Where,  $y_{it}$  represents the green total factor productivity of the i province in the t year, and  $\text{time} \times \text{treated}$  represents the interaction term of time and individual. If the current year is before 2013,  $\text{time} = 0$ ; In 2013 and after 2013,  $\text{time} = 1$ ;  $\text{treated} = 0$  when the province does not belong to the pilot area of carbon emission trading; When the province was the pilot area of carbon emission trading,  $\text{treated} = 1$ ;  $\varphi_{it}$ ,  $\mu_{it}$  and  $\varepsilon_{it}$  represent time fixed effect, individual fixed effect and random disturbance term respectively.

### Green Total Factor Productivity

Green total factor productivity can be understood as the part that the output can still increase when the input of all factors of production remains unchanged. Based on the traditional theory of production factors and the concept of green development in the new era, this paper calculates the growth rate of total factor productivity in each region considering environmental pollution. The input index considers capital, labor and energy inputs closely related to productivity. The expected output is the level of economic development. The non-expected output index selects five major industrial environmental pollutants. The selection of each indicator comprehensively draws on the practices of several scholars [24]-[26]. The specific index system established in this paper is shown in Table 1:

The main variables are described in Table 2. Among them, Strength of intellectual property protection draws on the practice, that is, using the modified G-P index, the intensity of intellectual property protection in a region = the level of intellectual property protection in China \* the intensity of law enforcement in each region. The law enforcement intensity of each region is the arithmetic average of the three indexes of social legalization degree, government law enforcement efficiency and patent non-infringement rate. The number of lawyers involved was sorted out by the Ministry of Justice, provincial justice departments and China Social Statistics Yearbook, and the patent infringement data year came from Guotai Junan database.

This paper uses the methods of scholars [27] to measure "the level of intellectual property protection in China". That is, five first-level indicators are used, including coverage of intellectual property protection, membership of international treaties, degree of loss of protection of rights, severity of law enforcement measures, duration of intellectual property protection, and 17 second-level indicators. According to the second-level indicators, 1 is assigned if they meet the situation,

Table 1. Regional green total factor productivity index.

Item	First-level indicators	The specific content	Unit	The data source
Input indicators	Capital	Fixed capital stock	One hundred million yuan	Perpetual inventory method is used to estimate the fixed capital stock of each province China Statistical Yearbook
	Labour	Number of persons employed	Ten thousand people	China Statistical Yearbook
	Energy	Total energy consumption	Tons of standard coal	China Energy Statistical Yearbook
Expected output	Level of economic development	Gross regional product	One hundred million yuan	China Statistical Yearbook
Non-expected output	Pollutant discharge	Carbon dioxide emissions	Ten thousand tons of	Calculated by IPCC method China Statistical Yearbook
		Sulfur dioxide emissions	Ten thousand tons of	China Statistical Yearbook
		Discharge of industrial wastewater	Ten thousand tons of	China Statistical Yearbook
		Industrial smoke (powder) dust emission	Ten thousand tons of	China Statistical Yearbook
		Production of general industrial solid waste	Ten thousand tons of	China Statistical Yearbook

otherwise 0 is assigned. Finally, the comprehensive scoring method is adopted to measure the level of intellectual property protection in all provinces of China.

In this paper, the following variables are selected as the control variables of the model.

(1) Industrial structure (str). The research of scholars [28, 29] show that industrial structure adjustment will affect industrial layout, total industrial output value and total industrial pollution emission, and then affect the overall productivity and environmental pollution level of the region, bringing about changes in green total factor productivity. Therefore, this paper takes it as one of the control variables and uses the calculation method as "GDP of secondary production/GDP of total production", with data from China Statistical Yearbook (2006-2020).

(2) Population density (dens). Studies by scholars [29, 30] show that population density has an important impact on the level of regional green development. High population density represents the potential investment of human capital with high intensity, and also brings about a significant increase in consumer demand, thus promoting the improvement of total industrial output value and bringing about environmental problems. Population density was taken as one of the control variables, and the calculation method was "Resident population/Area", based on data from China Statistical Yearbook (2006-2020).

(3) Urbanization rate (urb). Scholars [31, 32] have found that the urbanization rate is the proportion of urban population, which can directly reflect the level of local economic development and represent the degree of urban modernization development. The increase of the proportion of non-agricultural population also

means the improvement of workers' overall education level and comprehensive production capacity, which affects the green total factor productivity of a region. The urbanization level was taken as one of the control variables, and the calculation method was "Urban population/Total population", with data from China Statistical Yearbook (2006-2020).

(4) Employment quality (edu). According to the opinions of scholars [33], employment quality is regarded as a level of human capital, which is directly related to the overall production efficiency of regional industries and the ability of regional technological innovation, and plays a direct role in the output efficiency of regional green production. The employment quality was included in the control variable, and the calculation method was "Higher education population/Employed population", with data from China Labor Yearbook (2006-2020).

(5) Level of foreign direct investment (inv). This index represents the openness of the region. According to the "pollution paradise" hypothesis, whether local governments can lower environmental standards to attract foreign direct investment may lead to diversified competition. Underdeveloped regions may tend to reduce environmental conditions while developed regions usually choose to improve environmental standards, which will ultimately have an impact on regional green total factor productivity. Therefore, the level of FOREIGN direct investment is taken as one of the control variables in this paper. The calculation method is "Foreign direct investment/GDP", and the data are from China Statistical Yearbook (2006-2020) and provincial statistical Yearbook (2003-2020).

(6) GDP per capita (pgdp). According to the research of scholars [34, 35], the level of regional economic development will affect the input and output of regional

Table 2. Description of main variables.

Variable types	Variable name	Code	Instructions	Data source
Explained variable	Green total factor productivity	GTFP	It is calculated by Super-EBM model	China Statistical Yearbook
Explanatory variables	Carbon trading policy	<i>time × treated</i>	Before 2013, time = 0; 2013 and later, time = 1; When the province is not in the pilot area, treated = 0; When the province was the pilot area, treated = 1	Carbon trading policy paper
Control variables	The industrial structure	str	Secondary GDP/Gross GDP	China Statistical Yearbook
	The population density	dens	Resident population/Area	China Statistical Yearbook
	Urbanization rate	urb	Urban population/Total population	China Statistical Yearbook
	The employment quality	edu	Higher education population/ Employed population	China Labor Statistics Yearbook
	Level of foreign direct investment	inv	Foreign direct investment/GDP	China Statistical Yearbook
	GDP per capita	pgdp	Regional GDP/total population	China Statistical Yearbook
Mediating variable	Energy consumption	Energy	Energy consumption data	China Statistical Yearbook
	Energy consumption structure	Energy_str	Clean energy consumption/Total energy consumption	China Statistical Yearbook
	Technological innovation level	Innov	Number of invention patents granted	State Intellectual Property Office of China
Moderating variable	Level of financial development	Finance	Total regional deposits and loans/ total regional GDP	China Statistical Yearbook
	Strength of intellectual property protection	Property	The level of intellectual property protection in China * the intensity of law enforcement in each region	Documents of the Ministry of Justice
				Yearbook of Chinese Social Statistics
				Guotai Junan database

green innovation, and then affect the green total factor productivity. Therefore, GDP per capita is taken as one of the control variables in this paper, and the calculation method is "Regional GDP/Total population of the region". The data comes from China Statistical Yearbook (2006-2020).

## Results and Discussion

### The Benchmark Return

In order to improve the fitting degree of the model and ensure the robustness of the model, so that the influence direction of the core variable on the dependent variable does not change with different control variables, this paper adopts the method of gradually adding control variables to conduct regression successively, and the results are shown in Table 3. The regression results show that when six control variables are added at the same time, the model achieves the

maximum fitting degree of 0.61, and the influence coefficient of carbon emission trading policy on green total factor productivity is always positive, indicating that the regression model is robust and carbon emission trading policy has a positive effect on green total factor productivity.

The use of different fixed effect models may influence the regression results. In order to ensure the accuracy of regression results, Stata16 was used in this paper to conduct regression analysis of DID. Three regression methods, namely, no year fixed effect and regional fixed effect, only year fixed effect, and simultaneous year fixed effect and regional fixed effect, were used for comparative analysis to make the results more reliable and reasonable. The regression results are shown in Table 4.

The regression results show that the influence coefficient of carbon emission trading policy on green total factor productivity is always positive in the three models. Considering that the regression model with both year fixed effect and region fixed effect can avoid the

Table 3. Regression results of gradually adding control variables.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>time × treated</i>	0.0891** (2.47)	0.0790** (2.47)	0.0741** (2.54)	0.0885*** (3.00)	0.0992*** (3.57)	0.0878*** (3.03)	0.0549** (1.97)
<i>lnstr</i>		-0.184*** (-7.19)	-0.171*** (-7.17)	-0.166*** (-6.88)	-0.204*** (-8.27)	-0.208*** (-8.20)	-0.246*** (-8.96)
<i>lndens</i>			0.0688*** (15.77)	0.0623*** (13.98)	0.0513*** (10.65)	0.0407*** (8.10)	0.0284*** (5.23)
<i>lnurb</i>				0.1272*** (4.27)	0.3638*** (7.23)	0.2449*** (4.35)	-0.2078** (-2.33)
<i>lnedu</i>					0.1227*** (-5.50)	-0.092*** (-4.06)	-0.127*** (-5.75)
<i>lninv</i>						0.0324*** (3.64)	0.0352*** (4.28)
<i>lnpgdp</i>							0.2556*** (8.33)
Constant term	0.6853*** (64.19)	1.4009*** (14.13)	0.9988*** (10.18)	0.5279*** (3.36)	0.0885 (0.52)	0.5329*** (2.66)	2.4236*** (7.35)
<i>R</i> <sup>2</sup>	0.25	0.29	0.47	0.47	0.52	0.54	0.61

Note: t value in parentheses; \*\*\*, \*\*, \* indicate significant at the level of 1%, 5% and 10% respectively.

estimation bias caused by the heterogeneity of provinces and macroeconomic fluctuations, and this model has a higher fitting degree, this paper will conduct further specific analysis based on the results. The regression result of differential effect shows that the interaction coefficient is 0.0856, indicating that the implementation of the carbon emission right policy has a positive effect on regional green total factor productivity. After the implementation of the policy, the overall green total factor productivity increases by 0.0856, indicating that the implementation of the policy has a good effect.

### Dynamic Effect Analysis

The baseline regression only analyzes the average effect of carbon emission trading policy on green total factor productivity, but does not consider the dynamic impact of carbon emission trading policy on green total factor productivity. Therefore, in order to further test the impact time of carbon emission right trading policy on regional green total factor productivity, this paper will analyze the dynamic effect of carbon emission right policy.

Table 4. Analysis of the results of DID regression.

Variables	GTFP (1)	GTFP (2)	GTFP (3)
<i>time × treated</i>	0.0549** (1.97)	0.0481* (1.93)	0.0856** (2.46)
<i>lnstr</i>	Control	Control	Control
<i>lndens</i>	Control	Control	Control
<i>lnurb</i>	Control	Control	Control
<i>lnedu</i>	Control	Control	Control
<i>lninv</i>	Control	Control	Control
<i>lnpgdp</i>	Control	Control	Control
Year fixed effect	Don't control	Control	Control
Regional fixed effect	Don't control	Don't control	Control
Constant term	2.4236*** (7.35)	3.2990*** (11.44)	-0.4777 (0.795)
<i>R</i> <sup>2</sup>	0.61	0.70	0.92

Note: t value in parentheses; \*\*\*, \*\*, \* indicate significant at the level of 1%, 5% and 10% respectively.



Table 5. Dynamic regression results.

Variable	One year	Two year	Three year	Four year	Five year
<i>time × treated</i>	0.0741**	0.0817***	0.0741**	0.0655**	0.0450
t value	2.37	2.69	2.44	2.16	1.48
P value	0.018	0.007	0.015	0.032	0.139

Note: „\*\*\*”, „\*\*” and „\*” indicate significant at the level of 1%, 5% and 10% respectively.

The dynamic regression results show that the regression coefficients of all periods before 2013 are not significant, which also conforms to the hypothesis test of parallel trend. The regression results of all periods after 2013 are shown in Table 5.

The regression results show that before the implementation of carbon emission policy in 2013, the coefficient of influence of carbon emission policy on regional green total factor productivity is not significant. After 2013, carbon emission policy starts to have a positive promoting effect on regional green total factor productivity, with an influence range of about 0.07-0.08, and lasts for about 4 years. From the third year, the influence coefficient of carbon emission trading policy on regional green total factor productivity began to decline, indicating that the gradual enhancement of environmental regulations may form a crowding out effect. Environmental regulation increases the cost of pollution control, inhibits the production activities of enterprises to some extent, and inhibits technological innovation to some extent. From the fifth year, the influence coefficient is not significant, indicating that the policy has no significant effect on the improvement of total factor productivity.

Robustness Test

Parallel Trend Test

The dual difference method requires that the experimental group and the control group involved in the study must be comparable before the event or the policy, that is, to meet the “parallel trend”: Only when the treatment group and the control group are similar enough before the policy can we ensure that DID estimates the causal effect of the policy. Therefore, STATA16 is used to conduct parallel trend test on the DID model established in this paper, and the results are shown in Fig. 2. The results of parallel trend test show that carbon emission trading policy has no significant impact on green total factor productivity before the implementation of the policy. After the implementation of the policy, the carbon emission trading policy has a significant impact on green total factor productivity, and the coefficient is positive. This indicates that there is a significant difference between the experimental group and the control group, which satisfies the parallel trend

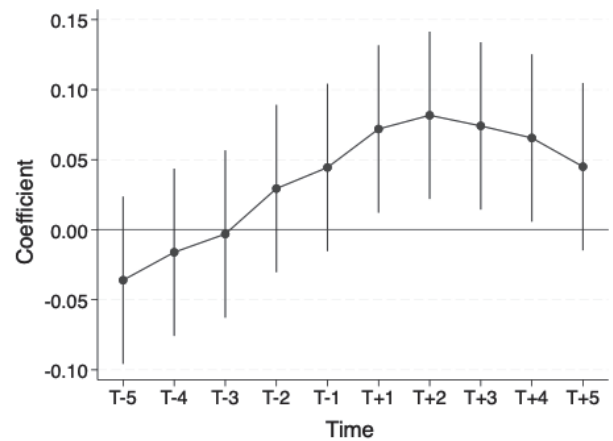


Fig. 2. Results of parallel trend test.

hypothesis and further proves that carbon emission trading policy has an impact on regional green total factor productivity.

Placebo Test

The “placebo” test is a randomized trial in which estimates are made using a fictitious treatment group or a fictitious policy implementation time. If the regression results of the estimators in different fictional ways are still significant, it indicates that the original estimation results are likely to be biased, and the change of explained variable y is likely to be affected by other policy changes or random factors. In this paper, Stata16 was used to test the DID model by placebo. 500 random samples were carried out in 30 provinces for baseline regression analysis, and 6 provinces were randomly selected in each sample as the treatment group and the remaining 24 provinces as the control group. Fig. 3 shows the kernel density distribution of the influence coefficient of carbon emission trading policy on regional green total factor productivity in the fictional way. The results showed that in 500 randomized trials, the baseline regression results obtained in this paper appeared at the tail of the kernel density graph, i.e., low probability events, indicating that the regression results were not accidental and the placebo test passed.

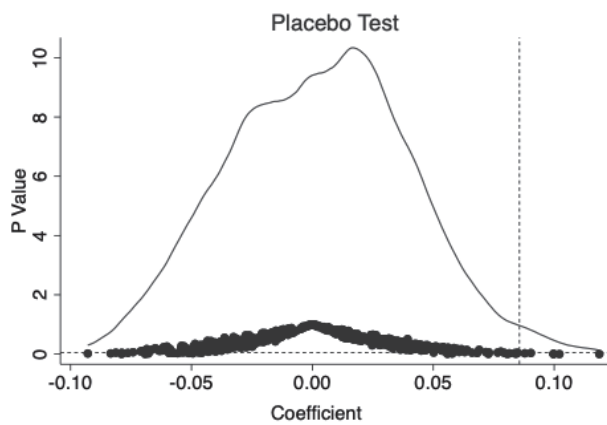


Fig. 3. Placebo test results.

### Mediating Effect Analysis

In order to further identify the specific improvement path of carbon emission trading policy on regional green total factor productivity, this paper examines and analyzes the mediating effect of carbon emission trading policy on regional green total factor productivity by taking energy consumption, energy consumption

structure and technological innovation level as intermediary indicators.

### Analysis of the Mediating Effect of Energy Consumption and Energy Consumption Structure

Total energy consumption and energy consumption structure were taken as intermediary variables respectively, and Stata16 was used to conduct stepwise regression test successively, with the results shown in Table 6.

The regression results show that the total energy consumption has a strong mediating effect, and it is part of the mediating effect. The influence coefficient of carbon emission trading policy on total energy consumption is significantly negative, and the influence of total energy consumption on regional green total factor productivity is significantly negative, indicating that the promotion effect of carbon emission trading policy on regional green total factor productivity is partially realized by reducing total energy consumption. The mediating effect value is  $(-0.1621) \times (-0.1980) = 0.0321$ , that is, the green efficiency value of 0.0321 is improved by reducing energy consumption.

Table 6. Mediating effect of energy consumption and energy consumption structure.

Variable	Do not add mediation variables	The mediating effect of total energy consumption		The mediating effect of energy consumption structure	
		lnEnergy	GTFP	lnEnergy_str	GTFP
<i>time × treated</i>	0.0856** (2.46)	-0.1621*** (-2.83)	0.0536* (1.77)	-0.2114 (-1.26)	0.0861** (2.42)
lnEnergy			-0.1980** (-2.34)		
lnEnergy_str					0.0022 (0.62)
lnStr	0.05961 (0.66)	0.1804 (1.39)	0.0953 (1.09)	-0.0863 (-0.16)	0.0569 (0.62)
<i>lndens</i>	0.2110 (0.85)	1.5885*** (3.26)	0.5255** (2.04)	-3.3274*** (-3.76)	0.2122 (0.86)
<i>lnurb</i>	-0.1538 (-0.82)	0.1234 (0.42)	-0.1293 (-0.61)	-0.3818 (-0.30)	-0.1523 (-0.80)
<i>lnedu</i>	0.0751 (1.55)	-0.0339 (-0.75)	0.0683 (1.38)	0.1023 (0.38)	0.0779 (1.56)
<i>lninv</i>	0.0189** (2.19)	-0.0312** (-2.20)	0.0127 (1.58)	0.0658 (1.22)	0.0183** (2.11)
<i>lnpgdp</i>	0.2569 (1.49)	0.6063*** (4.12)	0.3770** (2.26)	-1.8829 (-1.34)	0.2565 (1.45)
Constant term	-0.4777 (-0.26)	-4.2330 (-1.12)	-1.3158 (-0.70)	30.1783*** (6.40)	-0.5016 (-0.27)
Year fixed effect	control	Control	Control	Control	Control
Regional fixed effect	control	Control	Control	Control	Control
<i>R</i> <sup>2</sup>	0.92	0.99	0.93	0.82	0.92

Note: t value in parentheses; ‘\*\*\*’, ‘\*\*’ and ‘\*’ indicate significant at the level of 1%, 5% and 10% respectively.

Table 7. Sobel Test of mediating effect of energy consumption structure.

Value	The coefficient of Bootstrap	Z value	p value	A confidence interval
Indirect effect	0.0117	2.51	0.012**	[0.0025779,0.0209348]
Direct effect	0.0558	2.54	0.011**	[0.0127779,0.0988028]
Total effect	0.0675	-	-	-

Note: „\*\*\*”, „\*\*” and „\*” indicate significant at the level of 1%, 5% and 10% respectively.

The stepwise regression test of energy consumption structure as a mediating variable shows that the mediating effect of energy consumption structure is not significant. Due to the defects of stepwise regression mediation effect test in practice, it can not directly provide the point estimation of the mediation effect. In order to further verify whether the energy consumption structure has a mediating effect on the impact of carbon emission trading policies, the Bootstrap sampling method is used for further testing [36]. Regression results show that energy consumption structure has significant mediating effect on carbon emission trading policy, including direct effect and indirect effect. The direct effect coefficient is 0.0558, indicating that the influence of energy consumption structure is 0.0558, and the indirect effect significantly indicates the influence of other mediating variables.

### Analysis of Mediating Effect of Technological Innovation

According to the study of the paper [36], when the sign of the direct effect and the indirect effect of the mediation effect are opposite, the total effect is covered. Stepwise regression method is used to analyze the mediating effect of technological innovation. The results (Table 8) show that the regression coefficient of *did* to *innov* is -0.1562, and that of *innov* to *gtfp* is 0.0512. The two effects are different. In addition, in the fourth column of regression results, when *innov* is added as an intermediary variable, the regression coefficient of *did* on *gtfp* is 0.0937, which has a greater impact than that of 0.0856 when *innov* is not added as an intermediary variable, which fully indicates that this technological innovation has a masking effect [37], that is, under

Table 8. Mediating effect of technological innovation.

Variable	Do not add mediation variables	The mediating effect of technological innovation	
		<i>lninnov</i>	<i>GTFP</i>
<i>time × treated</i>	0.0856** (2.46)	-0.1562* (-1.72)	0.0937** (2.73)
<i>lninnov</i>			0.0512** (2.34)
<i>lnStr</i>	0.05961 (0.66)	0.7195 (1.54)	0.0227 (0.25)
<i>Indens</i>	0.2110 (0.85)	1.0962 (0.88)	0.1548 (0.66)
<i>lnurb</i>	-0.1538 (-0.82)	-0.3174 (-0.33)	-0.1375 (-0.61)
<i>lnedu</i>	0.0751 (1.55)	0.4799*** (3.77)	0.0505 (1.07)
<i>lninv</i>	0.0189** (2.19)	0.0260 (0.62)	0.0176* (1.91)
<i>lnpgdp</i>	0.2569 (1.49)	0.8030 (1.45)	0.2158 (1.24)
Constant term	-0.4777 (-0.26)	-2.8849 (-0.29)	-0.3299 (-0.19)
Year fixed effect	Control	Control	Control
Regional fixed effect	Control	Control	Control
<i>R</i> <sup>2</sup>	0.92	0.98	0.92

Note: t value in parentheses; „\*\*\*”, „\*\*” and „\*” indicate significant at the level of 1%, 5% and 10% respectively.

the condition that the technological innovation level remains unchanged, Carbon emission trading policy can improve regional green total factor productivity more.

The intermediary effect of technology innovation test results show that the implementation of the carbon emissions trading policy increased the blowdown cost of enterprises, in the short term has not formed the power of technology innovation, instead, by inhibiting the scale of enterprises with foreign capital, compression and other ways to form the extrusion effect of technology innovation [38], which failed to achieve the technology diffusion effect to the promotion of regional green total factor productivity.

In order to verify whether technological innovation has a masking effect, Bootstrap sampling method is further used to test the mediating effect of technological innovation. The results (Table 9) show that the indirect effect is not significant, indicating that in this study, technological innovation does produce a covering effect rather than a mediating effect. In other words, carbon emission trading policy can improve regional green total factor productivity, but the inhibition effect of carbon emission trading policy on technological innovation reduces this positive effect.

#### Analysis of Moderating Effect

In this paper, a moderating mediating effect model is constructed by adding the interaction terms of moderating variables and mediating variables on the basis of the DID model. In this paper, stepwise regression method is adopted to successively select financial development level and intellectual property protection intensity as moderating variables to test and analyze the moderating effect.

The interaction terms between independent variables and moderating variables, as well as between intermediate variables and moderating variables, are highly collinear with independent variables and moderating variables themselves, leading to deviation in model estimation. In view of this problem, this paper will correct it through the centralization command of Stata. Centralization can reduce the correlation between interaction terms and independent variables and moderating variables, and will not affect the estimated coefficients of core variables in the model. Therefore, the empirical process of this paper has made centralized treatment for all interaction terms.

#### Analysis on the Moderating Effect of Financial Development Level

Stepwise regression method is used to successively test the moderating mediating effect of financial development level on the relationship between carbon emission trading policy and regional green total factor productivity, and the results are shown in Table 10.

The regression results (Table 10) show that the interaction term  $\ln\text{Energy} * \ln\text{finance}$  has a significantly positive impact on the explained variable  $\text{gtfp}$ , indicating that the level of financial development has a moderating effect on energy consumption, that is, the impact of energy consumption on regional green total factor productivity is strengthened with the improvement of regional financial development level. The above methods are used to test the moderating effect of financial development level on energy consumption structure and technological innovation. The results show that the level of financial development has a moderating effect on energy consumption and technological innovation, but has no moderating effect on energy consumption structure. The influence of energy consumption and technological innovation on regional green total factor productivity is strengthened with the improvement of regional financial development level. Therefore, it can be concluded that the current financial development in China cannot help environmental regulation policies to form the driving force of technological innovation, energy saving and consumption reduction, but it can play a significant positive role in the end of the mechanism of policy effect, that is, transforming into social productivity.

#### Analysis on the Moderating Effect of Intellectual Property Protection Intensity

Stepwise regression method is used to test the moderating mediating effect of intellectual property protection intensity on the relationship between carbon emission trading policy and regional green total factor productivity. The regression results are shown in Table 11.

The regression results (Table 11) showed that the interaction term  $\ln\text{Energy} * \ln\text{property}$  had no significant effect on the explained variable  $\text{gtfp}$ , indicating that the intensity of intellectual property protection could

Table 9. Test of Bootstrap mediating effect of technological innovation.

Value	The coefficient of Bootstrap	Z value	p value	A confidence interval
Indirect effect	-0.0011	-0.34	0.732	[-0.0075438,0.0052963]
Direct effect	0.0687	2.91	0.004***	[0.0223737,0.1149672]
Total effect	0.0687	-	-	-

Note: „\*\*\*”, „\*\*” and „\*” indicate significant at the level of 1%, 5% and 10% respectively.

Table 10. Moderating effect of financial development level.

Variable	Do not add moderating variable	The moderating effect of financial development on energy consumption	The moderating effect of financial development on energy consumption structure	The moderating effect of financial development level on technological innovation
		GTFP	GTFP	GTFP
<i>time × treated</i>	0.0856** (2.46)	0.5632* (1.80)	0.0892** (2.42)	0.0615* (2.00)
lnfinnace		0.1606* (2.01)	0.1247* (1.84)	0.1951*** (3.65)
lnEnergy		-0.1526** (-2.57)		
lnEnergy*lnfinnace		0.1775*** (3.48)		
lnEnergy_str			0.0309 (1.21)	
lnEnergy_strlnfinnace			0.0515 (1.18)	
lninnov				0.0400** (2.03)
lninnov*lnfinnace				0.0836*** (4.14)
lnStr	0.05961 (0.66)	0.1208* (1.90)	0.0898 (1.10)	0.1118* (1.97)
<i>lndens</i>	0.2110 (0.85)	0.6596*** (2.75)	0.2650 (1.12)	0.1663 (1.08)
<i>lnurb</i>	-0.1538 (-0.82)	-0.2333 (-1.12)	-0.1816 (-1.02)	-0.1012 (-0.63)
<i>lnedu</i>	0.0751 (1.55)	0.0396 (0.87)	0.0816 (1.59)	0.0477 (1.10)
<i>lninv</i>	0.0189** (2.19)	0.0088 (1.39)	0.0227** (2.33)	0.0131** (2.09)
<i>lnpgdp</i>	0.2569 (1.49)	0.5702*** (2.93)	0.2976** (1.71)	0.3712** (2.67)
Constant term	-0.4777 (-0.26)	-2.5858 (-1.54)	-1.2861 (-0.72)	-1.4320 (-1.21)
Year fixed effect	Control	Control	Control	Control
Regional fixed effect	Control	Control	Control	Control
R <sup>2</sup>	0.92	0.94	0.92	0.94

Note: t value in parentheses; „\*\*\*”, „\*\*” and „\*” indicate significant at the level of 1%, 5% and 10% respectively.

not regulate the impact of energy consumption on regional green total factor productivity. The interaction term lnEnergy\_str\*lnproperty has a significant positive impact on regional green total factor productivity, indicating that with the improvement of intellectual property protection intensity, the improvement of energy consumption structure can improve regional green total factor productivity to a greater extent. Our quasi-natural experiment is based on the pilot period of China's carbon emission trading market, the study period is 2005-2019, and our research objects are seven carbon emission trading pilot regions (Guangdong, Hubei, Beijing, Tianjin, Shanghai, Chongqing, Shenzhen). The interaction term lnEnergy\_str\*lnproperty measures the

moderating effect of intellectual property protection intensity on energy consumption structure in the process of carbon trading affecting regional green total factor productivity through the intermediary effect of energy consumption structure. The results are significantly positive, indicating that in the process of carbon trading affecting regional green total factor productivity through the intermediary effect of energy consumption structure, the improvement of energy consumption structure can improve regional green total factor productivity to a greater extent with the improvement of intellectual property protection intensity. The higher the intensity of intellectual property protection, the more conducive to enhance people's motivation

Table 11. Moderating effect of intellectual property protection intensity.

Variable	Do not add moderating variable	The moderating effect of intellectual property protection intensity on energy consumption	The moderating effect of intellectual property protection intensity on energy consumption structure	The Moderating effect of intellectual property protection intensity on technological innovation
		GTFP	GTFP	GTFP
<i>time × treated</i>	0.0803** (2.25)	0.0544* (1.80)	0.0781** (2.34)	0.0875*** (2.77)
lnproperty	0.0380 (0.51)	-0.0321 (-0.79)	-0.0537 (1.97)	-0.0081 (-0.24)
lnEnergy		-0.1886** (-2.29)		
lnEnergy*lnproperty		0.0271 (0.65)		
lnEnergy_str			-0.0020* (-0.17)	
lnEnergy_str*lnproperty			0.0984*** (2.96)	
lninnov				0.0531** (2.34)
lninnov*lnproperty				0.0257 (1.13)
lnStr	0.0617 (0.68)	0.0968 (1.08)	0.0610 (0.65)	0.0277 (0.32)
<i>lndens</i>	0.2046 (0.82)	0.5207* (1.99)	0.2493 (0.97)	0.1455 (0.65)
<i>lnurb</i>	-0.1434 (-0.73)	-0.1245 (-0.59)	-0.1522 (-0.81)	-0.1077 (-0.59)
<i>lnedu</i>	0.0770 (1.60)	0.0653 (1.32)	0.0672 (1.35)	0.0483 (1.01)
<i>lninv</i>	0.0184** (2.14)	0.0125 (1.53)	0.0170* (1.96)	0.0165* (1.76)
<i>lnpgdp</i>	0.2572 (1.48)	0.3701** (2.21)	0.2660 (1.48)	0.2166 (1.23)
Constant term	-0.4981 (-0.28)	-1.3842 (-0.73)	-0.7459 (-0.39)	-0.4508 (-0.27)
Year fixed effect	Control	Control	Control	Control
Regional fixed effect	Control	Control	Control	Control
R <sup>2</sup>	0.92	0.93	0.92	0.93

Note: t value in parentheses; ,,\*\*\*", ,,\*\*" and ,,\*" indicate significant at the level of 1%, 5% and 10% respectively.

for knowledge creation, promote the technological innovation of low-carbon enterprises, continuously develop and introduce new energy products, promote the optimization of energy consumption structure, and further promote the improvement of regional green total factor productivity. The above methods are used to test the moderating effect of intellectual property protection intensity on technological innovation. The interaction coefficients are not significant, indicating that the intensity of intellectual property protection has no moderating effect on the masking effect of technological innovation. This indicates that the current intensity of intellectual property protection in China has

no obvious effect on promoting enterprise technological innovation caused by environmental regulation, which to some extent indicates that the increase of enterprise green technological innovation may be mainly driven by other factors.

## Conclusions and Recommendations

### The Research Conclusion

This paper uses Super-EBM model to measure and analyze green total factor productivity of 30 provinces

in China. The specific impact of carbon emission trading policy on China's regional green total factor productivity is tested and evaluated by using differential difference model, mediating effect model and moderating effect model, and the following conclusions are drawn:

(1) Carbon emission trading policy has promoted green total factor productivity in China. The dynamic effect analysis shows that the influence of carbon emission trading policy on the pilot area continues to decrease and disappear in the fifth period, indicating that the policy effect is offset by the influence of other factors.

(2) The analysis of mediating effect shows that total energy consumption and energy consumption structure have partial mediating effect, while technological innovation has masking effect. The results indicate that carbon emission trading policy can improve regional green total factor productivity partly by reducing total energy consumption and improving energy consumption structure. However, the implementation of carbon emission trading policy increases the emission cost of enterprises, not only does not form the motivation of technological innovation, but also forms the crowding out effect of technological innovation by inhibiting foreign capital and reducing the scale of enterprises.

(3) The moderating effect analysis shows that regional financial development level and intellectual property protection intensity influence the relationship between carbon emission trading policy and regional total factor productivity through adjusting the mediating variable. It is found that regional financial development level mainly regulates the relationship between energy consumption and technological innovation with regional green total factor productivity, while intellectual property protection intensity mainly regulates the relationship between energy consumption structure and regional green total factor productivity. This indicates that the level of financial development can form the amplification effect of regional green total factor productivity growth by saving energy consumption and promoting technological innovation. The intensity of intellectual property protection is the amplification effect of regional green total factor productivity growth through technological progress and improvement of energy consumption structure.

### Policy Suggestions

From the practice of developed countries, total factor productivity is the main driving force of national economic growth, and should also be the direction of China's future economic development. Local governments also need to rely more on the improvement of total factor productivity to promote economic growth. Based on the above research conclusions, the following policy recommendations are made in this paper:

(1) Improve the legislation and system related to carbon emission rights. We should accelerate the

improvement of the Content of the Regulations on the Management of Carbon Emission Trading and complete relevant legislation, so that the national carbon market can have laws to follow, promote the formation of a coordination mechanism between various departments, and ensure the long-term stability of the policies of the national carbon market. Although the current institutional framework of the national carbon market has been basically established, relevant rules still need to be issued to further improve the quota regulation mechanism, verification, credit supervision, joint punishment and other work, to supplement and improve the carbon market system. In order to further enhance the activity of carbon market, we should mainly start from the total quota setting, quota distribution system, trading system and trading subjects. We should promote a more even distribution of trading activities through stricter total volume control, appropriately increasing the proportion of paid distribution such as auction, covering more types of trading subjects, exploring innovation of trading varieties and reform of trading system, and realizing diversification of trading forms.

(2) Encourage enterprises to make green innovations and improve their ability to transform technological innovation achievements. Enterprises will be encouraged to engage in technological innovation in energy conservation and emission reduction through subsidies and tax cuts. Support enterprises and universities to carry out cooperative development, commissioned development or technology transfer of carbon emission reduction technologies, encourage enterprises and research institutes to build industry-university-research cooperation demonstration bases and R&D centers, and encourage them to jointly undertake major national double-carbon related projects. Promote the transformation of scientific and technological achievements of scientific research institutes and the industrialization of personal service inventions, so as to improve energy utilization efficiency and energy consumption structure.

(3) Enrich carbon financial products and enhance the participation of financial institutions. In view of the low financialization of China's carbon market, relevant financial institutions and carbon asset management companies are encouraged to participate in market transactions and innovate product tools. Self-regulatory associations, intermediaries and markets should be cultivated, and intermediaries in financing, investment, security and information consulting services should be encouraged to develop. We will encourage the deep integration of digital technology and carbon finance, and make use of advanced technologies such as big data, block-chain and intelligent investment consulting to provide more support in customer screening, investment decision-making, transaction pricing, investment/post-loan management, information disclosure and investor education. Thus, financial development will promote the support of green technology innovation, energy saving and consumption reduction, and optimization of energy

structure, so as to combine financial development with real economy.

(4) Strengthen the protection of intellectual property, especially to promote the formation of its driving force for technological innovation. Due to different technological complexity, technological gap, demand scale and market structure, the incentive effect of intellectual property protection on technological innovation is heterogeneous, and it is likely to inhibit technological innovation. Therefore, the intellectual property protection needs of different industries should be considered reasonably, and the strength of intellectual property protection should be adjusted in the case of market scale changes. Attention should be paid to the hindrance of intellectual property protection on technology application and technology diffusion, and the positive effect of intellectual property protection on improving regional green total factor productivity should be strengthened, so as to promote the transformation of social productivity with the effect of environmental regulation.

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### Conflict of Interest

The authors declare no conflict of interest.

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