Research on the impact of carbon emission trading on GTFP

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Abstract. Faced with the serious environmental pollution caused by greenhouse gas emissions, the Chinese government has put forward the target of controlling greenhouse gas emissions in the 12th Five-Year Plan and adopted a series of measures. Among them, the pilot policy of carbon emission trading is an important market-oriented instrument, which aims to control carbon dioxide emissions through the market mechanism. This paper studies the impact of this policy on GTFP, using the DID model to analyze the data of 30 provinces from 2004 to 2020. The study finds that the pilot carbon emission trading policy has significantly promoted the improvement of GTFP in the pilot areas. Moreover, the impact of policies on GTFP can be realized through two mechanisms: technological innovation and industrial structure upgrading. The impact of this policy is particularly significant in the central and western regions. These conclusions are of great significance for promoting green and low-carbon transformation, reducing carbon emissions and improving relevant carbon trading policies.

Keywords: GTFP;environmental regulation; difference-in-differences model.

1. Introduction

Since the reform and opening up, chinese economy has developed rapidly. However, with the rapid economic growth, the extensive production mode characterized by high input, high consumption and high emissions has caused serious environmental pollution problems. According to the World Bank's 2022 data statistics report, the total global energy-related greenhouse gas emissions increased by 1 percent to 41.3 billion tons of carbon dioxide emissions, becoming the highest level in history. According to the China’s Twelfth FiveYear Plan, China needs to control greenhouse gas emissions, and use a variety of means, such as adjusting the industrial structure and energy structure, saving energy and improving energy efficiency, and increasing forest carbon sinks, to significantly reduce energy consumption intensity and carbon dioxide emission intensity, and effectively control greenhouse gas emissions. China should properly control total energy consumption, strictly manage energy use, speed up the formulation of energy development plans, and clarify the target for total energy consumption control and the mechanism for its implementation.

In the early stage, under the new trend of market-oriented reform, China gradually explored the emission trading system, carbon emission rights and other trading forms. In order to further promote the development of carbon emission reduction field, promote the development of greenhouse gas resource emission reduction trading, and ensure the normal operation of carbon emission trading market, In October 2011, the National Development and Reform Commission of China issued the Notice on Carrying out the Pilot Work of Carbon Emission Trading, which established seven domestic pilot projects of carbon emission trading, including Beijing, Shanghai, Tianjin, Fujian, Hubei, Chongqing and Guangdong. The introduction of the policy signals China's determination and action in tackling climate change and promoting green development. From 2013 to 2014, the carbon emission markets of various provinces were listed one after another, which started the trading of carbon emission rights in China. After more than ten years of development, it has made positive progress in promoting the double reduction of total and intensity of carbon emissions and accelerating the low-carbon development of society, and has accumulated rich experience for the establishment of a national carbon emission trading market (Chen, 2022).

Total factor productivity (TFP) is an important indicator to reflect the high-quality development of regional economy. Since the 18th National Congress of the Communist Party of China (CPC), in order to avoid environmental problems caused by relying on investment and factor-driven economic growth, the Chinese government has proposed to change the mode of economic development.At present, environmental regulation is a rigid constraint, and energy consumption and environmental pollution are included in the production pain total factor productivity model to form green total factor productivity. Under the condition that the current environmental regulation has become a rigid constraint, energy consumption and environmental pollution are integrated into the traditional TFP model to form GTFP. GTFP emphasizes the green development concept of the coordinated development of economy, resources and environment. The improvement of GTFP means a win-win situation of economic and environmental benefits, so it is necessary to judge whether a region can develop sustainably-in the long run through this revision (Wang, 2010).

The content of this article is the impact of carbon emissions trading policies on green total factor productivity. Using a sample of 30 provinces from 2004 to 2020, a difference-in-difference (DID) model is constructed based on the regions and times of policy implementation in China. In the context of comprehensive green and low-carbon transformation, it is of great significance to deeply study the impact and mechanism of carbon emission trading pilot policy on GTFP, which is conducive to promoting green and low-carbon transformation, reducing carbon emissions, and further improving the relevant carbon trading system. Compared with the existing literature, the marginal contribution of this paper is mainly reflected in the following two aspects. First, in terms of policy, when studying the relationship between environmental regulation and GTFP, this paper takes the 2011 carbon trading pilot policy as the entry point to enrich the research on the effect of the policy. Secondly, at the mechanism level, this paper discusses technological innovation and industrial structure upgrading, and measures the upgrading of industrial structure into two perspectives: the optimization and rationalization of industrial structure, which makes a beneficial supplement to the existing literature.

2. literature review

As a kind of environmental regulation, carbon emission trading pilot policy aims to limit and regulate the carbon emissions of enterprises through market-based means, so as to promote the development of low-carbon economy and the improvement of environmental awareness. At present, the effect of environmental regulation policies such as carbon emission trading pilot policy has been widely concerned by scholars.

The first is to discuss the impact of policies on environmental governance. Some scholars believe that carbon emission trading policy can significantly reduce carbon intensity (Zhang et al., 2021), and the long-term effect of the policy is more significant than the short-term effect (Fan et al., 2017). Dong and Wang (2021) believed that the carbon emission reduction effect not only increases year by year, but also can form a neighboring demonstration effect to promote carbon emission reduction in adjacent areas. The second is to discuss the impact of policy on economic growth. Some scholars believe that relevant environmental regulation policies not only improve environmental conditions, but also promote urban economic growth, and the effect is positively correlated with time (Shi et al., 2017). The economic effect of the policy implementation is improved by increasing the proportion of scientific and technological personnel and optimizing the industrial structure (Zhang, 2017). In carbon emission trading, different allocation methods of carbon quota have different economic effects on the economic growth rate (Liu et al., 2017) in the long and short term (Tang et al., 2016). In addition, some scholars believe that the relationship between carbon emission trading and economic growth is not a simple linear relationship, but may also be nonlinear (Jia, 2017), or an inverted U-shaped relationship (Fan et al., 2015).

With the deepening of current research on green development, only taking energy and environment as exogenous variables of economic growth does not meet the requirements of a country or a region for green development (Yang, 2019). Some scholars have found that the total factor productivity

model that considers resource and environmental factors will underestimate the impact of environmental regulation policies on green economic development (Shen et al., 2017). Therefore, scholars used GTFP as a proxy indicator for the coordinated development degree of economy, environment and energy, and discussed it at the enterprise and regional levels:

(1) At the enterprise level

Xu et al. (2023) argued that the carbon trading pilot program promotes GTFP by forcing enterprises to make technological progress. At the same time, some scholars believe that carbon emission trading can play a positive role in regulating GTFP by screening the quality of foreign direct investment (Xiao and Zhang, 2023), promoting industrial upgrading (She et al., 2020) and technological progress (Li, 2023).

Huang et al. (2018) indicated that in the short term, the emission reduction policy has a significant impact on GTFP. However, in the long run, these policies may induce enterprises to accelerate the production of more polluting economic output in order to compensate for the cost of pollution reduction, which cannot continuously promote the growth of GTFP. However, Li Pengsheng and Chen Yanying (2019) came to the opposite conclusion, believing that environmental regulation would reduce enterprises' GTFP in the short term, while it would promote it in the long term.

(2) Regional level

Some scholars believe that regions with higher emission reduction technology have higher GTFP growth rate (Chen and Zhang, 2016), and low-carbon city pilot policies can effectively improve urban GTFP (Wang et al., 2022; Shang, 2024), especially in Hubei province, Beijing and Shanghai (Yin Yinggang and Chang Xiangdong, 2022). Feng et al. (2023) believed that the implementation of carbon emission policy can promote carbon emission reduction, but the effect of emission reduction varies with different geographical locations.

Some scholars also came to the opposite conclusion. Li et al. (2014) believed that the pilot areas of China's carbon emission trading market were scattered and the market was not mature enough. Lu (2020) used the difference-in-differences model and found through empirical analysis that GTFP has been on the rise in recent years, while the impact of carbon emission trading on GTFP is significantly negative.

3. Empirical Strategy

3.1 Model Construction

This paper uses the DID method to analyze the impact of government policy implementation. Using the sample of 30 provinces from 2004 to 2020, this paper constructs a DID model according to the region and time of China's implementation of the policy, and analyzes the impact of the Circular on the Pilot Work of Carbon Emission Trading on GTFP. In the selection of national low-carbon pilot in 2011, it is agreed that seven cities including Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong and Shenzhen will carry out carbon emission trading pilot. Since Shenzhen is under the jurisdiction of Guangdong province, the data of Shenzhen will be combined in Guangdong province.

Firstly, the DID model is constructed to test the impact of the establishment of carbon emission trading pilot on regional GTFP:

$$\mathrm{TPF}_{\mathrm{it}} = \beta_0 + +\beta_1 \mathrm{DID} + \beta_2 \mathrm{Control} + \epsilon_{\mathrm{it}} \quad (1)$$

Secondly, when testing the mechanism of carbon emission trading pilot policy affecting GTFP development, the stepwise regression method is used to set the mechanism variable as explained variable and explanatory variable respectively to construct the following model:

$$\mathrm{Mediation}_{\mathrm{it}} = \alpha_0 + +\alpha_1 \mathrm{did} + \alpha_2 \mathrm{Control} + \epsilon_{\mathrm{it}} \quad (2)$$

$$\mathrm{TFP}_{\mathrm{it}} = \gamma_0 + \gamma_1 \mathrm{Mediation}_{\mathrm{it}} + \epsilon_{\mathrm{it}} \quad (3)$$

In the formula, subscript i represents province and t represents year; GTFP represents the urban green total factor development index, and Mediation represents the mechanism variable. Treat*Time is the core explanatory variable. When Treat*Time=0, it means that city i has carried out carbon emission trading pilot program in year t; otherwise, Treat*Time=0 means that city i has not carried

out carbon emission trading pilot program in year t. Control is a group of control variables, and is the random error term.

3.2 Variable selection and data description

3.2.1 Explained variables

Green total factor productivity (GTFP) : referring to the method of Liu and Xin (2018), the annual GDP of each province in 2005 is taken as the expected output; With reference to Qian and Liu (2014), the "three industrial wastes" are taken as the undesirable output. The "three industrial wastes" include fixed waste, industrial waste water and industrial waste gas; Referring to the practice of Li (2020), capital, labor and energy are used as input factors, capital stock calculated by the perpetual inventory method is used as capital input, the number of employees at the end of the year is used as labor input, and the total regional energy consumption is used as energy input. Since the Angle, radial and other conditions need to be selected when using DEA method, and different conditions will lead to great differences in calculation results, this paper uses the non-angle, non-radial SBM model to calculate, which can reduce the deviation caused by the selection of input and output indicators of different angles and radial (Kaour Tone, 1997).

3.2.2 Core explanatory variables

Treat*Time, the carbon emission trading policy, is selected as the core explanatory variable. Due to the lag in the implementation of the policy, other carbon emission trading pilot projects, such as Fujian Province, only started in 2016. This paper considers the six provinces established in the first batch of the policy as the experimental group, and the other provinces as the control group. When the provinces are Beijing, Tianjin, Chongqing, Shanghai, Hubei and Guangdong and the Time is after 2011, Treat*Time is 1, and the rest is 0.

3.2.3 Mechanism variables

1. Technological innovation referring to the practice of Ma and Xu (2024), this paper uses the proportion of R&D internal expenditure in GDP to measure.

2. The industrial structure upgrading index is constructed from the perspectives of rationalization and advancement, following the approach of Gan et al. (2011).

3. The rationalization of industrial structure refers to the ability of industries in structural transformation and effective utilization of resources, which can also be regarded as an important index to measure the degree of coordination between factor input and output structure. This paper refers to the research method of Yu Binbin (2015) and uses the inverse of Theil index to measure the level of rationalization of industrial structure. The calculation formula is as follows:

$$IR_{it} = \frac{1}{TL_{it}} = \frac{1}{\sum_{j=1}^{3}\left(\frac{Y_{it,j}}{Y_{it}}\right)\ln\left(\frac{Y_{it,j}/Y_{it}}{L_{it,j}/L_{it}}\right)} \tag{3}$$

In the formula, i represents the province, t represents the year, IR represents the rationalization level of industrial structure, and TL represents the Theil index. Y_{it}Stands for regional GDP, stands for the value added of industry j. L_{it} stands for total employment, $L_{it,j}$stands for the number of employees in industry j. The larger the value of IR is, the closer the economic development is to the equilibrium state, and the higher the level of rationalization of industrial structure is.

4. The optimization of industrial structure is an indicator used to measure the development degree of the industrial structure along the primary, secondary and tertiary industries. This concept is usually based on Clark's theorem and from the perspective of "servitization of economic structure", the ratio of the output value of the tertiary industry and the secondary industry is used to reflect the level of industrial structure optimization. However, this measurement method often ignores the optimization of the primary industry. Therefore, this paper draws on the practice of Xu and Jiang (2015) and proposes a more comprehensive measurement method for the optimization of the industrial structure:

$$IS_{it} = \sum_{j=1}^{3} \frac{Y_{it,j}}{Y_{it}} * j \quad (4)$$

In the formula, represents the level of industrial structure optimization, and the larger the value of IS is, the higher the level of industrial structure optimization is ISy_{it}.And have the same meaning as above$Y_{it,j}$.

3.2.4 Control variables

Since GTFP is affected by foreign direct investment and other factors, some control variables need to be added to reduce the error of regression results caused by omitted variables. This paper selects the following methods as the control variables, referring to the research method of Liang and Li (2023) . The possible impacts are as follows:

Fiscal concentration: Government fiscal expenditure may affect the degree of pilot construction, which in turn affects the desired output and thus GTFP.

Foreign direct investment: Foreign direct investment may affect GTFP through technology spillover, notarization of trial production and other channels.

Financial development level: Cities may affect undesirable outputs, such as carbon dioxide and sulfur dioxide emissions, through the scale of economic activities and technological innovation. In general, economically developed regions pay more attention to environmental pollution control under the condition of economic development, while economically underdeveloped regions pay more attention to economic performance growth and invest less in pollution control.

Human capital level: Cities with higher human capital have a higher ability to apply knowledge and innovation, which can better improve the total factor productivity of enterprises. At the same time, it can also drive the upgrading of the industrial structure of enterprises, and is more likely to improve GTEP.

The level of population aging: the level of population aging may affect the supply and demand of labor force, and then affect the production efficiency and resource allocation.

Opening-up degree: it may promote the technological innovation and efficiency improvement of host countries through introducing foreign direct investment and technology spillover, thus accelerating the upgrading of industrial structure and affecting GTFP.

Table 3.1 Selection of relevant variables

Index name	Indicator symbol	Indicator selection
Green total factor productivity	GTFP	Calculated by the SDM method
Dummy variable for policy implementation	Treat	If the region is a pilot city of carbon emission trading The value is 1, otherwise it is 0
Time dummy variable	Time	Before 2011 vs. Time Assign a value of 1 and 0 otherwise
Technological innovation	INN	R&D to gross product ratio
Rationalization of industrial structure	IR	The output value ratio of the tertiary industry to the secondary industry
Optimization of the Industrial structure	IS	Theil index
Foreign direct investment	FDI	Total foreign investment /GDP in each province
Fiscal concentration	FIS	Government (public) finance payments/gross regional product
Population aging level	AGE	Number of people aged over 65 / urban population
Human capital level	HUM	Number of students in ordinary schools Proportion of the total population of the region at the end of the year

Opening-up degree	TR	The ratio of total imports and exports to gross production
Financial development level	FIN	Ratio of financial sector value added to gross product

3.2.5 Data sources

Considering the availability of data, this paper selects the panel data of 30 provinces in China from 2004 to 2020 (except Tibet, Hong Kong, Macao and Taiwan). The data come from wind database, China Statistical Yearbook, China Environmental Statistical Yearbook, China Energy Statistical Yearbook and statistical yearbooks of various provinces in China.

3.3 Empirical Analysis

3.3.1 Descriptive statistics

Table 3.2 Descriptive statistics of main variables

Variables	Minimum	Maximum	Mean	Variance
GTFP	0.608	0.608	1.531	1.531
Treat*Time	0	1	0.118	0.118
IS	1.227	1.227	9.276	9.276
IR	2.074	2.074	2.352	2.352
INN	0	0	0.0136	0.0136
AGE	0.0543	0.0543	0.0973	0.0973
FDI	3.11 e-05	3.11 e-05	0.00447	0.00447
FIN	0.000484	0.000484	0.0578	0.0578
TR	0.00146	0.00146	0.321	0.321
HUM	0.00461	0.00461	0.0179	0.0179
FIS	0.0885	0.0885	0.233	0.233

3.3.2 Benchmark regression

Table 3.3 Impact of carbon emission trading pilot policies on GTFP in various provinces

Variables	GTFP	
	(1)	(2)
Treat*Time	0.724 * * *	0.266 * * *
	(7.17)	(3.14)
AGE		6.409 * * *
		(4.79)
FDI		5.285
		(1.03)
FIN		3.914 * * *
		(3.15)
TR		0.375 * * *
		(3.85)
HUM		21.330 * * *
		(4.67)
FIS		1.070 * * *
		(3.76)
_cons	1.446 * * *	0.064
	(41.70)	(0.44)
Observations	510	459

R-squared	092.	361.

3.3.3 Robustness test

3.3.3.1 Parallel trend test

The prerequisite for using the DID model is to meet the parallel trend test, that is, the experimental group and the control group have the same trend before the implementation of the carbon emission trading pilot policy. Considering the implementation of the carbon emission trading pilot policy in November 2011, this paper sets 2012 as the base year, and the results are shown in the figure. The figure shows that in the nine years before the implementation of the policy, the coefficients are not significant, indicating that there is no difference in GTFP between pilot cities and non-pilot cities before the implementation of the carbon emission trading pilot policy, which meets the parallel trend test; After the implementation of the carbon emission trading pilot policy, it began to play an obvious role, showing a gradual growth trend, indicating that the impact of the pilot carbon emission trading policy on GTFP has a positive impact.

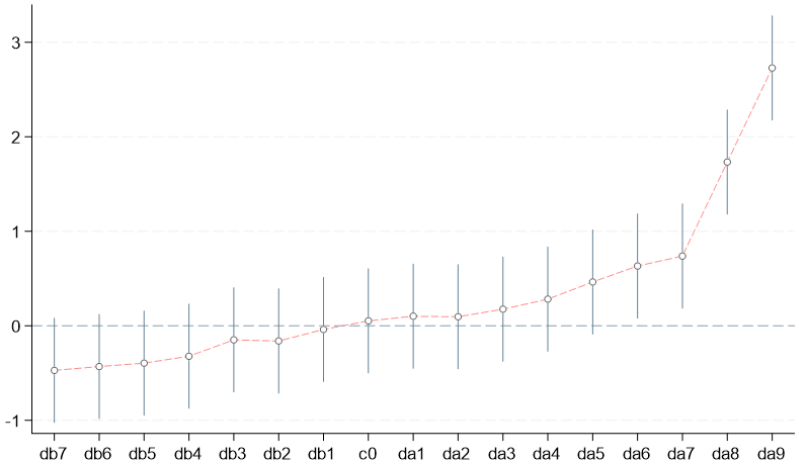

Figure 3.1 Parallel trend test

3.3.3.2 Placebo test

In addition to the control factors mentioned above, there may also be some unobservable factors that affect the estimation results. Therefore, this paper carries out the placebo test of the policy time randomization. If the policy still has a significant promotion effect on the pilot provinces after the time randomization, it indicates that the experimental conclusions need to be further verified.

Otherwise, it indicates that the policy can eliminate the influence of omitted variables and make the results more robust.

This paper sets the policy time in 2010 and conducts the experiment again, and the results are shown in the figure. The key coefficients are no longer significant, which proves that after the policy time is randomized, the policy has no significant impact on urban GTFP, indicating that the promotion effect of carbon emission trading policy on urban GTFP has nothing to do with other non-observed factors that do not change over time.

Table 3.4 Placebo test

Variables	GTFP	
	(1)	(2)
Treat*Time	0.324***	0.204***
	(4.02)	(3.12)
AGE		6.474***
		(4.82)
FDI		6.034
		(1.18)
FIN		4.487***

		(3.80)
TR		-0.394***
		(-4.05)
HUM		21.586***
		(4.74)
FIS		0.988***
		(3.52)
_cons	1.458***	0.038
	(38.20)	(0.26)
Observations	510	459
R-squared	0.002	0.347

3.3.3.3 Excluding the interference of other policies

During the policy implementation period, there are other policies that may interfere with GTFP. For example, in 2014, energy trading pilot projects were launched in Zhejiang, Fujian, Henan and Sichuan provinces in 2016. Due to the overlap between energy trading pilot projects and carbon trading pilot projects, the above four provinces were excluded from the sample to further test the benchmark regression and the regression with control variables.

The experimental results, as shown in the figure, show that the key coefficients are still significant at the level of 1%, which indicates that the carbon trading emission policy has a significant promotion effect on GTFP.

Table 3.5 Exclusion of other interference tests

Variables	GTFP	
	(1)	(2)
Treat*Time	0.695***	0.272***
	(6.461)	(2.956)
AGE		6.99***
		(4.467)
FDI		4.976
		(0.914)
FIN		3.845***
		(2.798)
TR		-0.376***
		(-3.593)
HUM		19.08***
		(3.764)
FIS		1.048***
		(3.219)
_cons	1.475***	0.064
	(37.197)	(0.386)
Observations	442	399
R-squared	0.087	0.342

3.4 Mechanism analysis

The regression results of mechanism analysis are shown in Table 1-6, where columns (1), (2) and (3) respectively represent the regression model results with the three mechanism variables of rationalization of industrial organization, optimization of industrial structure and scientific and technological innovation as explained variables.

Table 3.6 Mechanism analysis

Variables	(1)	(2)	(3)

	Rationalization of industrial structure	Upgrade the industrial structure	Scientific and technological innovation
Treat*Time	3.313***	0.035***	0.004***
	(2.871)	(3.218)	(2.85)
AGE	13.156	0.283	0.019
	(0.72)	(1.644)	(0.928)
FDI	192.788***	-2.366***	-0.09
	(2.759)	(-3.589)	(-1.129)
FIN	143.495***	2.319***	0.144***
	(8.478)	(14.518)	(7.418)
TR	6.806***	0.094***	0.003*
	(5.121)	(7.463)	(1.86)
HUM	-15.155	3.606***	0.504***
	(-.243)	(6.135)	(7.047)
FIS	-10.673***	0.083**	-0.022***
	(-2.748)	(2.272)	(-4.988)
_cons	-1.321	2.083***	-0.002
	(-0.676)	(112.876)	(-0.754)
Observations	459	459	459
R-squared	0.592	0.787	0.578

In columns (1), (2) and (3), the coefficients of the core explanatory variable Treat*Time are all significant, indicating that the rationalization of industrial organization, optimization of industrial structure and scientific and technological innovation are the mechanism variables between carbon emission trading policy and GTEP level.

3.4.1 Rationalization of industrial structure

Columns (1) and (2) in Table 4 show the test results of the rationalization of the industrial structure. In order to test whether the carbon emission trading pilot program can improve GTFP by promoting the rationalization of industrial structure, the inverse of Theil index is substituted into the above model as an indicator to measure technological innovation. It can be seen from the table that the regression coefficient of the optimization of the industrial structure on GTFP is significantly 0.007, indicating that the industrial development in the pilot areas is upgrading to high value-added and other productive service industries, which helps to promote the total factor growth of the economy under environmental regulation and improve the GTFP of the provinces. The coefficient value of the different-in-differences term in the table has decreased, indicating that the rationalization of industrial structure plays a part of the mechanism effect in the promotion effect of GTFP after the policy.

3.4.2 Optimization of industrial structure

In order to test whether the carbon emission trading pilot program can improve GTFP through the optimization of industrial structure, this paper substitutes the ratio of the tertiary industry to the secondary industry as an index to measure technological innovation into the above model. Columns (3) and (4) in Table 4 show the test results of the optimization of the industrial structure. It can be seen from the regression results that the regression coefficient of Treat*Time on technological innovation is significantly 0.172, indicating that the establishment of China's carbon emission trading pilot program can affect provincial GTFP through the optimization of industrial structure, and the regression coefficient of the optimization of industrial structure on GTFP is significantly 2.675. It can be concluded that the improvement of the optimization of industrial structure in the pilot areas can promote the GTFP of the provinces. The key coefficient values in the table have decreased, indicating that the optimization of industrial structure plays a part of the mechanism effect in the promotion effect of GTFP after the policy.

3.4.3 Technological innovation

In order to test whether the carbon emission trading pilot program promotes GTFP by promoting technological innovation, this paper substitutes the ratio of R&D to GDP as an indicator to measure technological innovation into the above model. Columns (1) and (2) in Table 4 show the test results of technological innovation. It can be seen from the regression results that the regression coefficient of Treat*Time on technological innovation is significantly 0.004, indicating that the establishment of China's carbon emission trading pilot program can affect provincial GTFP through technological innovation, and the regression coefficient of technological innovation on GTFP is significantly 5.981. It can be concluded that technological innovation in pilot areas can promote provincial GTFP. The values of key coefficients in the table have decreased, indicating that technological innovation plays a part of the mechanism effect in the promotion effect of GTFP after the policy. The above conclusions show that the carbon emission trading pilot program can promote the improvement of GTFP with the guidance of improving technological innovation.

3.5 Heterogeneity test

Referring to the division method of China's three economic zones, the research samples are divided into eastern, central and western regions for heterogeneity research.

Table 3.7 Heterogeneity test

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Eastern		Central		Western	
	GTFP	GTFP	GTFP	GTFP	GTFP	GTFP
Treat*Time	0.763***	0.363***	0.327	0.156	0.871***	0.736***
	(0.162)	(0.129)	(0.216)	(0.191)	(0.161)	(0.174)
AGE		10.42***		5.739*		-1.043
		(2.047)		(3.351)		(2.055)
FDI		0.602		61.69		88.40***
		(5.698)		(43.46)		(33.60)
FIN		5.289***		-4.302		0.810
		(1.709)		(5.310)		(2.217)
TR		-0.564***		-5.003***		-1.317**
		(0.124)		(0.956)		(0.574)
HUM		12.22		23.30		43.22***
		(7.498)		(16.52)		(6.300)
FIS		-0.471		4.567***		1.352***
		(0.721)		(1.050)		(0.385)
_cons	1.479***	0.195	1.430***	0.0581	1.423***	0.403*
	(0.0716)	(0.229)	(0.0552)	(0.332)	(0.0413)	(0.236)
Observations	204	181	153	135	153	143
R-squared	0.099	0.464	0.015	0.424	0.162	0.528

It can be seen from the table that the coefficient of Treat*Time is significant in the eastern and western regions, and the value in the western region is greater than that in the eastern region, indicating that the impact of carbon emission trading policy on GTFP in the western region is greater than that in the central and eastern regions. The possible reason is that the industrial structure dominated by heavy industry in the central region makes its carbon emissions larger, and it is more difficult to adjust the industrial structure and optimize the allocation of resources. The adjustment of industrial structure is slow, which leads to the limited improvement of GTFP. At the same time, the

research and development and application of environmental protection technology and new energy technology in the central region are relatively lagging behind, and the lack of core technology makes it difficult to form obvious competitive advantages, which restricts the improvement of GTFP. However, the eastern region of China has developed economy, the number and scale of enterprises are relatively large, and the carbon emissions are high. The industrial structure in the western region is relatively single, with a large number of enterprises in the energy and heavy industries. Due to the large number of enterprises with high energy consumption and high emissions, the implementation of the pilot policy of carbon emission trading will help enterprises in the region to reduce carbon emissions, improve the efficiency of resource utilization, promote industrial restructuring, and improve GTFP.

4. Main conclusions and policy recommendations

4.1 Key Conclusions

From the perspective of carbon emission trading pilot policy, based on the panel data of 30 provincial administrative regions in China from 2004 to 2020, this paper uses DID model to explore the impact and mechanism of environmental regulation urban GTFP, as well as the heterogeneity of the impact.

The following conclusions are drawn: (1) The pilot carbon emission trading policy significantly and directly promotes the improvement of GTFP in the pilot areas, which can significantly reduce carbon emissions and promote economic growth, forming a win-win situation. (2) Carbon emission trading policy can indirectly improve urban GTFP through improving technological innovation and upgrading industrial structure. Among them, the effect of the path through the optimization of industrial technology and technological innovation is obviously better than that of the rationalization of industrial technology. By increasing the operating cost of enterprises, carbon trading policy forms a forcing mechanism, which encourages enterprises to eliminate backward technologies and accelerate the research and development of new technologies to improve production efficiency, reduce costs, promote the optimization of industrial structure, and thus improve GTFP. The policy increases the operating costs of enterprises, forms a forced mechanism, promotes the elimination of outdated technologies, accelerates the research and development of new technologies to improve production efficiency, promote industrial structure optimization, and thus enhance green total factor productivity. (3) The pilot carbon emission trading policy has a higher role in promoting GTFP in the central and western regions of China.

4.2 Policy Suggestions

According to the research conclusions, this paper obtains the following relevant policy implications:

(1) Promote the upgrading of China's industrial structure. The government should explicitly support the development of high-tech industries and strategic emerging industries, and formulate corresponding industrial policies and preferential measures, such as tax incentives and financing support, to encourage enterprises to increase R&D investment and increase industrial added value, so as to promote the upgrading of China's industrial structure. Simultaneously, the government should implement differentiated environmental regulation according to the characteristics of different regions, find the common points and differences between the eastern and central and western regions, rationally use differentiated policy regulation tools, and establish a flexible incentive environmental regulation policy that can be dynamically adjusted. (2) Encourage enterprises to carry out low-carbon technology innovation. The government can improve the efficiency of environmental regulation policies by formulating a policy that combines environmental regulation with technological innovation incentives, implementing system and management reform and renewal, improving the innovation compensation system, and diversifying the efficiency of environmental regulation policies. In addition, the government should increase investment in scientific and technological innovation,

establish a diversified investment and financing system for scientific and technological innovation, guide social capital to invest in high-tech industries, and cultivate innovative enterprises with international competitiveness. (3) Increase the coverage of the carbon market. Accelerate the opening of the carbon trading market in the central and western regions, and connect with the national carbon trading market; Simultaneously, high polluting enterprises such as chemical and construction industries will be included in the national carbon trading market in an orderly manner, increasing the constraints of the carbon market.(4) Improve the efficiency of carbon market trading. Enrich the variety of financial assets traded in the carbon market, guide more investors to participate in the carbon trading market, improve product liquidity, increase market efficiency, and expand the scope and effect of national influence on pollution and carbon reduction.

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