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Original Paper

Whether the Establishment of Pilot Free Trade Zones Improves Urban Carbon Emission Efficiency: An Analysis Based on Difference-in-Difference Model

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Abstract

Pilot free trade zones are the key to achieving green and sustainable economic development and promoting high-level protection of the ecological environment. Based on the panel data of 282 cities from 2006 to 2018, this paper uses the non-radial DDF model to measure the urban carbon emission efficiency based on the establishment of pilot free trade zones, and establishes a double differential model to empirically analyze the impact of the establishment of pilot free trade zones on urban carbon emission efficiency and the impact mechanism therein. The results show that the establishment of pilot free trade zones can significantly promote the improvement of urban carbon emission efficiency, and this conclusion is still valid after a series of robustness tests such as PSM-DID and excluding other policy interference. Its mechanism analysis shows that the establishment of pilot free trade zones mainly affects urban carbon emission efficiency by improving urban energy efficiency and technical level, and promoting the optimization and upgrading of urban industrial structure. This paper provides useful policy enlightenment for promoting the green development of pilot free trade zones, achieving economic efficiency improvement and carbon emission reduction.

Keywords

Pilot Free Trade Zone, Carbon emission efficiency, difference-in- difference model

1. Introduction

The pilot free trade zone is a new exploration and new attempt for China to promote comprehensive opening up through institutional reform and innovation, and to promote the advanced experience of reform test fields to the whole country. From 2013 to 2021, the General Office of the State Council of

China issued the overall plan for the construction of each pilot free trade zone in batches, and as of December 2021, China has established a total of 21 pilot free trade zones, involving 67 areas, initially forming a new “wild geese array” of opening up with full coverage in the southeast, northwest, and central regions and coordinated development of various regions. Through a series of institutional innovations, such as the simplification and reform of the approval system, the pilot pilot integration of local and foreign currencies in the zone, and the promotion of the innovative development of cross-border RMB business, the pilot free trade zone has not only driven export growth, but also significantly improved the level of foreign capital introduction and utilization, which can effectively improve the regional financial level in the long run. As one of the important ways to expand foreign trade, the expansion of import and export trade in pilot free trade zones will cause changes in carbon emissions. As one of the important policies to balance economic development and environmental protection, the policy of the pilot free trade zone also attaches great importance to the issue of ecological environmental protection. For example, in Shanghai, Guangdong, Tianjin, Fujian, Liaoning, Shaanxi and other provinces, the regulations of pilot free trade zones propose to strengthen environmental protection in pilot free trade zones, improve the level and efficiency of environmental protection management, and strictly investigate and deal with environmental violations; Encourage enterprises in the zone to take the initiative to connect with international standards, adopt green and advanced production technologies, improve energy efficiency, strengthen end-of-production treatment, and reduce pollution emissions; Encourage pilot free trade zones to explore the construction and implementation of relevant policies and systems for green, low-carbon and sustainable development, promote green certification of export products, and build advanced demonstration zones for green, low-carbon and sustainable development. As one of the main indicators for evaluating the economic value of carbon emissions and the level of green and low-carbon economic development, carbon emission efficiency can effectively achieve energy conservation and emission reduction and promote green and stable economic growth. In order for cities established in pilot free trade zones to enjoy the maximum economic benefits of the establishment of pilot free trade zones and minimize environmental external costs, it is urgent to find a way to improve the carbon emission efficiency of cities in pilot free trade zones. In the face of China’s downward pressure on the economy and the task of carbon emission reduction, what is the impact of the establishment of pilot free trade zones on the carbon emission efficiency of the region? What is the mechanism of action? The answers to these questions can supplement the existing research and further promote the green development of the pilot free trade zone and low-carbon cooperation with foreign countries, which is of certain practical significance.

According to the research question of this paper, the research literature closely related to this paper can be roughly divided into the following two branches. The first literature has carried out a lot of relevant research on the policy effects of China’s pilot free trade zones from different perspectives. Lianghu Wang and Zhao Wang used the panel data of 196 cities in China from 2010 to 2017, and used industrial wastewater discharge, sulfur dioxide discharge, smog discharge and carbon dioxide discharge as urban environmental pollution indicators respectively, and used the PSM-DID model to analyze the free trade pilot zone. The empirical test of the environmental effect of the establishment shows that the establishment of the free trade pilot zone can not reduce the environmental pressure of the city, but aggravates the environmental pollution of the city in the pilot zone. Yufan Jiang and Hongyan Wang took the Shanghai Pilot Free Trade Zone as the research object, and used the synthetic control method (Synthetic Control Method, SCM) to show that the establishment of the Shanghai Pilot Free Trade Zone has a positive role in promoting the local green total factor productivity. The second literature uses a variety of measurement methods to measure carbon emission efficiency. One type of method calculates carbon emission efficiency based on a single factor, without considering the substitution effect of production factors, and uses carbon productivity to represent carbon emission efficiency (Kaya et al., 1997). Another type of method is based on all factors, mainly including two methods: Data Envelopment Analysis (DEA) and Stochastics Frontier Analysis (SFA). Data Envelopment Analysis (DEA) can directly deal with the multi-output situation without considering the specific form of the production frontier,

Based on the above literature, the academic circles have already paid attention to the environmental effects of the pilot free trade zones, but judging from the overall plans for the construction of the pilot free trade zones issued by the State Council, the establishment of the pilot free trade zones mainly promotes the construction of a new system of open economy through institutional innovation, The focus is on promoting trade and investment facilitation and deepening reform and innovation in the financial sector. Therefore, the existing literature pays more attention to the economic effects of free trade pilot zones, and there are relatively few related studies on the environmental effects of free trade pilot zones. In addition, for the analysis of the environmental effects of the free trade pilot zone, the existing literature mainly focuses on its impact on various pollutant emissions and the comprehensive indicators constructed, while the carbon emissions that achieve a “win-win” improvement in economic value and ecological value Efficiency studies are not yet available. Compared with the existing research, the possible marginal contribution of this paper: (1) Discuss the impact of the establishment of the free trade pilot zone on the carbon emission efficiency that takes into account both the improvement of economic value and the improvement of ecological value, and enriches the research on the policy effect of the free trade pilot zone new perspective. (2) Use the non-radial DDF model based on undesired output to measure the efficiency of urban carbon emissions, and use the implementation area of the free trade pilot zone as the basis for urban grouping to distinguish the experimental group and the control group of the double difference method, as far as possible Reduce estimation bias and ensure the reliability of research conclusions.

2. Impact Mechanism

The establishment of the pilot free trade zone not only improves the economic development level of the local area, but also has a positive impact on the level of import, import and export. The improvement of the economic level has made the public pay more attention to the polluting activities of enterprises while paying attention to the economic activities related to enterprises. When an enterprise's polluting activities have an impact on the public, the public can use a series of means such as laws to pressure the company to reduce its pollution emissions. At the same time, due to the public's own awareness of environmental protection, the public will practice the concept of green living to a certain extent and increase the use of clean energy. In addition, when the economic development reaches a certain level, the government's attention to environmental pollution and treatment will be further improved, and enterprises can be guided to increase the use of clean energy, optimize the energy structure, and improve the energy efficiency of enterprises through taxation, financial subsidies and other means. From this, this paper proposes:

Hypothesis 1: The establishment of pilot free trade zones can improve the carbon emission efficiency of cities by optimizing the city's energy structure and improving energy efficiency.

The establishment of the pilot free trade zone can not only introduce high-quality overseas enterprises, but also bring together high-quality enterprises at home and abroad to build a high-quality development leading zone. Through the technology spillover of high-quality enterprises, enterprises in the pilot free trade zone can achieve innovation and upgrading of their own technological level through the "demonstration effect" and "learning effect". In May 2021, eight departments, including the Ministry of Ecology and Environment and the Ministry of Commerce, jointly issued the Guiding Opinions on Strengthening the Protection of the Ecological Environment of the Pilot Free Trade Zones and Promoting High-quality Development (Huanquan [2021] No. 44, hereinafter referred to as the "Guiding Opinions"), which put forward a total of 25 provisions for each pilot free trade zone in terms of optimizing and upgrading the industrial structure, promoting green transformation in key areas, ecological environmental protection, comprehensively deepening reform and aligning with international rules. Ecological environmental protection puts forward target requirements. The issuance of the opinion has raised the green threshold for enterprises in the pilot free trade zone. Higher environmental protection requirements will prompt enterprises to increase the innovative research and development and use of green and clean production technology. The improvement of technical level, on the one hand, can improve the production efficiency of enterprises and increase the economic benefits of enterprises, on the other hand, it can realize the replacement of traditional technologies by greener and cleaner low-carbon technologies, thereby reducing carbon emissions, and ultimately improving carbon emission efficiency. From this, this paper proposes:

Hypothesis 2: The establishment of pilot free trade zones can improve the carbon emission efficiency of cities through technological progress to achieve economic efficiency and reduce carbon emissions.

Since 2017, the overall plan for the construction of the pilot free trade zone has included content such as strengthening ecological environmental protection and implementing the requirements of ecological civilization and green development. Strengthening environmental protection in the pilot free trade zone and promoting the formation of a green development layout have become one of the important contents of the construction of the pilot free trade zone. Through the guidance of relevant policy documents and policy tools such as taxation and subsidies, the government can guide enterprises in the pilot free trade zone to vigorously develop modern green service industries, build advanced green manufacturing, eliminate backward industries with high energy consumption and high pollution, and upgrade the industrial value chain in the zone to promote the formation of a green development layout. The optimization and upgrading of the industrial structure, on the one hand, can extend the product value chain of enterprises, increase the added value of products, and improve the economic benefits of enterprises, on the other hand, it can reduce carbon emissions through the optimization and upgrading of green industrial structure, thereby improving the carbon emission efficiency of cities. Therefore, this paper proposes:

Hypothesis 3: The establishment of pilot free trade zones can use the city's industrial structure as an influence channel, and achieve a "win-win" of increasing economic benefits and reducing carbon emissions by adjusting the city's industrial structure and upgrading the industrial value chain, so as to improve the city's carbon emission efficiency.

3. Method

3.1 Model Settings

In order to explore the impact of the establishment of pilot free trade zones on carbon emission efficiency more reasonably and rigorously, the following double difference model is constructed:

$$TCPI_{it} = \alpha + \beta treat_i \times post_{it} + \rho X_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \qquad (1)$$

In the formula(1), the subscript i represents the city and t represents the year; $TCPI_{it}$ is the explanatory variable in the model, indicating carbon emission efficiency; The $treat_i \times post_{it}$ is the core explanatory variable, indicating the status of the establishment of the pilot free trade zone., $treat_i$ is used to identify whether a pilot free trade zone is established or not, when a city establishes a pilot free trade zone, the value of $treat_i$ is 1, otherwise, the value of $treat_i$ is 0, and the value of $post_{it}$ is used to identify the time when the city establishes a pilot free trade zone, that is, whether city i establishes a pilot free trade zone in phase t, the value of the first year and subsequent years of the city's establishment of the pilot free trade zone is 1, and vice versa is 0; X_{it} represents a set of control variables; μ_i represents the fixed effect of the city, controlling for city-level factors that do not change over time; ϑ_t indicates the year fixed effect; ε_{it} is a random distractor.

2.2 Measurement of Urban Carbon Emission Efficiency

Chung, et al., introduced the directional distance function into the traditional DEA model, but this method increases the expected output and decreases the undesired output at the same rate, which does not match the actual needs of the decision maker and leads to the inefficiency of the estimated production decision unit. Zhou et al. proposed that the non-radial distance function (NDDF) that can consider both expected output expansion and non-desired output reduction is more consistent with the actual needs of policy makers, so this paper uses the non-radial DDF model to measure the carbon emission efficiency of cities. The non-radial directionality distance function is defined as: $\vec{D}(x,y,b,g) = sup\{\omega^T\beta: ((x,y,b) + g \times diag(\beta)) \in T\}$. Among them, x, y, and b represent the input element vector, expected output, and undesired output respectively; g is the direction vector; ω^T is the weight vector of input, expected output, and undesired output; β is the slack variable, Indicates the proportion of changes in input reduction, expected output increase, and undesired output decrease. Considering the availability of data, the article uses capital (K), labor (L) and energy (E) as input indicators, urban GDP (Y) as the expected output indicator, and carbon emissions (C) as the undesired output The indicators and the details of each variable are shown in Table 1. Taking each city studied in this paper as a decision-making unit (DMU), assuming constant returns to scale and n decision-making units, construct the following DEA model:

$$\vec{D}(K,L,E,Y,C;g) = \max(\omega_K,\omega_L,\omega_E,\omega_Y,\omega_C) * (\beta_K,\beta_L,\beta_E,\beta_Y,\beta_C)^T$$

$$s.t.\begin{cases} \sum_{j=1}^{n}\lambda_j K_j + \beta_K g_K \le K_o \\ \sum_{j=1}^{n}\lambda_j L_j + \beta_L g_L \le L_o \\ \sum_{j=1}^{n}\lambda_j E_j + \beta_E g_E \le E_o \\ \sum_{j=1}^{n}\lambda_j Y_j - \beta_Y g_Y \ge Y_o \\ \sum_{j=1}^{n}\lambda_j C_j + \beta_C g_C = C_o \\ \lambda_j \ge 0, j = 1, 2, \cdots, n \\ \beta_K, \beta_L, \beta_E, \beta_Y, \beta_C \ge 0 \end{cases} \tag{2}$$

Among them, λ_j is the weight of each DMU. In this paper, carbon dioxide emission efficiency is defined as the ratio of the target carbon emission intensity to the real carbon emission intensity:

$$TCPI = \frac{(C_o - \beta_C^* \times C_o)/(Y_o + \beta_Y^* \times Y_o)}{C_o / Y_o} = \frac{1-\beta_C^*}{1+\beta_Y^*} \tag{3}$$

The value of TCPI is between 0 and 1, which can reflect the green and low-carbon level of the city to a certain extent. The larger the value, the higher the carbon emission efficiency, and a certain energy loss and carbon emission can generate higher economic output. out, economic activity is greener.

Table 1. The Meaning and Calculation of Urban Carbon Emission Efficiency Indicators

First-level indicators	Second-level indicators	Third-level indicators
Input indicators	labor	Number of private and self-employed persons in units and cities and towns in each city over the years
	capital	The fixed capital stock of each city. Use the perpetual inventory method

		to calculate the capital stock, the formula is: : $K_{i,t} = K_{i,t-1}(1 - \delta_{i,t}) + I_{i,t}$, where $K_{i,t}$ is the physical capital stock of city i in year t; $\delta_{i,t}$ is the capital depreciation rate. This paper adopts 9.6% as the capital depreciation rate; $I_{i,t}$ is the total fixed asset formation of city i in period t
	energy	Urban energy consumption mainly includes natural gas, liquefied petroleum gas and electricity consumption. Since the units are not uniform, the energy consumption is converted into standard coal. Referring to the "General Rules for Calculation of Comprehensive Energy Consumption", the conversion coefficients are as follows:
expected output	GDP	Gross Regional Product of Urban Areas (Current Prices)
unexpected output	carbon emission	Urban carbon emissions include carbon emissions from coal gas, natural gas, liquefied petroleum, electric energy, heat energy and other energy sources.

3.2 Selection of Control Variables

In order to control the impact of other city-related variables on carbon emission efficiency, referring to previous relevant literature, control variables are introduced: economic development level (pgdp), measured by per capita GDP of each city over the years; education level (edu), measured by each city over the years Education expenditure is measured; foreign investment level (fdi) is measured by the amount of foreign direct investment in each city; population density (dep) is measured by the population per unit area of the city.

4. Result

4.1 Benchmark Regression

Table 2 reports the impact of free trade pilot zones on carbon emission efficiency. Among them, column (1) does not add control variables, and columns (2) to (5) add control variables in turn. It can be seen from columns (1) to (5) that after controlling the city and time fixed effects, whether the control variable is added or not, the influence of the free trade pilot zone on carbon emission efficiency is significantly positive, which means that the free trade pilot zone The establishment of the city can significantly improve the carbon emission efficiency of the city. Compared with the results in column (1), after adding all the control variables, the regression coefficients of the model are reduced, which to some extent means that the selection of control variables is reasonable.

Table 2. Benchmark Regression Results

variable	(1)	(2)	(3)	(4)	(5)
treat_post	0.1371***	0.1367***	0.1325***	0.1345***	0.1357***
	(3.9475)	(3.9595)	(4.0646)	(4.0080)	(4.1052)
lndep		0.0199	-0.0031	-0.0065	-0.0082
		(0.2037)	(-0.0375)	(-0.0922)	(-0.1133)
lnedu			0.1938***	0.0820**	0.0884***
			(5.9027)	(2.5328)	(2.6726)
lnpgdp				0.3275***	0.3466***
				(6.9431)	(7.0790)
lnfdi					-0.0193*
					(-1.6769)
Constant	-1.2468***	-1.3603**	-1.6602***	-2.2650***	-2.0718***
	(-124.3204)	(-2.4393)	(-3.4419)	(-5.3934)	(-4.6689)
time fixed effect	control	control	control	control	control
city fixed effect	control	control	control	control	control
Observations	3,666	3,666	3,666	3,666	3,666
R-squared	0.3138	0.3139	0.3361	0.3819	0.3842

Note. ***, **, and * indicate that the significance levels of the parameter estimates are 1%, 5% and 10%, respectively, and the robustness standard errors are in the brackets, and the following tables are the same.

4.2 Robustness Check

4.2.1 Parallel Trend Test

The construction of the double difference model must satisfy the parallel trend test, that is, there is no systematic difference between the cities established in the free trade pilot zone and the non-established cities before the establishment of the free trade pilot zone. This paper constructs the following model:

$$TCPI_{it} = \alpha + \sum_{k=-5}^{k=5} \beta_k D_{t_0+k} + \rho X_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \quad (4)$$

In formula (4), D_{t_0+k} represents a series of dummy variables, t_0 represents the first year of the establishment of the pilot free trade zone, and k represents the kth year before or after the establishment of the pilot free trade zone. The meanings of other variables and parameters are the same as formula (1). Since the sample research period of this article is from 2006 to 2018, and China's first free trade pilot zone was established in 2013, the time before policy implementation is long, so shrinking the dummy time variable will be less than or equal to - The relative time year of 4 is uniformly set to -4. β_k is the main variable of the model, and the parallel trend test requires that the trend is relatively stable when k<0, indicating that there is no significant systematic difference among cities before the establishment of the free trade pilot zone. As shown in Figure 1, the trend of β_k is relatively stable during the period of k<0, and there is no significant difference between established cities and non-established cities before the establishment of the pilot free trade zone; when k>0, the trend of β_k appears obvious The increase indicates that the establishment of the free trade pilot zone has significantly improved the carbon emission efficiency of the city in which it was established.

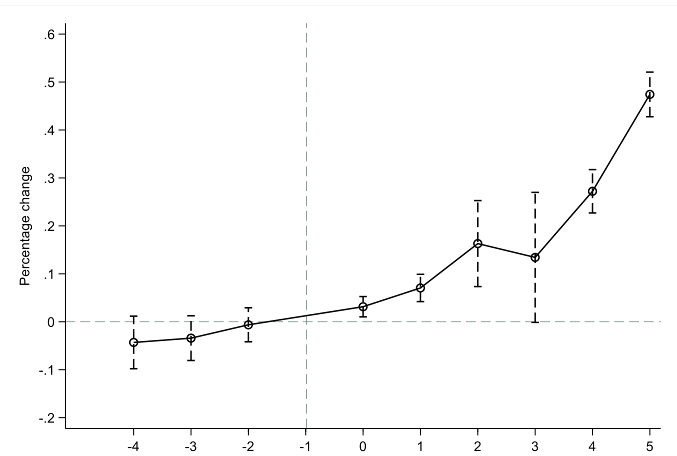

Figure 1. Parallel Trend Test Results

4.2.2 Placebo Test

In order to test whether there are unobservable accidental factors that have an impact on the estimated results, this paper conducts a counterfactual placebo test by randomly generating false free trade pilot zone establishment cities and establishment time. This paper has a total of 282 sample cities, including 22 cities in the experimental group. Compared with the number of cities in the real experimental group and the establishment time nodes, the corresponding number of cities in the experimental group and the establishment time nodes are randomly generated, and the corresponding dummy variable pair model is constructed (1) for regression to get the corresponding estimated value of β. The above operation was repeated 500 times, and the distribution results of the corresponding obtained coefficients were plotted in Figure 2. As shown in Figure 2, the estimated coefficients obtained after 500 false repetitions are smaller than the true regression coefficients (0.135), and are normally distributed around 0. Therefore, it can be denied that the results of benchmark regression are affected by unobservable accidental factors, and the estimated results are robust.

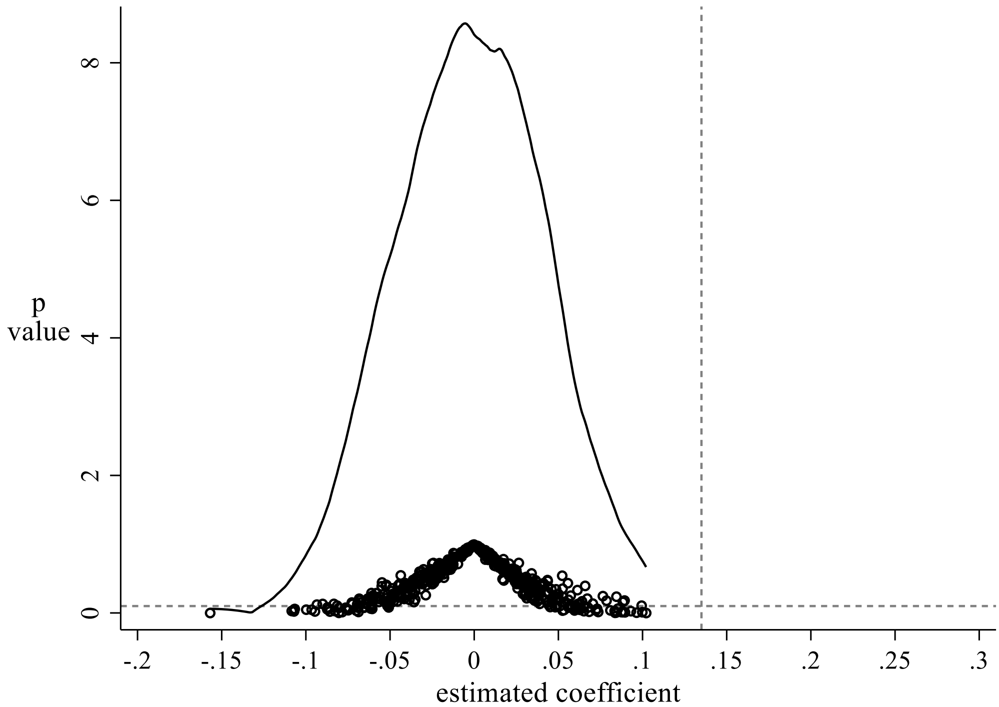

Figure 2. Placebo Test Results

4.3 Other Robustness Checks

4.3.1 PSM-DID Test

In order to avoid the influence of the estimated results due to the differences in urban characteristics between the experimental group and the control group, this article refers to the practices of Heyman et al. (2007) and Bockerman and Ilmakunnas (2009), and adopts the year-by-year matching caliper nearest neighbor 1: The matching method of 2 matches the control group cities according to the urban characteristics of the experimental group cities, finds a group of matching cities with the smallest difference with the experimental group cities, evaluates the net effect of the establishment of the free trade pilot zone, and further tests the benchmark regression results. robustness. Firstly, logit regression is performed on the control variable whether the city is set up as a free trade pilot zone, and the probability of setting up a free trade pilot zone in each city is calculated; secondly, the sample is matched based on the nearest neighbor matching method; finally, the matched samples are carried out according to formula (1). return. Table 4 (1) shows the PSM-DID estimation results based on caliper nearest neighbor matching. The results show that the PSM-DID estimation results are consistent with the benchmark regression results in direction, which further verifies the robustness of the benchmark regression results.

Table 3. Robustness Test Results

variable	PSM-DID	Low Carbon Pilot Policy	New energy demonstration	innovative city
	(1)	(2)	(3)	(4)
treat_post	0.0856**	0.1279***	0.1351***	0.1153***
	(2.3115)	(4.1021)	(4.1089)	(3.5218)
ditan		0.0552***		
		(3.2341)		
xinnengyuan			0.0212	
			(0.0236)	
cxcity				0.1328***
				(5.5709)
lndep	-0.0686	-0.0097	-0.0085	-0.0061
	(-0.6746)	(-0.1413)	(-0.1188)	(-0.0837)
lnedu	0.0568	0.0826**	0.0882***	0.0805**
	(1.4363)	(2.5016)	(2.6626)	(2.4269)
lnpgdp	0.3062***	0.3488***	0.3452***	0.3682***
	(4.8530)	(7.1992)	(7.0454)	(7.5537)
lnfdi	-0.0297**	-0.0184	-0.0187	-0.0191*
	(-2.0299)	(-1.6032)	(-1.6230)	(-1.6739)
Constant	-1.3995**	-2.0672***	-2.0728***	-2.1254***
	(-2.1648)	(-4.8142)	(-4.7081)	(-4.7513)
time fixed effect	control	control control	control	control
city fixed effect	control	control control	control	control
Observations	2,032	3,666	3,666	3,666
R-squared	0.4944	0.3901	0.3847	0.3939

4.3.2 Exclude other Policy Interference

Considering that other policies may have an impact on carbon emission efficiency during the sample study period of this paper, this paper conducts the following robustness tests: First, the interaction term (ditan) of the low-carbon pilot city dummy variable and the pilot time dummy variable is added to the baseline regression In the model, to control the impact of low-carbon city pilot policies on carbon emission efficiency, the results are shown in column (2) of Table 4; second, the interaction term of the new energy demonstration city dummy variable and the approval time dummy variable (xinnengyuan) was added to the baseline regression model to control the impact of new energy demonstration city policies on carbon emission efficiency, and the results are shown in column (3) of Table 4; thirdly, dummy variables of innovative pilot cities and pilot time The interaction term of the variable (cxcity) is added to the baseline regression model to control the impact of innovative pilot city policies on carbon emission efficiency, and the results are shown in column (4) of Table 4. From the above results, it can be seen that although the three policies have had a certain positive effect on promoting carbon emission efficiency, compared with the baseline regression results, the direction and significance of the core explanatory variables have not changed, which once again verifies the Robustness of the benchmark regression results in this paper.

4.4 Impact Mechanism Analysis

The previous benchmark regression results show that the establishment of the pilot free trade zone has significantly improved the carbon emission efficiency of the city where the city is established. So what mechanisms are used by the pilot free trade zone to improve the carbon emission efficiency of the city? In order to answer this question, based on the previous impact mechanism analysis, this paper starts from the three perspectives of energy utilization efficiency, technological progress and industrial structure, and uses this as an intermediary variable, referring to Pan Xiongfeng et al. ( ), Long Haiming et al. The ratio of energy consumption to energy consumption is used as a proxy index for energy utilization efficiency, the number of green invention applications is used as a proxy index for technological progress, and the ratio of the number of employees in the tertiary industry to the number of employees in the secondary industry is used as a proxy index for industrial structure. The following is established: Mediation effect model:

$$M_{it} = \alpha + \beta treat_i \times post_{it} + \rho X_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \quad (5)$$

$$TCPI_{it} = \alpha + \gamma M_{it} + \beta treat_i \times post_{it} + \rho X_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \quad (6)$$

Among them, M_{it} is an intermediary variable, and the meanings of other variables are the same as in formula (1). The regression results based on the mediating effect model are shown in Table 5.

Columns (1), (3) and (5) in Table 5 are the regression results based on the model (5) and using the intermediary variables energy utilization efficiency, technological progress, and industrial structure as the explained variables, and the results show the estimated coefficients of the interaction items Both are positive and significant, which means that the establishment of the free trade pilot zone can significantly improve the energy efficiency of the city, promote technological progress and optimize and upgrade the industrial structure. Columns (2), (4) and (6) of Table 5 take the intermediary variable as the explanatory variable and the regression results based on the model (6). Significantly improve the carbon efficiency of the city. Further based on the principle of intermediary effects, it can be concluded that the establishment of free trade pilot zones can improve the city's carbon emission efficiency by improving the city's energy utilization efficiency, technological level and upgrading the industrial structure. Hypothesis 1, Hypothesis 2 and Hypothesis 3 are confirmed.

Table 4. Test Results of the Mechanism of Action in the Pilot Free Trade Zone

变量	(1)	(2)	(3)	(4)	(5)	(6)
	lvsefaming	TCPI	nengyuan4	TCPI	jiegou	TCPI
treat_post	2,926***	0.0680**	47,978***	0.0468	0.1397*	0.1279***
	(750.5)	(0.0303)	(13,850)	(0.0357)	(1.8010)	(4.0274)
lvsefaming		2.31e-05***				
		(4.00e-06)				
nengyuan				1.85e-06***		
				(3.47e-07)		
jiegou						0.0561***
						(6.2540)
lndep	1,142	-0.0346	6,776	-0.0207	-0.1864	0.0023
	(794.5)	(0.0642)	(18,094)	(0.0670)	(-0.7006)	(0.0295)
lnedu	851.1***	0.0687**	18,316***	0.0545*	-0.0166	0.0894***
	(252.4)	(0.0327)	(5,595)	(0.0312)	(-0.1630)	(2.7479)
lnpgdp	-630.7**	0.361***	10,571	0.327***	-0.7196***	0.3870***
	(251.5)	(0.0478)	(6,461)	(0.0460)	(-6.0305)	(8.0756)
lnfdi	-55.40	-0.0180	-440.4	-0.0185*	-0.0685**	-0.0154
	(45.17)	(0.0115)	(1,655)	(0.0103)	(-2.0172)	(-1.3536)
Constant	-5,932	-1.935***	-86,479	-1.912***	5.4200***	-2.3759***
	(4,238)	(0.407)	(104,071)	(0.413)	(3.4061)	(-5.1064)
time fixed effect	control	control	control	control	control	control
city fixed effect	control	control	control	control	control	control
Observations	3,666	3,666	3,666	3,666	3,666	3,666
R-squared	0.250	0.398	0.345	0.440	0.0949	0.4098

5. Discussion

Based on the city panel data from 2006 to 2018, this paper takes the cities established as pilot free trade zones as the research object, and discusses the impact of the establishment of pilot free trade zones on the efficiency of urban carbon emissions and the mechanism of action. The research results show that: ① The establishment of the free trade pilot zone has significantly promoted the improvement of the city’s carbon emission efficiency, and the conclusion still holds after a series of robustness tests such as PSM-DID and excluding other policy interference. ② The establishment of the free trade pilot zone has significantly improved the city’s energy utilization efficiency, promoted the city’s technological progress and industrial structure upgrade, and used this as a channel to improve the city’s carbon emission efficiency.

Based on the research conclusions of this paper, the following policy implications are proposed:

(1) Continue to promote the green and low-carbon development of cities in the pilot free trade zones, and increase the replication and promotion of advanced innovations in the pilot free trade zones. The implementation of the policy of the pilot free trade zone follows the gradual reform model in my country since the reform and opening up. Using the pilot free trade zone as a test field for reform and innovation is not only conducive to avoiding potential risks brought about by large-scale system innovation, but also to explore advanced green development. experience. According to the research conclusions of this paper, the establishment of pilot free trade zones can significantly improve the carbon emission efficiency of cities. Therefore, to achieve the peak of carbon emissions in 2030 and to fight the tough battle of pollution prevention and control, as a “win-win” that can achieve carbon emission reduction and high-quality economic development. The policy of pilot free trade zones is even more important. In the future, each pilot free trade zone should be promoted to try first, consolidate the green development achievements of the free trade pilot zone, increase the replication and promotion of advanced experience, and give full play to the benchmarking, demonstration and leading role of the reform and innovation of the free trade pilot zone.

(2) Continuously improve the city’s innovation capability, and promote progress and development through innovation. The research results of this paper show that the progress and innovation of technology can significantly improve the carbon emission efficiency of cities, but from the perspective of the number of green invention applications in each city, there is a large gap in the level of green technology in cities, and there is obvious heterogeneity. In order to better build an ecological environment safety zone and better carry out the demonstration work of green technology innovation transfer and transformation in the free trade pilot zone, each free trade pilot zone should pay attention to guiding enterprises in the zone to increase investment in low-carbon technology research and development, and pay attention to advanced talents. To ensure the innovative R&D, application and promotion of low-carbon technologies, strengthen the construction of ecological environment intelligence, improve the level of informationization of ecological environment protection, promote the construction of an intelligent platform for ecological environmental protection and decision-making

support, improve the efficiency of carbon emissions, and help achieve carbon peaking And carbon neutral.

(3) Promote the green upgrading of the industry and realize the layout of the green development of the industry. According to the research results of this paper, the optimization and upgrading of industrial structure can effectively promote the improvement of urban carbon emission efficiency. Therefore, each urban free trade pilot zone should use system innovation to drive the green innovation of industries in the zone, increase the promotion of green transformation of various industries, improve the green level of the manufacturing industry in the zone, encourage the development of various strategic emerging industries, and vigorously build green manufacturing. Encourage the development of various new models and new formats such as "Internet +" ecological and environmental protection, and vigorously develop the green service industry.

(4) Improve the urban energy structure and promote the low-carbon and clean utilization of energy. In order to further promote the high-quality economic development of the pilot free trade zones to form an important driving force for high-level ecological and environmental protection, and at the same time take into account economic growth and environmental improvement, each city's pilot free trade zones should accelerate the green transformation of key areas and accelerate the green low-cost development. For the development of carbon transportation, replace traditional old vehicles with clean energy vehicles, accelerate the low-carbon transformation of infrastructure, and explore the construction of low-carbon and zero-carbon energy consumption systems. The government should vigorously promote the concept of green, encourage people and enterprises to reduce the consumption of fossil energy through tax cuts and subsidies, and replace fossil energy with non-fossil energy and natural gas. In addition, encourage the research and development and application of strategic energy technologies, promote energy storage technology innovation, improve energy utilization efficiency, reduce energy loss, and improve energy-saving effects.

References

WANG, L., WANG, Z., & MA, Y. (2021). Environmental Effects of Trade Liberalization–Evidence from China's Pilot Free Trade Zone. *Journal of International Commerce, Economics and Policy (JICEP)*, *12*(03), 1-24. https://doi.org/10.1142/S1793993321500137

JIANG, Y., WANG, H., & LIU, Z. (2021). The impact of the free trade zone on green total factor productivity—Evidence from the shanghai pilot free trade zone. *Energy Policy*, *148*, 2000. https://doi.org/10.1016/j.enpol.2020.112000

KAYA, Y., & YOKOBORI, K. (1998). In *Environment, energy and economy: Strategies for sustainability*. BROOK-0356/XAB, Aspen Inst., Washington, DC (United States); Brookings Institution, Washington, DC (United States), 1998.

CHUNG, Y, H., & FÄRE, R. (1997). GROSSKOPF S. Productivity and Undesirable Outputs: A Directional Distance Function Approach. *Journal of Environmental Management*, *51*(3), 229-240.

ttps://doi.org/10.1006/jema.1997.0146

ZHOU, P., ANG, B. W., & WANG, H. (2012). Energy and CO2 emission performance in electricity generation: A non-radial directional distance function approach. *European Journal of Operational Research*, *221*(3), 625-635. https://doi.org/10.1016/j.ejor.2012.04.022

HEYMAN, F., SJÖHOLM, F., & TINGVALL, P. G. (2007). Is there really a foreign ownership wage premium? Evidence from matched employer–employee data. *Journal of International Economics*, *73*(2), 355-376. https://doi.org/10.1016/j.jinteco.2007.04.003

BÖCKERMAN, P., & ILMAKUNNAS, P. (2007). *Unemployment and self-assessed health: Evidence from panel data*. https://doi.org/10.2139/ssrn.962834