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Establishment of Free Trade Zones Does Not Suppress Urban Carbon Emissions

-- Based on a Quasi-natural Experimental Study of 287 Cities

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Abstract: Constructing free trade pilot zones is an important strategic move for promoting reform and opening up in China in the new era. However, pollution control and emission reduction are obstacles that must be overcome in this process. This study takes cities implementing free trade pilot zone policies in China as the experimental group and other cities as the control group, establishing a "quasi-natural experiment." Based on panel data from 287 cities from 2010 to 2021, the study uses the Difference-in-Differences (DID) method to empirically test the impact of free trade zone construction on carbon emissions in the cities and further analyse its influencing mechanisms. The research findings indicate: (1) the construction of free trade zones has a significant inhibitory effect on carbon emissions in the cities; (2) the establishment of free trade pilot zones can suppress carbon emissions in cities through levels of openness to the outside world, technological innovation, and upgrading of industrial structure; (3) different regions and batches of free trade zones have varying impacts on carbon emissions. In light of these findings, it is suggested to systematically expand the implementation scope of free trade pilot zone policies in China during the development of free trade pilot zones, stimulate the potential for urban carbon reduction, implement tailored low-carbon policies, and promote the coordinated development of economic and environmental benefits in free trade pilot zones.

Keywords: Free trade pilot zone; carbon emissions; Multiple Time Periods Double Difference.

1. Introduction and Literature Review

The traditional economic growth model in the past relied on extensive growth of resources and factor inputs, which severed the universal connection between production methods and ecological protection. However, various links in the process of high-quality economic development are interconnected, and the "non greenification" behavior of production methods will unconsciously erode relevant links, thereby having a negative inhibitory effect on high-quality economic development (Li Mengxin, Ren Baoping, 2018)[1]Since the reform and opening up, China's economic growth model that comes at the cost of consuming resources has brought miraculous growth to the country's economy, but it has lowered the quality of economic growth and accelerated the deterioration of the ecological environment. In response, the report of the 19th National Congress of the Communist Party of China and the 14th Five Year Plan have pointed out that high-quality development has become the fundamental goal and core requirement of building socialism with Chinese characteristics in the new era.

Energy is the foundation of economic and social development, and high-quality energy development is an inevitable requirement for national high-quality development (Liu Xiaolong et al., 2021)[2][3]This is the first time China has proposed the goals of carbon neutrality and peak carbon emissions. As the world's largest carbon emitter, this decision is of crucial significance for global carbon peaking and carbon neutrality (Hu Angang, 2021)[4].

Since the establishment of the Shanghai Pilot Free Trade Zone in 2013, as of December 2023, China has successively established 21 pilot free trade zones, including Beijing, Tianjin, Guangdong, etc., gradually expanding from coastal areas to inland areas, gradually forming a new pattern of all-round foreign development in multiple fields. The pilot free trade zone is a new window for China to open up to the outside world in the new era, and bears important responsibilities in implementing the new development concept and constructing a new development pattern. In 2021, the Ministry of Ecology and Environment, in conjunction with the Ministry of Commerce and eight other departments, issued the Guiding Opinions on Strengthening the Ecological Environment Protection of Pilot Free Trade Zones and Promoting High quality Development, which clearly puts forward the overall requirements for reducing pollution and carbon emissions in the pilot free trade zone[5]In the implementation plans of the 21 free trade pilot zones that have been released, there are more than 130 clauses on ecological requirements, and the content is more detailed (Zhang Guoqing, 2023)[6]In the new policy environment, can the establishment of free trade pilot zones improve urban carbon emissions, become the vanguard of regional green development, and create a new situation for comprehensive green transformation? Clarifying this issue is an important evaluation of the pilot policy of the free trade pilot zone. Building the free trade pilot zone into a new highland of ecological civilization and a leading area for comprehensive green transformation and development is of great significance for China to actively adapt to the new global development situation, improve the new pattern of opening up to the outside world, and promote accelerated economic transformation and upgrading.

Based on existing literature, since the establishment of China's pilot free trade zones, researchers have roughly divided their research on free trade zones into two levels: macro and micro. Firstly, at the macro level, the main focus is on studying the development process and historical logic of the pilot free trade zones（Yu Wentao, Chen Mengxin, 2023）[7]And its policy effects, discussing the strategic significance of free trade zones through the historical background of promoting the strategy of free trade pilot zones (Zhang Youwen, 2016)[8]Evaluate the development of free trade zones from the perspective of their strategic positioning and commonalities (Zhou Hanmin, 2015)[9]Taking Shanghai as an example, evaluate the "institutional dividend" of the free trade zone by comparing the economic performance of counterfactual measures (Tan Na et al., 2015)[10]Evaluate the policy effects of setting up free trade zones from the perspectives of location selection and economic effects (Bai Zhonglin et al., 2020)[11]The policy effects will become increasingly significant over time, but there are significant spatial differences between different regions, that is, the impact of different free trade zones on the quality of economic development and its driving mechanism is significantly heterogeneous (Li Zilian, Liu Dan, 2021)[12]Secondly, at the micro level, the establishment of free trade zones has a significant impact on economic growth, institutional innovation, industrial structure upgrading, and environmental effects. The construction of free trade zones has a significant driving effect on regional economic growth, and coastal areas are significantly better than inland free trade zones (Wang Aijian et al., 2020; Liu Bingsickle, Lv Cheng, 2018)[13][14]And it has a radiating effect on the mother city and surrounding areas (Wei Yanqiu, Qiu Licheng, 2015)[15]; The institutional innovation of the new round of free trade pilot zones pays more attention to the balance between trade promotion and industrial development, the balance between internal and external development, and the balance between top-level design and grassroots innovation (Ding Hong, 2020)[16]The lack of motivation for institutional innovation is a misconception about the institutional innovation of free trade pilot zones and its systemic dilemma,The free trade zone can not only significantly promote the entrepreneurial vitality of the city, but also radiate and drive the entrepreneurial development of neighboring cities (Zhang Liuqin et al., 2023)[17]，Deepening institutional openness is a need to adapt to the new situation. The Shanghai Free Trade Zone replaces policy incentives with institutional innovation, providing China with replicable experiences in an innovative manner (Yin Chen et al., 2019)[18]However, in the short term, the construction of the Shanghai Free Trade Zone will have a "siphon effect" on the institutional innovation in the surrounding areas. However, in the long run, it will bring more radiation effects to the surrounding areas, which is conducive to a new round of industrial transfer (Cao Xuping, 2015)[19]; As a test field for China's further reform and opening up in the new era, the Free Trade Pilot Zone, since its establishment, has further promoted financial openness and trade investment facilitation to attract capital accumulation due to favorable policy advantages such as convenient investment, complete services, and efficient supervision. Although the construction of the Free Trade Zone has effectively promoted the increase of outward direct investment and the upgrading of industrial structure(Yang Xu, Liu Yi, 2020; Zhang Yihui et al., 2021)[20][21]; The establishment of free trade zones can improve the local air pollution situation through industrial structure optimization and green innovation (Hu Zongyi, 2022)[22]The establishment of free trade zones can also improve the environmental performance of listed companies through their green innovation capabilities and environmental investment (Li et al., 2022)[23]However, when analyzing the environmental effects of a single free trade zone, due to differences in factor endowments and infrastructure among different free trade zones, there may be significant differences in the environmental effects of different free trade zones. Taking Guangdong Free Trade Zone as an example, due to technological and infrastructure reasons, it has fallen into an environmental "policy trap", and the establishment of free trade zones has actually worsened the local environmental quality (Zhou et al., 2021)[24].

In summary, it is found that existing literature on the study of China's free trade zones mostly presents a logical analysis of the policy effects and historical development of free trade zones from a macro level, while at a micro level, it mostly elaborates on the impact of free trade zone policies on economic growth from various perspectives. However, when empirically testing the impact of free trade zone policies from the perspective of environmental effects, existing research has not yet reached a consistent conclusion, There is relatively little literature evaluating the pilot policies of free trade zones from the perspective of carbon emissions, and there are different opinions. One believes that the establishment of free trade zones has exacerbated the environmental pollution problem of the pilot zones, but over time, the impact of free trade zones on the environmental pollution of the pilot zones has gradually weakened（Lianghu WWait, 2021)[1]; Another view is that establishing free trade pilot zones can improve environmental quality (LIN X, 2022;Fei XWait, 2023)[26][27]; Similarly, domestic empirical analysis of the environmental effects of free trade pilot zones has been conducted from different perspectives such as air pollution, environmental quality, and carbon emissions (Ma Bingxin et al., 2023; Shao Liangshan et al., 2023; Hu Zongyi et al., 2022; Cao Xiang et al., 2021; Wang Zhe et al., 2023)[28][29][30][31][32]Moreover, most of the selected provincial panel data and earlier sample data, or taking individual free trade zones as examples, have not conducted in-depth analysis of the impact of pilot policies on carbon emissions in pilot cities. Only considering provincial panel data cannot fully accurately evaluate the impact of China's free trade zones on local carbon emissions, and there are regional differences when using a certain free trade zone as an example, It cannot fully reflect the impact of free trade pilot zones on carbon emissions reduction. Therefore, this article attempts to use more diverse and detailed data to analyze and explore the policy effects of free trade pilot zones from the perspective of carbon emissions, attempting to more accurately answer whether setting up free trade pilot zones can suppress urban carbon emissions and provide empirical research ideas for the study of environmental effects of free trade zones.

In view of this, this article uses panel data from 287 cities in China from 2001 to 2021, and adopts a multi time point double difference method to examine the impact and mechanism of free trade pilot zones on local carbon emissions,byThe marginal contribution of this article lies in the following: firstly, from the perspective of data selection, this article uses panel data from 287 prefecture level cities from 2010 to 2021. Compared with previous literature, more refined urban panel data can provide more comprehensive, high-precision, multi-dimensional trends and empirical analysis with factual verification. Secondly, from the perspective of research methods, this article considers the different time dimensions of policy implementation in free trade pilot zones, After considering the issue of multicollinearity, a multi time point DID model was adopted to confirm that the establishment of free trade pilot zones effectively suppresses local carbon emissions, in order to examine whether the establishment of free trade pilot zones can improve China's environmental quality. Thirdly, in terms of research content, This article uses the mainstream model of evaluating policy effects, the multi time point DID model, to verify that the establishment of free trade pilot zones can suppress local carbon emissions. Three mediating variables, namely technological innovation, opening up to the outside world, and industrial structure upgrading, are introduced to further examine the diversified paths of the impact of free trade pilot zones on carbon emissions. This helps to provide new ideas for the establishment of free trade pilot zones on carbon reduction in the cities where they are locate.

2. Theoretical Mechanism

The current transition of China's economy from a stage of high-speed growth to a stage of high-quality development is not only a huge shift in social behavior, but also requires adaptive changes in thinking patterns and leading innovations （Jinbei, 2018）[33]In this context, as a new round of reform experimental fields, the Free Trade Pilot Zone, with strong policy support from the central government and active cooperation from local governments, absorbs a large amount of foreign investment, expands the local level of opening up to the outside world, and increases the openness of pilot cities (Zhang Jun et al., 220)[34]On the one hand, the establishment of free trade experiments can not only expand the level of opening up to the outside world and absorb a large amount of foreign trade investment in the process of actively connecting with foreign trade enterprises, but also expand the local economic scale with the influx of a large number of foreign merchants. As a result, trade activities increase, and the government can have more funds to invest in environmental governance (Si Chunxiao et al., 2021; Wang Daozhen, Ren Rongming, 2011)[35][36]At the same time, the entry of foreign high-tech enterprises has injected new vitality into local technological innovation. Foreign high-tech industries can bring emerging technologies, provide support for high-tech enterprises, and greatly increase their innovation vitality. Foreign direct investment will have a positive impact on the technological innovation of Chinese enterprises (Xian Guoming, Bo Wenguang, 2006)[37]On the one hand, the entry of foreign high-tech industries can also introduce advanced industries and technologies to achieve industrial transformation and upgrading (Jiang Xinying, Zhao Shuang, 2019)[38]As a major coal consuming country, energy consumption pollution has always been one of the main sources of air pollution in China. Optimizing and upgrading the industrial structure can effectively improve energy utilization efficiency (Yang Bo et al., 2021)[39]Effectively reduce the intensity of carbon emissions.

2.1. Promote the upgrading of industrial structure

The establishment of free trade pilot zones can effectively promote the upgrading of urban industrial structure, thereby having a positive impact on carbon emissions reduction. On the one hand, policies of free trade pilot zones can strongly support the level of urban opening up to the outside world, guide local areas to shift from primary and secondary industries to tertiary industry specialties. With strong support from government policies, it can effectively increase the strength of industrial specialties and accelerate enterprise transformation and upgrading (Yang Bo et al., 2021; Feng Rui et al., 2020)[39][40]On the other hand, the clustering of industries in free trade parks can also form a clustering effect, while also increasing competition among enterprises, subtly strengthening the role of the market in resource allocation, optimizing resource structure, eliminating outdated technology and low efficiency, and transferring resources and labor to enterprises with higher productivity (Luo Chaoyang, Li Xuesong, 2019)[41]It can effectively promote urban carbon reduction.

2.2. Expand the level of opening up to the outside world

The establishment of free trade pilot zones can attract more foreign direct investment through more convenient and open trade policies, thereby expanding the level of local openness to the outside world and promoting local economic and trade development. The expansion of the level of openness to the outside world can not only promote local consumption through trade facilitation, but also allow a large amount of foreign investment to expand the local economic scale. At the same time, local governments can obtain more fiscal revenue to invest in local environmental governance. Generally speaking, the larger the economic scale of cities, the greater the investment in environmental pollution control. Therefore, the establishment of free trade pilot zones can promote carbon reduction by improving the level of openness to the outside world.

2.3. Enhance the level of technological innovation

The establishment of free trade pilot zones can introduce high-tech and bring advanced foreign technology and management models to China, thereby reducing the carbon dioxide emissions of enterprises; On the other hand, the policy of free trade pilot zones can attract a large amount of foreign investment. The investment of foreign enterprises will generate reverse technology spillover benefits, promoting domestic related enterprises to learn advanced green technologies from abroad. The improvement of technology level will also force technologically backward enterprises to innovate, ultimately promoting the reduction of local carbon emissions.

Based on the above analysis, this article proposes the following hypotheses:

Hypothesis 1: The construction of free trade pilot zones can effectively suppress carbon emissions in the cities where they are located;

Hypothesis 2: The establishment of free trade pilot zones can suppress carbon emissions in local cities by promoting industrial structure upgrading, expanding the level of opening up to the outside world, and enhancing the level of technological innovation in cities.

3. Research Design

3.1. Model settings

3.1.1. Benchmark regression model

This article selected panel data from 287 cities in China from 2010 to 2021, with a sample size of 3439. As the latest data was selected from 2021, the pilot cities were established from 2013 to 2019, with a total of 5 batches and 40 prefecture level cities. By observing the batches and times of the establishment of free trade pilot zones, it can be found that the geographical location, economic development status, population density, and other conditions of the cities selected for free trade pilot zones are different. Therefore, this article regards the policy of free trade pilot zones as a quasi natural experiment. Considering the different implementation times of free trade pilot zone policies, this article uses a multi period DID method to evaluate the impact of free trade pilot zones on carbon emissions of prefecture level cities. The establishment of free trade pilot zones will be a quasi natural experiment. The cities in the trade pilot zone were used as the experimental group, and no free trade pilot zone was established as the control group. In order to estimate the impact of free trade pilot zone policies on carbon emissions more effectively, a double fixed effects model was adopted. The bidirectional fixed effects can solve the problem of omitted variables that do not change over time but vary with individuals, and the problem of omitted variables that do not change with individuals but change over time. The specific model settings are as follows:

$$CE_{i,t} = \alpha_0+\beta_1 DID_{i,t} + \beta_3 X_{i,t} + \delta_t + \mu_i + \varepsilon_{i,t} \quad (1)$$

In equation (1), CE represents the amount of carbon dioxide emissions as the dependent variable, DID represents the urban dummy variable of the free trade zone policy, X represents the control variable, subscript i represents the city, and t represents the year,α_0Refers to the constant termδ_tUsed to measure time effects in the time dimension, μ_i Used to measure fixed effects on individual dimensions,$\varepsilon_{i,t}$The model refers to a random disturbance term that varies with individuals and time. It controls both fixed effects in the individual dimension and fixed effects in the time dimension. This model is called bidirectional fixed effects. If the establishment of free trade pilot zones can promote carbon emissions reduction, that is, can suppress carbon emissions, then β_1 Displayed as negative, on the contrary, if the establishment of free trade pilot zones suppresses carbon emissions reduction, i.e. promotes carbon emissions, thenβ_1Display as positive, while the size of the impact is displayed asβ_1The absolute value size of β_1.

3.1.2. Transmission mechanism model

Introducing the level of openness to the outside world (Foreign), level of technological innovation (Patent), and upgrading of industrial structure (Stru) as transmission mechanisms, this study investigates the effects of these three factors on carbon reduction in free trade pilot zones. The model is as follows:

$$CE_{i,t} = \alpha_0+\beta_1 DID_{i,t} + \beta_2 Controls_{i,t} + \delta_t + \mu_i + \varepsilon_{i,t} \quad (2)$$

$$M_{i,t} = \alpha_0+\beta_1 DID_{i,t} + \beta_2 Controls_{i,t} + \delta_t + \mu_i + \varepsilon_{i,t} \quad (3)$$

$$CE_{i,t} = \alpha_0+\beta_1 M_{i,t} + \beta_2 DID_{i,t} + \beta_3 Controls_{i,t} + \delta_t + \mu_i + \varepsilon_{i,t} \quad (4)$$

Among them,$M_{i,t}$Refers to the mediating variables Stru, Patent, and Foreign,α_0Refers to the constant term,β_iRefers to the regression coefficients of each variable,δ_tUsed to measure time effects in the time dimension,μ_iUsed to measure fixed effects on individual dimensions, $\varepsilon_{i,t}$ The term refers to a random disturbance term that varies with individuals and time. The use of a bidirectional fixed effects model can solve the problem of omitted variables that do not change with time but vary with individuals, and the problem of omitted variables that do not change with individuals but vary with time.

3.2. Selection of variables and data explanation

3.2.1. Dependent variable

The dependent variable of this article is urban carbon emissions. Currently, there is no consistent standard for selecting carbon dioxide emissions in domestic and foreign literature. Existing literature sources mainly include statistical yearbooks of various cities and the China Statistical Yearbook. This article references (Ma Bingxin et al., 2023)[28]The study used carbon dioxide emission data provided by the China Carbon Accounting Database (CEADS).

3.2.2. Core explanatory variables

The core explanatory variable of this article is the establishment of a free trade pilot zone (DID), which is a dummy variable. The sample cities are assigned values based on the official listing time of the free trade zone, that is, the year in which the processing group cities established the free trade zone and subsequent years are assigned values of 1, the year before the establishment of the free trade zone is assigned values of 0, and the control group cities are assigned values of 0. Considering the time difference between the listing time of the free trade pilot zone in the first and second half of the year, The listing in the second half of the year may not have a significant impact on the current year. Therefore, if the policy period is in the first half of the year, the current year is the time for establishing a free trade zone. If the policy period is in the second half of the year, the following year is the time for establishing a free trade zone.

3.2.3. Control variables

Referring to existing research (Shao Liangshan et al., 2023; Hu Zongyi et al., 2022; Cao Xiang et al., 2021; Wang Zhe et al., 2023)[29][30][28][31][32]The level of local economic development, level of opening up to the outside world, population size, infrastructure, etc. will all affect the carbon dioxide emissions of cities. Therefore, the control variable selected in this article is per capita Gross Regional Product (PGDP); Government budget expenditure (Gov): Local general public budget expenditure/regional GDP; Regional financial development level (Finance): RMB loan balance of financial institutions/regional GDP; Network usage range (Inter): the natural logarithm of the number of Internet broadband access users; Waste treatment situation: centralized treatment rate of sewage treatment plants; Urban energy consumption: the industrial electricity consumption of the entire city; Social retail consumption (Cons): the natural logarithm of the total retail sales of social consumer goods; Road passenger volume: Highway passenger volume; Innovation level: Innovation expenditure/City wide science and technology expenditure.

3.2.4. Mediating variables

The mediating variables used in this article are industrial structure upgrading, technological innovation level, and degree of openness to the outside world. Among them, industrial structure upgrading draws inspiration from (Wu Hong, 2022)[42]The approach is measured by the proportion of the tertiary industry in GDP; Reference for Technological Innovation Level (Xue Fei et al., 2022)[43]The approach is measured by the number of patent applications authorized; Reference to the level of opening up to the outside world (Zhang Yan et al., 2022)[44]The approach is measured by the proportion of actual utilization of foreign investment to GDP.

The above variables have been logarithmically processed during the variable selection process in order to ensure data validity and avoid outliers affecting the estimation results.

3.2.5. Data Description

This article takes 287 prefecture level cities in China from 2010 to 2021 as the research object. The data of each prefecture level city comes from the China Carbon Accounting Database (CEADS), China Urban Statistical Yearbook, China Environmental Statistical Yearbook, and various city statistical yearbooks. To increase the stationarity of panel data, this article excluded cities with severe data missing, and truncated numerical variables by 1% and 99%. The selection of variables is shown in Table 1, The descriptive statistics of each variable are shown in Table 2.

Table 1. Variable Table

	symbol	Meaning of variables
Dependent variable	CE	Natural logarithm of total carbon dioxide emissions
Explanatory variables	DID	Treat * Post, where the free trade zone sample Treat=1, otherwise=0; Post=1 for setting up a free trade zone, otherwise=0. In addition, the handling method for the time of setting up a free trade zone is as follows: when the policy time is in the first half of the year, the current year is the time of setting up the free trade zone; if the policy time is in the second half of the year, the following year is the time of setting up the free trade zone
Mediating variables	Stru	The proportion of the tertiary industry
	Patent	The natural logarithm of the number of patent authorizations
	Foreign	Actual utilization of foreign investment in the current year in US dollars * exchange rate/regional GDP
control variable	PGDP	The natural logarithm of per capita regional gross domestic product
	Gov	Local general public budget expenditure/regional GDP
	Finance	Balance of RMB loans from financial institutions/regional GDP
	Inter	Natural logarithm of the number of Internet broadband access users
	Waste	Centralized treatment rate of sewage treatment plants
	Energy	The natural logarithm of the city's industrial electricity consumption
	Cons	The natural logarithm of the total retail sales of consumer goods in society
	Road	The natural logarithm of highway passenger volume
	Innovate	Innovation expenditure, natural logarithm of the city's science and technology expenditure

Table 2. Descriptive statistics

variable	sample	mean value	standard deviation	minimum value	Maximum value
CE	3439	8.062	0.55	6.363	11.563
DID	3439	0.014	0.117	0	1
Stru	3439	0.42	0.102	0.097	0.838
Patent	3439	4.804	3.865	0	12.549
Foreign	3439	0.022	0.038	0	0.46
PGDP	3439	10.707	0.584	9.332	12.065
Gov	3439	0.201	0.101	0.076	0.626
Finance	3439	1.026	0.588	0.31	3.403
Inter	3439	5.62	3.291	1.332	14.37
Waste	3439	0.87	0.135	0.343	1
Energy	3439	13.066	1.302	9.421	15.693
Cons	3439	15.563	1.048	13.191	18.204
Road	3439	8.215	1.117	5.1	11.205
Innovate	3439	10.378	1.407	7.585	14.459

4. Empirical Analysis

4.1. Benchmark regression analysis

Table 3 reports the results of the benchmark regression. Column (1) shows the estimated results of the model that only included DID, while column (2) shows the estimated results of all control variables included on the basis of including DID. According to the results of column (1), controlling for other variables remains unchanged, the coefficient of DID is -0.0318, which is significant at the 1% level, indicating that the experimental group has significantly reduced carbon emissions compared to the control group under the pilot policy of the free trade zone, The pilot policy of the free trade zone has a significant inhibitory effect on carbon emissions. The experimental group showed an average decrease of 0.0318% in CE compared to the control group and after the policy compared to before. The results of column (2) showed that, while controlling for other variables, the coefficient of DID was -0.0313, which was significant at the 1% level, indicating that the experimental group had a significant reduction in carbon emissions compared to the control group under the pilot policy of the free trade zone, The experimental group showed an average decrease of 0.0313% in CE compared to the control group and after the policy compared to before. This is consistent with the conclusion in column (1), and hypothesis 1 is validated.

Table 3. Benchmark Regression Results

	(1)	(2)
variable	CE	CE
DID	-0.0318***	-0.0313***
	(0.0054)	(0.0056)
PGDP		0.0029
		(0.0042)
Gov		0.0265
		(0.0386)
Finance		0.0133**
		(0.0046)
Inter		0.0057***
		(0.0010)
Waste		-0.0051
		(0.0105)
Energy		0.0030**
		(0.0012)
Cons		0.0063
		(0.0055)
Innovate		-0.0002
		(0.0025)
Constant	7.9031***	7.6617***
	(0.0001)	(0.0570)
Observations	3,439	3,439
R-squared	0.559	0.560
Number of groups	287	287
Urban fixed effects	YES	YES
Year fixed effect	YES	YES

Standard errors in parents
***P<0.01, * * p<0.05, * p<0.1

4.2. Robustness testing

4.2.1. Parallel trend test

Multi time point DID is one of the most commonly used methods for evaluating a policy, but it needs to meet parallel trend testing before use, which means that there is no significant difference in the overall development trend between the experimental group and the control group before the policy implementation. Therefore, the results of the double difference method only have practical significance under the condition of parallel trend. As shown in Figure 1, before the current and before the implementation of the free trade zone policy, the control variables PGDP, Gov, Finance, Inter, Waste, Energy, Cons In the case of Innovation, there was no significant difference in the dependent variable between the control group and the experimental group (with the upper and lower confidence intervals including 0), and the establishment of free trade zones did not have an early impact on urban carbon emissions, indicating that the assumption of parallel trends is met.

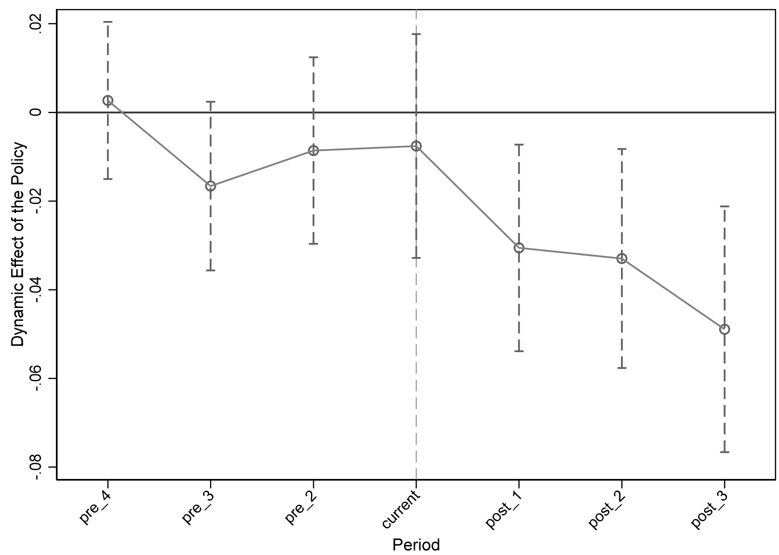

Figure 1. Parallel Trend Test

4.2.2. Placebo test

In order to eliminate the influence of differences between cities at the prefecture level on the research conclusions, a placebo test was repeated 500 times. Each placebo test was randomly assigned and different cities were selected as the pseudo experimental group. The regression results were subjected to placebo test, and a total of 500 randomized experiments were conducted. From Figure 2, it can be seen that the coefficients of DID generally follow the characteristics of normal distribution, and the p-values of the majority of estimated values are greater than 0.1, And the regression results show obvious outliers in the graph (the vertical line in the graph represents the coefficient of DID -0.313), indicating that the pilot policy of the free trade zone is indeed an important reason for the significant reduction of carbon emissions, indicating that the placebo test has been passed, once again proving the robustness of the model.

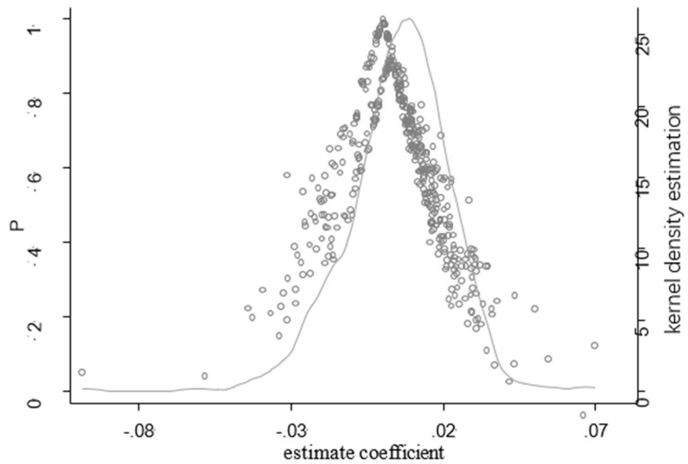

Figure 2. Placebo test

4.2.3. PSM propensity score matching method

For the neighboring matching method using PSM propensity score matching for data, 792 samples were removed from the control group and 26 samples were removed from the experimental group, with a total of 3334 retained samples, 454 in the experimental group and 2880 in the control group. When unmatched, there was a significant difference in standard deviation (% bias) between the experimental group and the control group, while the difference in standard deviation after matching was around 10% or less, indicating that the standard deviation of the above control variables in both groups was small, Having the conditions for balance testing; At the same time, the majority of variables showed a p-value greater than 5% in the t-test after matching, indicating that there was no statistically significant difference between the two groups. Please refer to Table 4 for details.

Table 4. Balance test of covariates

Variable	Unmatched/Matched	Mean		%Bias	%Reduct Bias	T-test	
		Treaded	Control			t	p> T
PGDP	U	11.119	10.64	87.2		17.38	0.000
	M	11.091	11.136	-8.2	90.6	-1.26	0.208
Gov	U	.16204	.20776	-53.8		-9.34	0.000
	M	.16337	.15443	10.5	80.5	1.96	0.051
Finance	U	1.4658	.95459	81.5		18.54	0.000
	M	1.4362	1.4858	-7.9	90.3	-0.96	0.339
Inter	U	6.499	5.477	31.0		6.35	0.000
	M	6.5067	6.4436	1.9	93.8	0.28	0.776
Waste	U	.88331	.86789	11.8		2.33	0.020
	M	.88115	.87967	1.1	90.4	0.18	0.861
Energy	U	13.82	12.944	68.4		14.07	0.000
	M	13.763	13.862	-7.8	88.6	-1.22	0.225
Cons	U	16.562	15.401	110.4		24.37	0.000
	M	16.486	16.471	1.4	98.7	0.21	0.837
Innovate	U	11.673	10.168	106.3		23.40	0.000
	M	11.56	11.629	-4.9	95.4	-0.68	0.498

Figure 3shows the distribution of standard deviations of control variables before and after PSM matching (marked with a black dot [·]). The results show that the covariate deviations are relatively large, mostly exceeding 10%, without PSM matching. However, after PSM matching, the deviations of each covariate are all around 0, indicating that the covariate differences in the samples are well balanced.

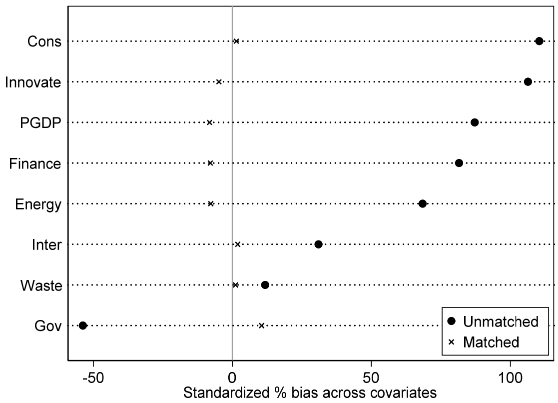

Figure 3. Distribution of standard deviation of covariates

To verify the robustness of the model, regression estimation was performed on the samples after PSM. If the results are consistent with the original model results, it indicates that the original model results are robust, as shown in Table 5. In column (1), the results show that, while controlling for other variables, the coefficient of DID is -0.0329, which is significant at the 1% level, indicating that the experimental group has significantly reduced carbon emissions compared to the control group under the pilot policy of the free trade zone, The pilot policy of the free trade zone has a significant inhibitory effect on carbon emissions. The results of column (2) show that, while controlling for other variables, the coefficient of DID is -0.0327, which is significant at the 1% level, indicating that the experimental group has significantly reduced carbon emissions compared to the control group under the pilot policy of the free trade zone. The conclusion is consistent with the original model's conclusion, and the coefficient size is very small compared to the original model, indicating that the original model is robust.

Table 5. PSM Sample Model Results

	(1)	(2)
variable	CE (PSM)	CE (PSM)
DID	-0.0329***	-0.0327***
	(0.0057)	(0.0064)
PGDP		0.0010
		(0.0053)
Gov		0.0355
		(0.0531)
Inter		0.0051***
		(0.0010)
Waste		-0.0058
		(0.0118)
Energy		0.0008
		(0.0021)
Cons		-0.0001
		(0.0062)
Innovate		0.0007
		(0.0029)
Constant	7.9035***	7.8124***
	(0.0004)	(0.0355)
Observations	3,334	3,334
R-squared	0.566	0.567
Number of groups	287	287
Urban fixed effects	YES	YES
Year fixed effect	YES	YES

Standard errors in parents
***P<0.01, * * p<0.05, * p<0.1

4.2.4. Excluding the impact of the epidemic

To verify the robustness of the model and avoid the instability of the results caused by epidemic factors, the model estimation was carried out by excluding samples from 2020 and later. If the results are consistent with the original model results, it indicates that the original model results are robust.

From 6, it can be seen that according to the results of column (1), while controlling for other variables, the coefficient of DID is -0.0385, which is significant at the 1% level. This indicates that the experimental group has significantly reduced carbon emissions compared to the control group under the pilot policy of the free trade zone, indicating that the pilot policy of the free trade zone has a significant inhibitory effect on carbon emissions.

The results in column (2) show that the DID coefficient is -0.0357, which is significant at the 1% level when other variables are controlled unchanged, indicating that the carbon emissions of the experimental group are also significantly reduced compared with the control group under the pilot policy of the free trade zone. The conclusions are consistent with the conclusions of the original model, indicating that the factors of the COVID-19 epidemic do not affect the results, and the difference between the coefficient and the original model is very small, which indicates that the original model is robust. See Table 6 for details.

Table 6. Propose the impact of the epidemic

	(1)	(2)
variable	CE (Sub Sample)	CE (Sub Sample)
DID	-0.0385***	-0.0357***
	(0.0061)	(0.0055)
PGDP		-0.0023
		(0.0039)
Gov		0.0512
		(0.0442)
Inter		0.0057***
		(0.0012)
Waste		-0.0197
		(0.0127)
Energy		0.0036**
		(0.0012)
Cons		0.0094
		(0.0091)
Innovate		-0.0025
		(0.0020)
Constant	7.9032***	7.7008***
	(0.0001)	(0.1164)
Observations	2,866	2,866
R-squared	0.479	0.481
Number of groups	287	287
Urban fixed effects	YES	YES
Year fixed effect	YES	YES

Standard errors in parents
***P<0.01, * * p<0.05, * p<0.1
***P<0.01, * * p<0.05, * p<0.1

4.2.5. Excluding provincial capital cities

To verify the robustness of the model and avoid the impact of more policy and resource advantages in provincial capital cities on the estimation results, we now use subsamples excluding provincial capital cities for model estimation. If the results are consistent with the original model results, it indicates that the original model results are robust. Please refer to Table 7 for details.

The results of column (1) show that, while controlling for other variables, the coefficient of DID is -0.0362, which is significant at the 1% level, indicating that the experimental group has significantly reduced carbon emissions under the pilot policy of the free trade zone compared to the control group. That is to say, the pilot policy of the free trade zone has a significant inhibitory effect on carbon emissions. The results of column (2) show that, while controlling for other variables, the coefficient of DID is -0.0363, which is significant at the 1% level, indicating that the experimental group has significantly reduced carbon emissions under the pilot policy of the free trade zone compared to the control group, This also indicates a significant reduction in carbon emissions. The conclusion is consistent with the original model, indicating that the provincial capital cities in the sample did not have an impact on the results, and the coefficient size is very close to the original model, indicating that the original model is robust.

Table 7. Excluding provincial capital cities

	(1)	(2)
variable	CE	CE
DID	-0.0362***	-0.0363***
	(0.0052)	(0.0042)
PGDP		-0.0030
		(0.0051)
Gov		0.0456
		(0.0378)
Finance		0.0116***
		(0.0035)
Inter		0.0036***
		(0.0005)
Waste		0.0064
		(0.0105)
Energy		0.0040**
		(0.0018)
Cons		0.0092*
		(0.0051)
Innovate		0.0014
		(0.0021)
Constant	7.9202***	7.6861***
	(0.0001)	(0.0920)
Observations	3,115	3,115
R-squared	0.577	0.578
Number of groups	260	260
Urban fixed effects	YES	YES
Year fixed effect	YES	YES

Standard errors in parents
***P<0.01, * * p<0.05, * p<0.1

4.3. Mechanism verification

In terms of mechanism testing methods, the most common method is Baron&Kenny's causal stepwise regression method. As can be seen from the results of benchmark regression in the previous section, cities with free trade pilot zones have significantly promoted local carbon reduction compared to cities without them, The establishment of free trade pilot zones can effectively suppress local carbon emissions. So, through what mechanisms does the establishment of free trade pilot zones have an impact on carbon reduction? To answer this question, based on the theoretical mechanism analysis section in the previous text, this article introduces three mediating variables: technological innovation level, industrial structure upgrading, and level of openness to the outside world into the model, and constructs a mediation effect model (2), (3), and (4). The test results are detailed in Table 8.

The results of column (1) have been validated in the previous section of the main effect model, that is, controlling for other variables to remain unchanged, the coefficient of DID is -0.0313, which is significant at the 1% level, indicating that DID has a significant negative impact on CE. Hypothesis 1 has been validated. The results of column (2) indicate that controlling for other variables to remain unchanged, the coefficient of DID is 0.0154, which is significant at the 1% level, indicating that DID has a significant positive impact on Stru, The pilot policy of the free trade pilot zone is beneficial for the upgrading of urban industrial structure. The results of column (3) indicate that, controlling for other variables, the coefficient of Stru is -0.0842, which is significant at the 1% level, indicating that Stru has a significant negative impact on CE. However, the coefficient of DID is -0.0300, which is significant at the 1% level, and the absolute value of coefficient -0.0300 is smaller than the coefficient of -0.0313 in model (1), indicating the existence of partial mediation, A part of DID has a negative impact on CE by positively influencing Stru, while the other part directly has a negative impact on CE; The results of column (5) indicate that, while controlling for other variables, the coefficient of DID is 0.0129, which is significant at the 1% level, indicating a significant positive impact of DID on Foreign. The results of column (6) indicate that, while controlling for other variables, the coefficient of Foreign is -0.3898, which is significant at the 1% level, indicating a significant negative impact of Foreign on CE. The coefficient of DID is -0.0263, which is significant at the 1% level, and the absolute value of coefficient -0.0263 is smaller than the coefficient of -0.0313 in column (4), Therefore, it indicates the existence of partial mediators, that is, a portion of DID has a negative impact on CE through a positive impact on Foreign, while the other portion directly has a negative impact on CE; The results of column (8) indicate that, while controlling for other variables, the coefficient of DID is 1.2208, which is significant at the 5% level, indicating that DID has a significant positive impact on Patent. The results of column (9) indicate that, while controlling for other variables, the coefficient of Patent is -0.0018, which is significant at the 1% level, indicating that Patent has a significant negative impact on CE. The coefficient of DID is -0.0292, which is significant at the 1% level, and the absolute value of the coefficient of -0.0292 is smaller than the coefficient of -0.0313 in column (7), Therefore, it indicates the existence of partial mediators, that is, a portion of DID has a negative impact on CE by positively influencing Patents, while the other portion directly has a negative impact on CE. Hypothesis 2 is validated.

Table 8. Mechanism Verification

variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	CE	Stru	CE	CE	Foreign	CE	CE	Patent	CE
DID	-0.0313***	0.0154***	-0.0300***	-0.0313***	0.0129***	-0.0263***	-0.0313***	1.2208**	-0.0292***
	(0.0056)	(0.0022)	(0.0056)	(0.0056)	(0.0011)	(0.0067)	(0.0056)	(0.4266)	(0.0055)
Stru			-0.0842***						
			(0.0200)						
Foreign						-0.3898***			
						(0.0946)			
Patent									-0.0018***
									(0.0005)
Constant	7.6617***	0.4588*	7.7004***	7.6617***	-0.0630***	7.6372***	7.6617***	-7.5751	7.6484***
	(0.0570)	(0.2119)	(0.0586)	(0.0570)	(0.0092)	(0.0561)	(0.0570)	(4.5672)	(0.0600)
control variable	YES	YES	YES	YES	YES	YES	YES	YES	YES
Urban fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	3,439	3,439	3,439	3,439	3,439	3,439	3,439	3,439	3,439
R-squared	0.560	0.764	0.561	0.560	0.0545	0.563	0.560	0.741	0.561

Standard errors in parents
***P<0.01, * * p<0.05, * p<0.

4.4. Heterogeneity testing

4.4.1. Regional heterogeneity

The geographical location of free trade pilot zones may affect the impact of pilot policies on regional carbon emissions reduction. Referring to the method of Wang Aijian et al. (2020), this article conducts heterogeneity analysis of policy implementation from the perspective of setting up free trade pilot zones. The samples are divided into coastal areas (Coastal) and non coastal areas (Not). Based on equation (1), equation (5) is introduced to test its heterogeneity:

$$CE_{i,t} = \alpha_0 + \beta_1 DID_{i,t} \times Coastal_{i,t} + \beta_2 DID_{i,t} \times Not_{i,t} + \beta_3 X_{i,t} + \delta_t + \mu_i + \varepsilon_{i,t} \quad (5)$$

In equation (5),$Coastal_{i.,T}$The dummy variable representing the coastal free trade pilot zone, if the geographical location of city i is located along the coast, then $Coastal_{i.\ T}=1$. No lateral position 0; $Not_{i.\ T}$A dummy variable representing inland areas, if $Not_{i.\ T=1}$,Represents a free trade zone located inland, otherwise 0. The results are detailed in Table 9.

According to Table 9, while keeping other variables constant, the coefficient of the coastal free trade zone is -0.0261, which is significant at the 1% level. This indicates that the pilot policy of the free trade zone has a significant inhibitory effect on carbon emissions in coastal areas. Compared with the control group, the experimental group has an average decrease of 0.0261% in CE after the policy compared to before; However, the DID coefficient in inland free trade zones is not significant, indicating that pilot policies in free trade zones have a significant inhibitory effect on carbon emissions in coastal areas.

The reason for this phenomenon may be, firstly, due to the superior geographical conditions of coastal areas compared to the mainland, and the use of shipping and other means, import and export are more convenient compared to the mainland, thereby driving the improvement of local economic development level. The related industrial clusters and structures are also more complete and mature compared to non coastal areas; Secondly, after the implementation of the free trade pilot zone policy, it further helps coastal areas open up trade barriers. The influx of foreign capital will further drive the upgrading of industrial structure in coastal areas and enhance the technological innovation capabilities of enterprises. On the contrary, non coastal areas may face a series of obstacles such as increasing transportation costs for enterprises due to the lack of geographical advantages, and the government may lack experience in relevant open policies, The uneven quality of settled enterprises will make the pilot policies of free trade zones have a slightly weaker impact on carbon reduction compared to coastal areas.

Table 9. Regional Heterogeneity Test

	(1)	(2)
variable	CE (Coastal)	CE (Not)
DID	-0.0261***	-0.0412***
	(0.0040)	(0.0259)
PGDP	-0.0040	0.0081
	(0.0080)	(0.0093)
Gov	-0.0445	0.0815
	(0.0399)	(0.0515)
Finance	-0.0046	0.0236***
	(0.0064)	(0.0072)
Inter	0.0014	0.0098***
	(0.0014)	(0.0022)
Waste	0.0284**	-0.0161
	(0.0118)	(0.0112)
Energy	0.0050	0.0025
	(0.0034)	(0.0023)
Cons	0.0021	0.0089
	(0.0029)	(0.0087)
Innovate	-0.0055	0.0031
	(0.0038)	(0.0026)
Constant	8.1332***	7.3204***
	(0.1101)	(0.0775)
Observations	1,355	2,084
R-squared	0.771	0.477
Number of groups	113	174
Urban fixed effects	YES	YES
Year fixed effect	YES	YES

Standard errors in parents
***P<0.01, * * p<0.05, * p<0.1

4.4.2. Batch heterogeneity in the establishment of free trade zones

The establishment of free trade pilot zones is carried out in batches, so the timing of the establishment of free trade pilot zones may also affect the impact of pilot policies on regional carbon emissions, with phased characteristics. Referring to the approach of Li Ben et al. (2018), equation (6) is set on the basis of equation (1) to examine the impact of different batches of free trade pilot zones on the carbon emissions of their respective cities:

$$CE_{i,t} = \alpha_0 + \sum_{n=1}^{4} \gamma_n DID_{i,t} \times P_{i,t} + \beta_3 X_{i,t} + \delta_t + \mu_i + \varepsilon_{i,t} \quad (6)$$

In equation (6), P_{IT}A dummy variable representing the establishment batches of free trade zones. In China, a total of six batches of free trade zones were approved from 2010 to 2021. Considering the unique geographical location and implementation scope of Hainan Free Trade Port compared to other free trade zones, and the fact that the fifth batch approved in 2020 is relatively recent, this article focuses on examining the four batches of free trade zones in 2013, 2015, 2017, and 2019. That is, n=1,2,3,4. If city i is the first batch of free trade zone cities, then $P_{1\ ton}$=1. And so on, we obtain P_{2T}, P_{3t}, P_{4t}By estimating the absolute values of coefficients for different free trade zones, the heterogeneity of the impact of different batches of free trade zones on carbon emissions can be tested.

From 10, it can be seen that controlling for other variables remains unchanged, the coefficients of the first and second batches are not significantly different, but the coefficients of the first batch are more significant. The inhibitory effect of the third and fourth batches on carbon emissions is significantly weaker than the first two batches, and the later the batch, the smaller the inhibitory effect. The possible reasons for this result are as follows: Firstly, The establishment of early batches of free trade pilot zones has had a long time to implement and integrate sustainable practices, formulate and enforce stricter environmental regulations, and invest in cleaner technologies and infrastructure. These cities may have a leading advantage in environmental awareness and technological innovation, and are more inclined to develop knowledge-based industries and service industries, with relatively less reliance on high carbon emitting heavy industries, thereby reducing overall carbon emissions; Secondly, this article found that most of the early free trade pilot zones were established in coastal cities, which is consistent with the results of regional heterogeneity testing in this article. Cities with earlier batches mostly have more convenient transportation and logistics, are easier to cooperate with international partners, introduce advanced environmental protection technologies and management experience, and generally have larger economic scales, More likely to invest funds and resources in green technology innovation and environmental protection facility construction to reduce carbon emissions; Thirdly, there may be a time lag in the impact of the construction of free trade pilot zones on carbon emissions. There is a time gap between government decision-making,policy formulation, implementation, implementation, and final results, and the pilot policies of free trade zones may also have a "policy lag". However, we can also find that the longer the pilot policies are implemented, the better the inhibitory effect on carbon emissions. Therefore, under the influence of these factors, the first two batches of free trade zones, It shows a more significant inhibitory effect on urban carbon emissions.

Table 10. Batch Heterogeneity Testing

variable	（1）
	Batch heterogeneity
	CE
The first batch of free trade zones	-0.0377***
	(0.0117)
The second batch of free trade zones	-0.0392**
	(0.0132)
The third batch of free trade zones	-0.0279
	(0.0173)
The fourth batch of free trade zones	-0.0244
	(0.0173)
Constant	8.1617***
	(0.1699)
control variable	YES
City	YES
Year	YES
Observations	480
R-squared	0.662

Standard errors in parents
***P<0.01, * * p<0.05, * p<0.1

5. Conclusion and Policy Recommendations

5.1. Research conclusion

China actively responds to the challenge of global climate change by formulating and implementing a series of carbon peaking and carbon neutrality policies to promote green and low-carbon development. To achieve carbon neutrality and carbon reduction, both gradual and disruptive innovation is needed. The establishment of free trade pilot zones also has its purpose, targeting the different needs of carbon reduction for trade, energy, and innovative technology, and achieving gradual innovation, even breakthrough or disruptive innovation, The establishment of free trade pilot zones can become a cutting-edge layout for achieving carbon peak goals. Therefore, this article selected panel data from 287 cities in China from 2010 to 2021 and used a multi time point double difference model to examine the impact of the establishment of free trade pilot zones on urban carbon reduction from multiple perspectives. The research results found that: firstly, the establishment of free trade pilot zones can significantly promote carbon reduction and suppress carbon emissions in cities, And this conclusion still holds after a series of robustness tests; Secondly, the establishment of free trade pilot zones can promote urban carbon reduction and effectively suppress carbon emissions by promoting industrial structure upgrading, expanding the level of opening up to the outside world, and enhancing technological innovation capabilities; Thirdly, the establishment of free trade pilot zones also has regional heterogeneity in their impact on carbon emissions, with coastal free trade pilot zones having a more significant inhibitory effect on promoting carbon emissions. Fourthly, the establishment of free trade pilot zones also has a time lag effect on carbon emissions, with earlier established free trade pilot zones having a more significant inhibitory effect on carbon emissions.

5.2. Policy recommendations

Based on the above conclusion, the following suggestions are proposed:

Firstly, the implementation scope of pilot policies for free trade zones should be expanded in an orderly manner to stimulate the potential for improving urban carbon emissions reduction. Based on the previous research conclusions, it has been proven that the establishment of free trade zones is an effective way to curb urban carbon emissions. Therefore, it is necessary to summarize the current experience of pilot areas, refine and promote the pilot policies for free trade zones nationwide, and actively implement the policies for free trade zones in pilot areas, Adhere to ecological priority and low-carbon development. Promote major ecological and environmental protection reform measures to be prioritized in pilot free trade zones, guide and support the demonstration and creation of ecological civilization in pilot free trade zones, which will contribute to the backbone of carbon peaking and carbon neutrality;

Secondly, continue to optimize the industrial structure and transform the mode of economic development. While maintaining economic growth, pilot cities in free trade zones should also further optimize the industrial structure, develop high-tech industries and tourism services, standardize industrial production methods, establish strict enterprise access standards, fully absorb technology and knowledge spillovers from developed regions and foreign enterprises, reduce the proportion of the primary and secondary industries, increase the proportion of the tertiary industry, eliminate backward production capacity, control carbon emissions from the source, and achieve decoupling between economic performance and carbon emissions;

Thirdly, increase investment in scientific research and improve technological innovation capabilities. ContinuingIncrease research and development investment, leverage technological advantages, optimize energy structure, vigorously support the development of clean energy, improve energy utilization efficiency, effectively reduce the use of disposable energy, pay attention to the introduction of advanced foreign technologies, and effectively enhance the development level of enterprises and cities themselves;

Fourthly, pilot areas should implement proactive low-carbon policies tailored to local conditions. Based on the different regions and types of cities where pilot cities are located, differentiated low-carbon policies should be implemented from a practical perspective. For coastal and other cities with convenient transportation, while continuing to expand the level of openness, high standard enterprise admission regulations should be established, foreign high-tech green technologies should be introduced, and enterprise innovation capabilities should be enhanced. For inland cities in the central and western regions, efforts should be made to develop low-carbon lifestyles, actively leverage the advantages of clean energy such as solar and wind energy, accelerate the transformation of urban energy structure, and reduce carbon emissions.

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