Can the Establishment of Free Trade Zones Promote Carbon Emission Reduction? ----Based on Multi-period Double Difference Model

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Abstract. As the Shanghai Free Trade Zone (FTZ) celebrates its 10th anniversary, it is crucial to examine the impact of the FTZ's construction on regional carbon emissions under the dual carbon targets of carbon neutrality and carbon peaking. Based on panel data from 282 prefecture-level cities between 2006 and 2021, this article aims to provide insight into the impact of the Free Trade Zone (FTZ) pilot policy on urban carbon dioxide emissions levels. By constructing a difference-in-differences (DID) model, this study aims to investigate the effects of the Free Trade Zone (FTZ) policy on carbon emission reduction. In order to perform a mechanism test, two more mechanistic variables—namely, technical advancement and upgrading of the industrial structure—are incorporated. According to the findings from experiments, the policy of free trade zones can effectively reduce carbon emissions from urban areas. This is primarily achieved by optimizing the industrial structure and scientific and technological mechanisms.

Keywords: Free Trade Zone, Carbon Dioxide Emission, Difference-in-Difference Method.

1. Introduction

In October 2013, the China (Shanghai) Pilot Free Trade Zone was officially established. Since then, a total of 22 Pilot Free Trade Zones have been deployed in seven batches, forming a pattern of opening-up and innovation that covers the whole country, and coordinates the development of coastal, inland, and border areas. 2023 marks the 10th anniversary of the construction of China’s Pilot Free Trade Zone and the first year to implement the “Free Trade Zone promotion strategy”. Free trade zone expansion has sped up China's latest phase of reform and opening-up, encouraged superior economic growth, and improved environmental advantages are an essential component of all of these.

China's excessive carbon dioxide emissions have resulted in a growing number of environmental issues that are impeding the country's economy's high-quality growth. With the objectives of "Carbon Dioxide Peaking" and "Carbon Neutrality," China's Free Trade Zone building is confronted with new difficulties. In an effort to transform the Free Trade Zones into demonstration models that coordinate the promotion of high-quality economic development and high-level ecological environment protection, eight departments in China collaborated to formulate and release the "Guiding Opinions on Strengthening the Ecological Environment Protection in Free Trade Pilot Zones and Promoting High-quality Development" in June 2021. Thus, there are practical and policy benefits to investigating how the creation of free trade zones affects regional carbon emissions.

Currently, the impact of trade politics on regional development has attracted the attention of many scholars, who have conducted research and discussions on this topic. The current domestic research on Free Trade Zones mainly focuses on their economic benefits. JIANG Ling-duo [1] (2021) has discovered that there is a synergistic effect between China's free trade zone policy and other major national strategies, which has significantly boosted foreign trade. Using counterfactual methods, TAN Na [2] (2015) examined the short-term economic impact of the free trade zone and discovered that the establishment of the FTZ had a significant positive effect on economic growth in Shanghai. Those findings highlight the beneficial impact of the FTZ on the local economy mainly through increased foreign investment, trade liberalization, and other mechanisms. Most discussions on the environmental aspect focus on the overall impact of urban environmental pollution. HU Yan [3] (2023) characterized urban pollution based on three dimensions: industrial wastewater, sulfur dioxide, and smoke (dust) emissions. HU Zongyi [4] (2002) examined the issue of urban air pollution. Relevant studies have shown that pilot free trade zone policies can effectively improve environmental problems and promote regional sustainable development. As for the regional carbon emission level, the current research is limited to the analysis of inter-province data. According to Shao Liangshan's [5] (2023) proposal, China's policy of free trade zones primarily reduces carbon emissions by maximizing the regional industrial structure's intermediary effect and advancing the invention of green technologies.

One might observe that, while free trade zones have been shown to have environmental benefits, the connection between domestic free trade zones and carbon emissions has received very little attention in the literature. However, the data selection in the current research has to be further improved. Thus, the purpose of this research is to investigate the potential effects of free trade zones creation on urban carbon dioxide emissions and conduct an empirical analysis of the energy consumption of 282 Chinese prefecture-level cities. Different from previous research, this paper's marginal contribution resides in the following areas: First, this article investigates the effect of Free Trade Zones (FTZs) on urban carbon dioxide emissions based on data analysis of prefecture-level cities. This study adds to the body of knowledge on the environmental advantages of FTZs by improving and enhancing the empirical research findings about the connection between FTZ pilot initiatives and urban carbon emissions. Secondly, this paper further investigates the impact mechanism of FTZs on carbon emissions, examining two mechanism variables: industrial structure upgrading and technological progress. This provides references for further improving regional carbon emission reduction policies. Thirdly, this paper offers pertinent policy recommendations for relevant departments, which have a certain reference value for encouraging high-quality economic development in pilot Free Trade Zones (FTZs) and accomplishing the dual carbon targets of carbon neutrality and carbon peaking as soon as possible. The suggestions offered are based on the results of the empirical analysis.

The remainder of this paper's structure is arranged as follows: The theoretical analysis is presented in Section 2 and focuses at the underlying mechanisms and concepts with references to earlier research. In Section 3, the variables utilized in the analysis are explained along with the multi-period Difference-in-Differences (DID) model's architecture. Section 4 employs empirical analysis to examine how the creation of free trade zones affects urban carbon emissions. Finally, the conclusions and policy recommendations are presented.

2. Theoretical Analysis

Free Trade Zones reduce urban carbon emissions in a favorable way. First, in order to establish a model of ecological and environmental protection and to assist in the development of high-level free trade zones, relevant departments have developed guidelines on the reduction of carbon emissions. Second, the government directs green and low-carbon development, and free trade zones fully implement the general standards for carbon reduction.

In light of the analysis above, this paper proposes research hypothesis 1:

H1: The establishment of free trade zones can significantly reduce the level of carbon dioxide emissions in cities.

2.1. Mechanism in Upgrading of Industrial Structure

Over time, the strategy of the pilot free trade zone is expected to facilitate the advanced development of the regional industrial structure [6]. First, by maximizing the distribution of capital, production elements, and information, a free trade zone's policy enhances the impact of resource allocation and encourages the growth and modernization of related industries [7]. Second, the institution of free trade zones stimulates the upgrading of the industrial structure by enhancing the industrial aggregation impact and continuously enhancing the industrial chain structure within free trade zones.

Regional carbon dioxide emissions are inhibited by industrial structure upgrade. Of the three industries, the secondary industry's development model—which is defined by “high input, high pollution, and low output”—produces the most carbon emissions. Modernizing the industry structure will, on the one hand, greatly improve energy efficiency [8]. However, by increasing quality, efficiency, and lowering costs, the upgrading of the industrial structure can progressively lessen the secondary industry's reliance on energy consumption, resulting in a positive feedback loop that promotes both environmental preservation and economic growth [9]. This has a major impact on cutting carbon dioxide emissions.

In light of the analysis above, this paper proposes research hypothesis 2:

H2: The establishment of free trade zones can significantly reduce the level of carbon dioxide emissions by encouraging the upgrading of industrial structures.

2.2. Mechanism in Technological Innovation

The establishment of free trade zones can gradually enhance the regional scientific and technological innovation capacity. Firstly, the trade facilitation brought about by the establishment of the free trade zone will intensify the competition intensity of regional enterprises, forcing them to constantly iterate on technologies, products, and services to enhance their competitiveness, to improve the level of urban scientific and technological innovation. Secondly, the open policy environment in the free trade zone can speed up the flow of talent, make the alternate of knowledge and technology more frequent, and its spillover effect will enhance the degree of city scientific and technological innovation [10]. Thirdly, the relevant fiscal and tax policies furnished via the pilot free trade zone cities will stimulate the innovation vitality of enterprises and research institutions, guide social investment, and thus promote technological progress.

Innovation in science and technology significantly accelerates the reduction of carbon emissions from metropolitan areas. One way to improve the environment is through scientific and technical advancement, as noted by Beckerman [11] (1992). The endogenous growth theory states that as technology advances, natural resource utilization rates will increase and allow for large-scale resource conservation and recycling. This will further reduce energy consumption at a given output level and the associated carbon emissions and ecological damage [12].

In light of the analysis above, this paper proposes research hypothesis 3:

H3: The establishment of free trade zones can significantly reduce the level of carbon dioxide emissions by promoting technological progress in cities.

3. Model Design and Variable Declarations

3.1. Specification of Model

This paper uses the multi-time difference-in-differences (DID) model to analyze the mechanism effect and industry heterogeneity of the impact of pilot free trade zone policies on carbon dioxide emissions in prefecture-level cities using panel data of 282 Chinese cities from 2006 to 2021. Official statistics, such as the "China Urban Statistical Yearbook" and the "China Energy Statistical Yearbook," provide the necessary data. Interpolation techniques are used to fill in the missing values. Since the policies for free trade zones have been gradually established in multiple phases and cities since 2013, a difference-in-differences (DID) model is constructed as follows:

$$Y_{it} = \alpha_0 + \alpha_1 FTZ_{it} + \sum \alpha_j C_{it} + City_i + Year_t + \varepsilon_{it} \tag{1}$$

In this model, the explained variable Y_{it} represents the carbon dioxide emissions of prefecture-level *city i* in *year t*. FTZ_{it} is the core explanatory variable, which takes a value of 1 for the year and all subsequent years when *city i* is listed as a free trade zone in *year t*, and 0 for years prior to that.

C_{it} represents a series of control variables. $City_i$ is the individual fixed effect, $Year_t$ is the time fixed effect, and ε_{it} is the random error term.

3.2. Variable Settings

(1) Explained variable

Y_{it} represents the carbon dioxide emissions of a city. Referring to the carbon dioxide emission factor accounting method of Liu [13] (2020), this paper selects three energy sources: electricity, coal and petroleum. Firstly, the measurement units of energy are uniformly converted to standard coal. Then, the corresponding carbon emission factors are calculated using the estimated parameters for carbon dioxide emission reduction. Based on this, the carbon emissions of each prefecture-level city are obtained and logged. The specific data is as follows:

Table 1. Carbon Dioxide Emission Factor Accounting

Energy Consumption	Carbon Dioxide Emission Factor
Electricity	7.50t CO_2/MWH
Coal	1.89t CO_2/t
Petroleum	3.02t CO_2/t

(2) Core explanatory variable

FTZ_{it} represents a dummy variable for the free trade zone policy. If *city i* is established as a free trade zone in *year t*, then for that year and all subsequent years, it is considered as the treatment group with $FTZ_{it} = 1$ $(m \le t)$. Prefecture-level cities that have not implemented the free trade zone policy serve as the control group with $FTZ_{it} = 0$.

(3) Control variables

According to the existing literature, regional carbon emission intensity is related to factors such as economic development level, population density, degree of openness, financial development, local fiscal expenditure, and environmental quality. Therefore, this paper introduces important variables that affect urban carbon dioxide emissions, including GDP per capita (*GDP_capita*), which measures the economic development level of the city; population density (*den_pop*); the degree of openness is measured by the logarithm of foreign direct investment in the region (*lnFDI*); The logarithm of the balance of loans from financial institutions in different regions (*lnloan*); local fiscal expenditure is measured by the logarithm of the fiscal budget expenditure of prefecture-level cities for the current year (lnfiscal); and the green coverage rate of built-up areas (green), which measures the environmental quality of cities.

(4) Mechanism variables

The industrial structure's advancement and the degree of technological innovation are the mechanism factors used in this study. Specifically, considering the technique of Gan Chunhui [14] (2011), the ratio of the tertiary industry's production value to that of the secondary industry is used to measure the advancement of the industrial structure. The percentage of the city's current year's expenditures on science and education is used to gauge technological innovation.

4. Empirical Analysis

4.1. Descriptive Statistics of Variables

Table 2 displays the descriptive statistical results for the major model variables.

Table 2. Descriptive Statistics of Variables

	Variables	Sample Capacity	Mean	Standard Deviation	Minimum Value	Maximum Value
Explained Variables	CO_2 Emissions	4512	15.42349	1.266148	11.05697	18.86535
Core Explanatory Variable	FTZ_{it}	4512	0.0352394	0.1844047	0	1
Control Variables	*GDP_capita*	4512	43202.6	33379.34	99	467749
	den_pop	4512	435.7433	373.7626	4.7	8898.6
	lnFDI	4512	9.687106	2.025791	1.098612	14.94127
	lnloan	4512	16.10889	1.294007	12.54772	20.51304
	lnfiscal	4512	14.4123	1.01559	10.80617	18.24054
	green	4512	39.78819	101.1871	0.36	95.25
Mechanism Variables	*Industry*	4512	0.9567143	0.5604723	0.0943168	9.482223
	Technology	4512	0.1946042	0.0447986	0.0158138	0.497399

4.2. Benchmark Regression

Next, according to the benchmark model formula, the effect of the free trade zone policy on the carbon emissions of prefecture-level cities is examined. Table 3 displays the outcome.

Table 3. Benchmark Regression

	(1)	(2)	(3)
	CO_2 Emissions	CO_2 Emissions	CO_2 Emissions
FTZ_{it}	-0.434***	-0.387***	-0.167***
	(-12.33)	(-10.64)	(-2.74)
Control Variables	-	Control	Control
$City_i$	Control	Control	Control
$Year_t$	Control	Control	Control
PSM	-	-	Control
Constant Term	15.439***	9.012***	19.84***
	(2499.31)	(10.70)	(12.69)
Sample Capacity	4512	4512	2296
$Adjusted-R^2$	0.8990	0.9026	0.9697

Note: *, **, *** represents significant in 10%, 5%, 1% level respectively. t-values are in parentheses.

Based on the estimation of Model (1), Table 3 reports the regression results of the establishment of free trade zones on urban carbon dioxide emissions. Column (1) includes city-fixed effects, time-fixed effects, but excludes control variables. Column (2) incorporates city-fixed effects, time-fixed effects, and control variables.

According to Column (2), the regression coefficient of the pilot policy for free trade zones is negative and significant at the 1% level. this indicates that the establishment of free trade zones can significantly promote the effect of urban carbon emission reduction, verifying Hypothesis 1. The regression coefficient of -0.387 suggests that the establishment of free trade zones has led to a 38.7% decrease in urban carbon dioxide emissions. After adding control variables, the $Adjusted-R^2$ value increases, indicating that Column (2) provides a better explanation.

4.3. Robustness Test

(1) Parallel trend test

The main purpose of the Difference-in-Differences (DID) model is to assess how an event or policy affects a certain outcome variable. Its basic presumption is that the treatment group's (affected by the policy) and the control group's (unaffected by the policy) outcome variables would trend in the same direction in the absence of policy intervention. Validating the establishment of this underlying assumption is the goal of the parallel trend test.

To conduct a parallel trends test and further examine the impact of the establishment of free trade zones on urban carbon emission reduction, this paper utilizes the following model:

$$\begin{aligned} Y_{it} = \alpha &+ \beta_1 Before8_{it} + \beta_2 Before7_{it} + \beta_3 Before6_{it} + \beta_4 Before5_{it} + \beta_5 Before4_{it} \\ &+ \beta_6 Before3_{it} + \beta_7 Before2_{it} + \beta_8 Before1_{it} + \beta_9 Current_{it} + \beta_{10} After1_{it} \\ &+ \beta_{11} After2_{it} + \beta_{12} After3_{it} + \beta_{13} After4_{it} + \beta_{14} After5_{it} + \beta_{15} After6_{it} \\ &+ \sum \gamma_j C_{it} + City_i + Year_t + \varepsilon_{it} \end{aligned} \tag{2}$$

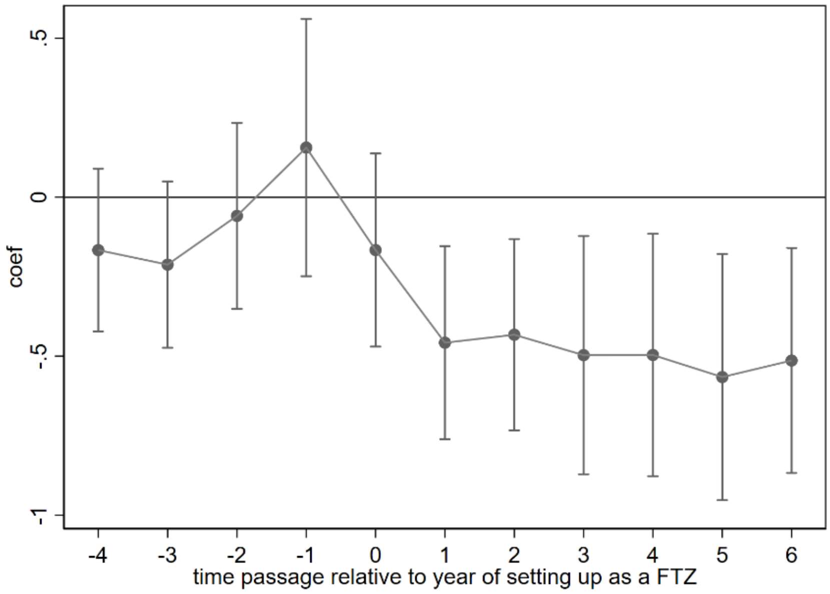

Figure 1. Parallel Trend Test

The treatment group refers to the pilot areas that carried the free trade zone policy into reality, whereas the control group comprises other regions. Figure 1 depicts the parallel trends test, from which it can be observed that the regression coefficients for the first four years before the implementation of the free trade zone policy in the treatment group are statistically not significant at the 10% level, this suggests that there was no discernible difference in the trend of carbon emissions between the treatment and control groups prior to the policy intervention, thereby satisfying the parallel trends assumption and validating the baseline regression conclusion. However, following the implementation of the free trade zone policy, the regression coefficient for the treatment group exhibits a negative and statistically significant trend at the 10% level, indicating that the policy has a sustained inhibitory effect on regional carbon emissions.

(2) PSM-DID

To address the issue of sample selection bias, propensity score matching analysis was employed. Cities implementing Free Trade Zone (FTZ) pilot policies may have factors such as economic structure optimization, energy efficiency improvement, clean energy technology innovation, and effective environmental policies, all of which may promote carbon emission reduction. Consequently, there may be biases in the sample selection of this study. To further address this issue, this paper employs propensity score matching methods. Based on controlling variables such as foreign direct investment (FDI), population density, regional GDP per capita, and green coverage rate, a logit model was established to determine whether an FTZ was established in a region. A nearest neighbor 1:1 matching approach was then used to match prefecture-level cities, and the benchmark regression was repeated using the matched samples. The regression results in Column (3) of Table.3 show that the estimated coefficient using propensity score matching is still significantly negative at the 1% level, with no fundamental changes in the sign and significance level, consistent with the main regression results. This further verifies the reliability of the theoretical analysis and empirical findings in this study.

(3) Placebo test

This study utilizes a placebo test to determine the unpredictability of the carbon emission reduction effect in order to determine whether the influence of free trade zone development on urban carbon dioxide emissions is not due to other random causes. In the placebo test, a random selection of different prefecture-level cities is made as pseudo-treatment groups, and the test is repeated 500 times. Regression is then performed using the original benchmark model to examine the distribution of coefficients. With a mean around zero and a regression coefficient that is much greater than the benchmark, the results, as illustrated in Figure 2, suggest that the distribution of regression coefficients for urban carbon dioxide emissions on the "pseudo-policy dummy variable" is close to a normal distribution. This shows that other random factors are not responsible for the influence of the free trade zone policy on the reduction of urban carbon emissions, supporting the validity of the outcomes from the benchmark regression.

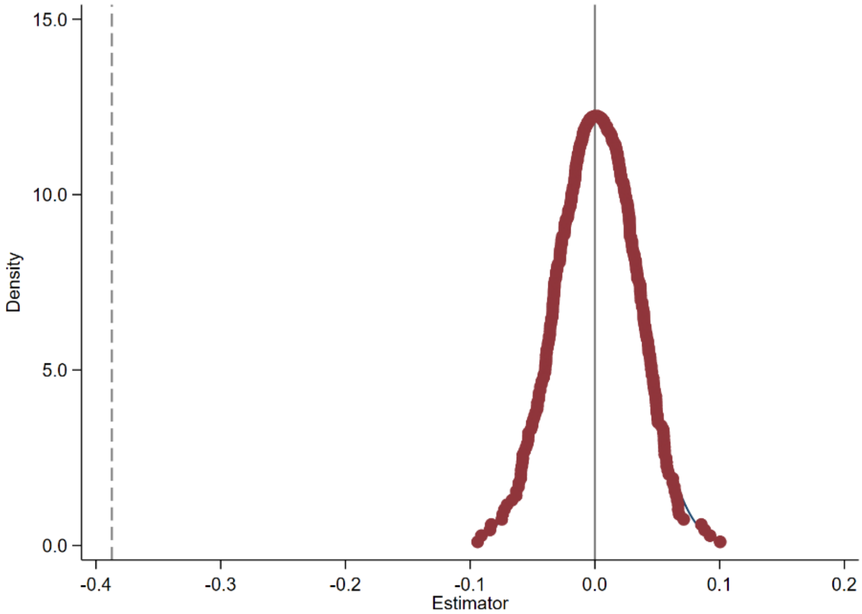

Figure 2. Placebo Test

4.4. Mechanism Test

The aforementioned empirical findings indicate that free trade zones can have a substantial impact on reducing urban carbon emissions. Theoretically, through the benefits of technological innovation and upgrading of industrial structures, free trade zone pilot policies may lower urban carbon dioxide emissions. In order to verify this mechanism, the model that follows is created in this paper:

$$Inter_{it} = \alpha_0 + \alpha_1 FTZ_{it} + \sum \alpha_j C_{it} + City_i + Year_t + \varepsilon_{it} \quad (3)$$

$$Y_{it} = \beta_0 + \beta_1 Inter_{it} + \beta_2 FTZ_{it} \times Inter_{it} + \sum \beta_j C_{it} + City_i + Year_t + \varepsilon_{it} \quad (4)$$

In this model, $Inter_{it}$ represents the mechanism variable, which is replaced by two variables reflecting the industrial structure upgrading effect (*Industry*) and technological innovation effect (Technology). If both coefficients α_1 and β_2 are significant, it indicates that the mechanism effect is established. The empirical results of the mechanism test are presented in Table 4.

Table 4. Mechanism Test

0	(1)	(2)	(3)	(4)
	Industry	CO_2 Emissions	*Technology*	CO_2 Emissions
FTZ_{it}	0.125***		0.006***	
	(4.02)		(2.68)	
$FTZ_{it} \times Industry$		-0.232***		
		(-10.63)		
$FTZ_{it} \times Tecchnology$				-2.002***
				(-9.62)
Control Variables	Control	Control	Control	Control
Constant Term	3.62***	8.92***	0.82***	9.04***
	(6.35)	(10.37)	(11.31)	(9.96)
Sample Capacity	4512	4512	4512	4512
$Adjusted - R^2$	0.7562	0.9027	0.7197	0.9025

Note: *, **, *** represents significant in 10%, 5%, 1% level respectively. t-values are in parentheses.

(1) The impact of improving industrial structures

According to Column (1), the dummy variable's coefficient for the formation of a free trade zone on the improvement of industrial structure is 0.125, indicating a substantial positive correlation at the 1% level. With a 12.5% contribution rate, it shows that the setting up of a free trade zone can be beneficial in advancing the modernization of urban industrial structure. According to Column (2), the regression coefficient of the advancement of industrial structure on carbon dioxide emissions is significantly negative at the 1% level, suggesting that cities can successfully lower their carbon emissions by upgrading their industrial structure. Hypothesis 2 is confirmed: for every 1% optimization in industrial structure, there will be a 23.2% decrease in urban carbon emissions.

(2) The effect of scientific and technological innovation

With a regression coefficient of 0.006, Column (3) demonstrates that the dummy policy variable for the free trade zone has a significantly positive coefficient at the 1% level, suggesting that the pilot program for the free trade zone is helpful in raising the degree of urban innovation in science and technology. According to Column (5), scientific and technological innovation has a considerably negative coefficient at the 1% level, demonstrating that technological innovation has the potential to lower carbon dioxide emissions. In conclusion, Hypothesis 3 is verified by the free trade zone pilot strategy, which encourages the reduction of urban carbon emissions by boosting the degree of regional technological and scientific creativity.

5. Further Discussion

For the free trade zone policy, an interaction term between the industry variable and dummy variable ($Industry \times FTZ_{it}$) is carried out in order to investigate the variations in the effects of various industries on the decrease of urban carbon emissions. The following is the established model:

$$Y_{it} = \alpha_0 + \alpha_1 FTZ_{it} + \alpha_2 industry \times FTZ_{it} + \alpha_3 C.industry + \sum \alpha_j C_{it} + City_i + Year_t + \varepsilon_{it} \quad (5)$$

The detailed regression results using the decentered ratios of the secondary and tertiary industries to GDP as interaction terms are presented in Table 5. These interaction terms were constructed to investigate the differential impact of different industries on urban carbon emission reduction based on the model established earlier.

Table 5. Mechanism Test

	(1)	(2)
	Secondary Industry	Tertiary Industry
$Industry \times FTZ_{it}$	0.011***	-0.121***
	(3.58)	(-4.98)
Control Variables	Control	Control
$City_i$	Control	Control
$Year_t$	Control	Control
$Adjusted-R^2$	0.9099	0.9095
Sample Capacity	4512	4512

Note: *, **, *** represents significant in 10%, 5%, 1% level respectively. t-values are in parentheses.

(1) The proportion of the secondary industry

The secondary industrial structure and the free trade zone policy have an estimated coefficient of interaction that is significantly positive at the 1% level, according to the results from Column (1). This suggests that the free trade zone policy has less of an effect on promoting the decrease of urban carbon emissions in places where the secondary industry makes up a larger percentage of GDP.

(2) The proportion of the tertiary industry

The interaction term between the free trade zone policy and the tertiary industrial structure has an estimated coefficient that is notably negative at the 1% level, as indicated by the data obtained from Column 2. This suggests that the free trade zone pilot program has a greater effect on encouraging the reduction of urban carbon emissions in cities with more developed tertiary industries.

6. Research Conclusion and Policy Suggestions

6.1. Research Conclusion

The establishment of free trade zones has had a major positive impact on the environment in addition to increasing international trade and fostering regional economic prosperity. This study investigated the effect of FTZ guidelines on urban carbon dioxide emissions using panel data from 282 prefecture-level cities ranging from 2006 to 2021. A multi-period double difference-in-differences model (DID) was utilized. The results show that the setting up of free trade zones greatly aids in achieving targets for reducing urban carbon emissions. Additional mechanism testing reveals that the mechanisms of industrial structure upgrading, and technical advancements underpin the substantial impact of free trade zone standards on carbon dioxide emissions. Furthermore, the study discovered that the development of free trade zones has a more noticeable impact on encouraging the reduction of urban carbon emissions in municipalities with more developed tertiary industries. The report makes the following policy recommendations in light of these findings:

6.2. Policy Recommendations

(1) Strategic Planning for Industrial Growth and Structural Optimization

Prioritizing Industries: Establish clear development priorities for various industries to guide social capital and resources toward key sectors.

Restructuring the Industrial Chain: Optimize the industrial chain for greater synergy and competitiveness, phase out polluting industries, and encourage the development of green and innovative industries to promote structural transformation.

(2) Fostering Technological Research and Innovation

Financial Support: Establish a dedicated green technology innovation fund with tax incentives or rebates, encourage financial institutions to provide loans and financing services, and support enterprises and research institutions.

Industry-Research Collaboration: Promote partnerships between enterprises, universities, and research institutions, encouraging the application and commercialization of innovative technologies.

(3) Tailoring Policies to Local Conditions

Tailored Policy Design: Develop differentiated policies tailored to specific regions and industries, aligned with local needs.

Feedback Mechanism: Establish a feedback loop to adjust and optimize policies based on carbon reduction effectiveness, ensuring their sustained relevance.

Public Education and Awareness: Enhance public understanding of green and low-carbon cities through promotional activities, educational facilities, and outreach programs.

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