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Original Paper

The Impact of the Construction of Pilot Free Trade Zones on Reducing Carbon Emissions in Resource-based Cities

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Abstract

As the world accelerates its response to climate change, resource-based cities that have long depended on resource development face a particularly difficult task in cutting carbon emissions. This study focuses on China's Pilot Free Trade Zones (FTZs), a major institutional innovation, and takes a closer look at how they affect the environment of resource-based cities. Using a difference-in-differences (DID) model, the study analyzes panel data on carbon emissions from resource-based cities before and after FTZs establishment. The results show that establishing FTZs significantly reduce carbon emissions in these cities. This carbon-reduction effect works through three channels: lowering energy consumption intensity, increasing foreign direct investment, and enhancing green technological innovation. The effect is more pronounced in the central and western regions and in declining cities. These findings offer useful implications for promoting coordinated regional development and designing differentiated policies. They also highlight the critical role of institutional innovation in achieving the "dual carbon" goals.

Keywords

Construction of Pilot Free Trade Zones, Difference-in-Differences, Resource-based city, carbon emission

1. Introduction

Global warming has made carbon reduction a central task for sustainable urban development worldwide. In China, the development problems facing resource-based cities have drawn growing attention in recent years. Drawing on abundant natural resources, these cities made important contributions at particular stages of national economic development and helped drive industrialization. But an extensive development model that leaned too heavily on resource extraction has badly damaged their ecological environments. As resources run down, these cities now face a dual crisis—economic decline and ecological degradation—and an urgent need to find new development paths. Pilot Free Trade Zones

(FTZs) have been at the forefront of China's efforts to deepen reform and expand opening-up. Since the first one, the Shanghai FTZ, was established in 2013, the number of FTZs has grown steadily and their geographical coverage has continued to expand. With their special policy advantages, these zones have attracted considerable domestic and foreign investment and helped trade grow rapidly. More importantly, they have actively experimented with green development, providing useful experience and models for resource-based cities seeking to cut carbon emissions. Research on how FTZs development affects carbon reduction in resource-based cities is therefore important not only for the green transformation of these cities but also for improving regional ecological environments and advancing sustainable development.

The literature relevant to this study falls into three main strands. The first concerns the impact of establishing pilot free trade zones. Most work in this area looks at the issue from economic and innovation perspectives. On the economic side, many scholars have examined the economic benefits of transnational or interregional free trade zones [1][2], while other studies focus on China's economic security [3] and export behavior [4]. On the innovation side, some argue that FTZs can strengthen international competitiveness by shifting from old growth drivers to new ones [5]. A second body of work looks at carbon emissions. At the provincial level, there is evidence that pilot FTZs policies lower regional carbon emissions by roughly 30 percent [6]. At the city level, the picture is similar: creating FTZs sub-zones seems to have positive emission-reduction effects, with local carbon emissions growth falling by about 2.0 percentage points on average [7]. Some studies take this further. They suggest that FTZs do not only curb emissions directly; they may also help cities move toward relative "zero emissions" by strengthening carbon absorption, which supports low-carbon transition [8]. From a policy-evolution perspective, the phased establishment of FTZs appears to have brought down both total carbon emissions and emission intensity, and the effect seems to reach surrounding cities as well [9]. Not everyone agrees, though. One line of work finds negative spatial spillovers: FTZs may lower local emissions while putting more pressure on neighboring cities [10].

A third strand examines the relationship between China's pilot FTZs policies and the ecological environment. On the environmental side, studies report that FTZs policies can significantly reduce PM2.5 concentrations [11] and improve green total factor productivity [12]. Some scholars argue that FTZs help reduce environmental pollution and protect ecosystems, and that further progress depends on staying on a green development path [13]. Trade openness matters for the environment [14], and FTZs are seen as an important foundation for high-quality green trade [15]. Zhaolian Hu et al. find that trade liberalization has both positive and negative effects on environmental pollution. In their sample, the negative effects—the ones that worsen pollution—dominate [16]. FTZs can also push service-sector structural upgrading through imitation or independent innovation [17], which lowers the share of the secondary sector. This has become one of the key ways to improve environmental quality [18].

Taken together, existing studies have looked at FTZs policies from many angles. Yet the environmental evidence remains somewhat mixed, and relatively few studies focus specifically on resource-based cities. This paper therefore looks at how FTZs development affects carbon reduction in resource-based cities.

Combining theoretical analysis with empirical research, it tries to clarify the mechanisms at work, compare FTZs across different regions, and offer a theoretical basis and practical guidance for resource-based cities as they design scientific and reasonable carbon-reduction strategies. The broader aim is to support green transformation and sustainable development in these cities and to contribute to China's ecological civilization agenda.

2. Theoretical Analysis and Assumptions

Pilot free trade zones are the core vehicle for China's institutional opening-up. Their development is essentially an institutional transformation. This transformation centers on trade facilitation and investment liberalization [19]. These pilot platforms allow China to benchmark against high-standard international economic and trade rules. The CPTPP and DEPA are examples. China incorporates relevant provisions on environmental market access, carbon management, and green technology cooperation. These provisions help align domestic regulatory standards with international norms. They also help integrate the two. The alignment of rules can raise the regional threshold for environmental access, compel the orderly exit of inefficient production capacity, improve the allocation of production factors, and establish a collaborative mechanism to support the low-carbon transition [7]. For resource-based cities that have long relied on resource extraction and primary processing, this institutional shift reshapes—from the outside—the environment for factor allocation and the rules of industrial competition. Institutional openness has strengthened the market signals of environmental regulations, driving the gradual phase-out of energy-intensive and high-emission industries. Under the combined influence of internal and external forces, the total carbon emissions of resource-based cities will show a downward trend.

Based on this, we propose Hypothesis 1: The establishment of pilot free trade zones has a significant negative impact on the carbon emissions of resource-based cities.

Pilot free trade zones lower barriers to technology transfer. They also make market competition more intense. Enterprises in these cities improve their production processes. They optimize how they use energy. Energy consumption per unit of GDP falls steadily. The zones set strict institutional constraints. These include environmental access requirements and dual-control mechanisms for energy consumption. These constraints force existing energy-intensive enterprises to upgrade their production processes. These enterprises can get the same economic output with less energy. Pilot programs open up the energy sector. Green energy policies help raise the share of clean energy in industrial production and park operations. Examples are natural gas and green electricity. This supports low-carbon development.

Negative list management is central to zone operations. It relaxes foreign investment access. It improves the business environment. This helps expand capital inflows. It also makes them more stable [20]. The access catalog has a green orientation. New foreign investment goes toward new energy, energy conservation and environmental protection, high-end manufacturing, and production-oriented services. The technological content and environmental standards of incoming capital improve overall. Foreign-

invested enterprises bring advanced production processes, environmental management systems, and green supply chain standards. Domestic enterprises absorb these through demonstration and competitive effects. This helps reduce carbon emissions.

Institutional opening-up in the Pilot Free Trade Zones speeds up the gathering of innovation factors. These factors include knowledge, technology, and talent. Intellectual property protection and R&D incentive policies inside the zones lower the cost of green technology R&D. Domestic and international technological exchanges and cooperation widen access to green technologies. These conditions encourage market entities to engage in green technological innovation. Green technology innovation can drive clean energy substitution. It can drive end-of-pipe carbon capture and utilization. It can drive low-carbon transformation of production processes. This reduces carbon emissions at the source. It becomes a core driving force for institutional openness empowering low-carbon development.

Hypothesis 2 is proposed: The development of Pilot Free Trade Zones can curb carbon emissions in resource-based cities by reducing energy consumption intensity, increasing the level of foreign direct investment, and promoting green technology innovation.

3. Research Design

3.1 Model Design

This paper uses a double-difference model. We want to see how Pilot Free Trade Zones development affects carbon reduction in resource-based cities. We compare pilot cities with non-pilot cities. That comparison makes it easier to identify the effects. The model is set up as follows.

$$y_{it} = \beta_0 + \beta_1 DFTZ + \beta_2 Cont + u_i + \gamma_t + \varepsilon_{it}$$

Here,i indexes cities and t indexes years, and The dependent variable is y_{it}. DFTZ is the key explanatory variable. It takes the value 1 in the year a city is designated as a pilot city for the Free Trade Zones, and stays 1 in the years after that. In all other cases it is 0.Cont collects the control variables. The individual fixed effect is denoted by μ_i ,while γ_t picks up the time fixed effect. The random error term is ε_{it} .and β_0 is the constant term.The coefficient on DFTZ, β_1, captures the direct impact of FTZs development on carbon reduction in resource-based cities. This is the main parameter of interest in this paper.

3.2 Selection of Variables

3.2.1 Dependent Variable

The dependent variable in this study is urban carbon dioxide (CO_2) emissions. Given data availability constraints, we measure urban carbon emissions using the logarithm of CO_2 emissions.

3.2.2 Independent Variables

The core independent variable in this study is the interaction term for pilot cities in the Pilot Free Trade Zones (DFTZ), obtained by crossing the spatial dummy variable Treat with the temporal dummy variable Post. Specifically, Treat is used to distinguish the sample of cities included in the Pilot Free Trade Zones program. It is set based on whether a prefecture-level city has been designated as a pilot site; the variable takes a value of 1 if a pilot zone is established, and 0 otherwise. Post is used to identify the timing of

Pilot Free Trade Zones construction. For city i, once the pilot program begins in year t, Post takes a value of 1 for that year and subsequent periods; otherwise, it is set to 0.

3.2.3 Control Variables

Drawing on relevant studies [6–10] and further considering that social production and daily life typically generate substantial carbon emissions, the following control variables are selected to minimize bias as much as possible: level of economic development (lnagdp), represented by the natural logarithm of each city's per capita gross domestic product; government support (gov), measured by the ratio of local general budget expenditures to GDP; level of financial capital investment (fin), measured as the ratio of year-end deposit and loan balances at financial institutions in each city to GDP; population density (lnpeo), defined as the natural logarithm of the ratio of the permanent resident population to the land area of the administrative region; urbanization level (ur), expressed as the ratio of the urban permanent resident population to the total permanent resident population; and human capital (edu), calculated as the number of college students per 10,000 people.

3.2.4 Mechanism Variables

These include energy consumption intensity, foreign direct investment (FDI) levels, and green technology innovation levels. Among these, energy consumption intensity (energy) is represented by the ratio of a city's annual energy consumption to GDP, while green technology innovation levels (lngreenpat) are measured using 1 plus the logarithm of the number of green invention patents granted. Meanwhile, FDI levels (lnfdi) are represented by the logarithm of each city's actual foreign capital utilization for the year.

3.3 Sample Selection and Data Sources

This paper matches data on pilot cities for free trade zones with data on resource-based cities. The data on pilot cities for free trade zones were compiled from the list of free trade zones disclosed by the Ministry of Commerce of the People's Republic of China, while the data on resource-based cities were compiled from the *National Sustainable Development Plan for Resource-Based Cities (2013–2020)* issued by the State Council of the People's Republic of China. Other relevant data were obtained from the annual *China Urban Statistical Yearbook*, city-level statistical yearbooks, government websites at various levels, and government work reports. Table 1. presents the descriptive statistics for each variable.

Table 1. Descriptive Statistics

VarName	Obs	Mean	SD	Min	Median	Max
lnco2	1495	7.725	0.976	5.455	7.787	10.333
DFTZ	1495	0.027	0.161	0.000	0.000	1.000
lnagdp	1495	10.679	0.521	8.936	10.673	12.486
gov	1495	0.233	0.102	0.057	0.207	0.717
fin	1495	2.322	0.831	0.588	2.208	8.777

lnpeo	1495	5.318	0.931	2.114	5.365	7.171
ur	1495	55.820	13.595	21.479	54.880	100.000
edu	1495	3.933	3.907	0.029	2.667	26.142

4. Empirical Analysis

4.1 Benchmark Regression

Table 2 reports the baseline regression results. These results show the impact of Pilot Free Trade Zones development on carbon reduction in resource-based cities. Column (1) gives a coefficient of -0.102. This coefficient is significant at the 1% level. The establishment of Pilot Free Trade Zones has a negative correlation with carbon dioxide emissions in resource-based cities. Column (2) includes the control variables. The coefficient for Pilot Free Trade Zones development is still significantly negative at the 1% level. Pilot Free Trade Zones development can be an effective measure. It can help resource-based cities reduce carbon emissions and pollution.

Table 2. Benchmark Regression Results

	(1)	(2)
	lnco2	lnco2
DFTZ	-0.102***	-0.098***
	(-4.628)	(-4.047)
lnagdp		0.032
		(0.579)
gov		0.092
		(0.602)
fin		-0.011
		(-0.664)
lnpeo		0.189
		(1.487)
ur		-0.001
		(-0.237)
edu		0.001
		(0.160)
_cons	7.727***	6.415***
	(13158.716)	(7.115)
N	1495	1495
R^2	0.988	0.988
adj. R^2	0.987	0.987

4.2 Parallel Trend Test

This paper defines the event window as the four years prior to policy implementation and the four years following it, using the period immediately preceding the policy as the control group for estimation. Figure 1.presents the results of the parallel trend test for carbon dioxide emissions. The event study findings show that prior to the implementation of the pilot free trade zones policy, the dynamic effect coefficients for all periods were not significant, and the confidence intervals included zero, indicating that there was no significant difference in the trends of carbon emissions between the treatment group and the control group of cities. In the early stages of the pilot program, the carbon reduction effects were not immediately apparent; however, the dynamic coefficients gradually became significantly negative, reflecting a lag in the emission-reduction effects of this open pilot program, with policy benefits continuing to materialize over time. Therefore, the sample passed the parallel trend test required for estimation using the difference-in-differences method.

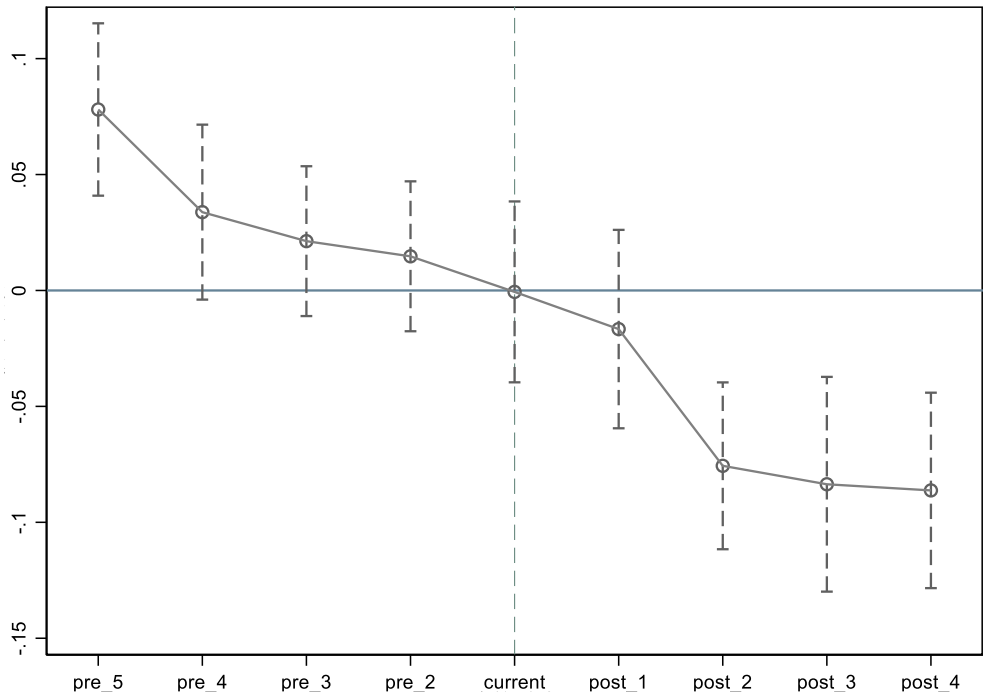


Figure 1. Parallel Trend Test Plot for Carbon Dioxide

4.3 Placebo Test

To avoid the influence of other unobservable factors following policy intervention, we conducted a placebo test. Figure 2 shows that the estimated coefficients, with a mean of 0, follow a normal distribution, indicating that the estimation results in this paper are unlikely to be affected by unobservable factors and are therefore robust.

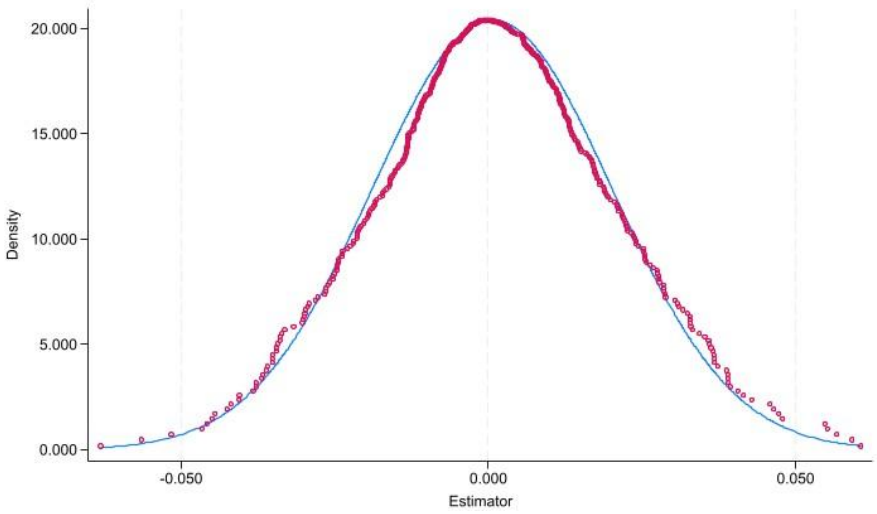


Figure 2. Placebo Test Plot for Carbon Dioxide

4.4 Robustness Test

The benchmark regression results in this paper may be subject to estimation errors due to other factors; therefore, to verify the reliability of these results, robustness tests were conducted from the following perspectives, with the results presented in Table 3.

4.4.1 Excluding samples from the year the policy was implemented. This paper re-ran the regression after excluding samples from the year of the policy shock.Column (1) reports a DFTZ coefficient. It is significantly negative at the 1% level. The direction matches the baseline regression. The significance level does not change. Samples from the year the policy was implemented do not bias the research conclusions.

4.4.2 Lag the core explanatory variable by one period. Pilot free trade zones development may affect carbon emissions with a time lag. Policy effects may not show up in the current period. We re-estimated the model with the DFTZ variable lagged one period (L.DFTZ). Column (2) reports the results. The lagged L.DFTZ coefficient remains significantly negative at the 1% level. The carbon reduction effects of pilot free trade zones are persistent. The policy effects remain robust with time lags.

4.4.3 Exclude samples from exceptional years. The sample period may contain exceptional years affected by external shocks, such as the COVID-19 pandemic. Carbon emission fluctuations in these years may not come from pilot free trade zones policies. We re-estimated the model without these samples. Column (3) shows DFTZ remains significantly negative at the 1% level. The absolute coefficient value is even slightly larger than in the baseline regression. This further supports the robustness of the conclusion.

4.4.4 Exclude samples affected by special policies. Concurrent low-carbon city pilot policies related to carbon emissions may affect the estimates during the sample period. We re-ran the regression without city samples affected by overlapping policies. Column (4) reports a DFTZ coefficient of -0.092. It remains significantly negative at the 1% level. The carbon reduction effect of pilot free trade zones is not driven by other concurrent environmental policies. The core conclusion is highly exclusive.

Table 3. Robustness Test Results

	(1)	(2)	(3)	(4)
	lnco2	lnco2	lnco2	lnco2
DFTZ	-0.111***		-0.118***	-0.092***
	(-4.244)		(-4.272)	(-3.625)
L.DFTZ		-0.098***		
		(-4.192)		
lnagdp	0.032	0.023	0.043	0.091
	(0.577)	(0.431)	(0.750)	(1.388)
gov	0.094	0.075	0.089	0.041
	(0.615)	(0.527)	(0.574)	(0.220)
fin	-0.011	-0.010	-0.010	-0.007
	(-0.659)	(-0.659)	(-0.624)	(-0.449)
lnpeo	0.189	0.130	0.182	0.137
	(1.482)	(1.220)	(1.314)	(1.108)
ur	-0.001	-0.000	-0.001	-0.000
	(-0.217)	(-0.105)	(-0.347)	(-0.163)
edu	0.001	0.003	-0.000	-0.002
	(0.183)	(0.381)	(-0.059)	(-0.374)
_cons	6.411***	6.813***	6.338***	6.105***
	(7.097)	(8.313)	(7.008)	(5.834)
N	1488	1380	1144	1040
R^2	0.988	0.990	0.988	0.990
adj. R^2	0.987	0.989	0.987	0.989

4.5 Mediation Effect Analysis

Table 4 shows the regression results for the pathways linking pilot free trade zones development to urban carbon reduction. In resource-based cities, pilot free trade zones development significantly reduced energy consumption intensity. This suggests that institutional openness and technological spillover helped enterprises improve their production processes and use energy more efficiently. Pilot free trade zones development also helped increase foreign direct investment. That foreign investment brought industrial collaboration and talent exchange, which provided direct financial and human capital support for regional carbon reduction. Green technology innovation also plays an important role in cutting carbon emissions in pilot free trade zones. Alignment with high-standard economic and trade rules raises local environmental standards and changes the competitive landscape. As a result, enterprises have an incentive to invest more in green technology R&D. This helps develop more low-carbon processes and

emission-reduction technologies.

Table 4. Results of the Mediation Effect Analysis

	(1)	(2)	(3)
	energy	lnfdi1	lngreen
DFTZ	-0.029**	1.770**	0.424***
	(-2.357)	(0.678)	(0.132)
lnagdp	-0.031	1.454***	0.448**
	(-1.599)	(0.4715)	(0.204)
gov	-0.116**	-0.087	-0.074
	(-2.539)	(1.892)	(0.618)
fin	0.013	-0.108	0.063
	(1.205)	(0.121)	(0.059)
lnpeo	0.006	1.177	0.895*
	(0.296)	(1.238)	(0.484)
ur	0.002**	0.025	-0.013
	(2.157)	(0.015)	(0.009)
edu	0.001	0.077*	0.046*
	(0.816)	(0.044)	(0.025)
_cons	0.310	-21.271**	-7.015*
	(1.216)	(8.384)	(3.640)
N	1482	1,282	1,495
r2	0.781	0.721	0.836
r2_a	0.760	0.689	0.820

4.6 Heterogeneity Analysis

4.6.1 Locational Heterogeneity

This paper runs a regression analysis on 115 resource-based cities. The sample is divided into eastern, central, and western regions. Table 5 reports the results. The coefficient for central cities is significantly negative at the 1% level. Pilot free trade zones development has a significant carbon-reduction effect on resource-based cities in the central region. These cities have a heavy industrial structure. Pilot free trade zones development promotes trade facilitation and attracts foreign investment. It pushes energy-intensive industries to transform and upgrade. This generates notable carbon emission reductions.

The coefficient for the western region is significantly negative at the 5% level. Its absolute value is the largest of the three regions. The carbon-reduction effect of pilot free trade zones is most pronounced in resource-based cities in the western region. These cities have long relied on resource extraction and

primary processing. Their technological capabilities are relatively weak. Institutional openness and external exchanges in pilot free trade zones can more effectively bring in green technologies and low-carbon management expertise. These cities can suppress carbon emissions through a "latecomer advantage."

The coefficient for the eastern region is not statistically significant. The carbon-reduction effect of pilot free trade zones on resource-based cities in the eastern region is not significant. Eastern cities have a strong economic base. Trade liberalization has driven economic expansion. Economic expansion has raised carbon emissions. The scale effect may have offset the emission reductions from industrial upgrading and technological progress. The net policy effect is insignificant.

Table 5. Results of the Heterogeneity Test by Location

	East	Central	West
	lnco2	lnco2	lnco2
DFTZ	0.009	-0.108***	-0.124**
	(0.356)	(-3.251)	(-2.062)
lnagdp	-0.027	0.057	-0.022
	(-0.355)	(0.666)	(-0.120)
gov	-0.129	-0.002	0.280
	(-0.346)	(-0.005)	(1.377)
fin	-0.014	-0.022	0.006
	(-0.430)	(-0.973)	(0.112)
lnpeo	0.411	0.037	0.443*
	(1.360)	(0.329)	(1.944)
ur	-0.010**	0.002	-0.001
	(-2.152)	(0.530)	(-0.106)
edu	-0.014**	0.008	0.016
	(-2.408)	(0.795)	(0.601)
_cons	6.994***	6.889***	5.296**
	(3.652)	(5.403)	(2.476)
N	325	650	520
R^2	0.993	0.983	0.987
adj. R^2	0.992	0.981	0.986

4.6.2 Heterogeneity in Resource-Based City Types

This paper draws on the official classification criteria for resource-based cities and groups the sample into four types: regenerating, mature, growing, and declining. It then looks at how the carbon-reduction

effect of pilot free trade zones development varies across these different development stages. Table 6 presents the results. For declining cities, the DFTZ coefficient is significantly negative at the 1% level, meaning that pilot free trade zones development has its strongest carbon-reduction effect in these cities. Declining resource-based cities face a tough combination of challenges: resources are running out, economic development is lagging, and ecological and environmental pressures are serious. Energy-intensive, high-emission resource industries still account for a large share of the local economy, so the pressure to transform is especially urgent. Pilot free trade zones help shift the industrial structure away from resource dominance and toward more diversified alternatives. Greater openness also tightens environmental regulation. Together, these forces produce a strong "policy-driven" emission reduction effect.

Regenerating, mature, and growing cities, by contrast, did not pass the significance test. There are several possible reasons. Regenerating cities have largely moved past their dependence on resources, and their transformation is more or less complete. Their carbon emissions are already relatively low, so the marginal room for further emission reductions through pilot free trade zones policies may be limited. Mature cities are in a stable phase of resource development, and the internal urgency for industrial transformation is not particularly strong; policy effects may simply not have fully materialized yet. Growing cities, meanwhile, are still in a phase of expanding resource development. The additional carbon emissions that come with that expansion may offset the carbon reduction gains from pilot free trade zones.

Table 6. Results of the Heterogeneity Test by City Type

	Regenerating Cities	Mature Cities	Growing Cities	Declining Cities
	lnco2	lnco2	lnco2	lnco2
DFTZ	-0.055	-0.074	-0.142	-0.273***
	(-1.410)	(-1.544)	(-1.035)	(-4.925)
lnagdp	-0.006	-0.015	0.024	0.364*
	(-0.092)	(-0.295)	(0.085)	(2.009)
gov	-0.182	0.059	0.826	0.227
	(-0.915)	(0.439)	(1.642)	(0.715)
fin	0.017	-0.001	-0.082	-0.026
	(1.049)	(-0.109)	(-0.749)	(-0.662)
lnpeo	0.181	0.095	1.248	0.234
	(0.980)	(0.623)	(1.700)	(1.444)
ur	-0.005	-0.003	0.011	0.001
	(-1.239)	(-1.002)	(1.347)	(0.396)
edu	-0.010**	0.010	-0.018	0.017
	(-2.756)	(1.060)	(-0.573)	(0.865)

_cons	7.682***	7.489***	0.874	2.291
	(6.104)	(7.655)	(0.360)	(0.863)
N	195	806	195	299
R^2	0.998	0.990	0.984	0.981
adj. R^2	0.998	0.989	0.981	0.978

5. Conclusion and Enlightenment

This paper employs panel data covering 115 resource-based cities over 2011–2023 to investigate the impacts of Pilot Free Trade Zones (FTZs) construction on carbon emission reduction in resource-based cities. The empirical results indicate that FTZs development significantly suppresses carbon emissions and facilitates the carbon abatement process of such cities, and this finding survives a battery of robustness checks. Heterogeneity analysis demonstrates that the carbon-reduction effects of FTZs differ substantially across resource-based cities. Regionally, the effect is the most salient among western resource-based cities, a pattern explained by the latecomer technology dividend available in western China. By city subtype, the emission-mitigating effect is strongest for declining resource-based cities. This is mainly because these cities suffer from resource exhaustion and feature a high proportion of carbon-intensive industries, which creates ample space for institutional opening-up to drive industrial transformation. Mechanism tests further suggest that FTZs construction curbs carbon dioxide emissions by reducing energy intensity, attracting foreign direct investment, and stimulating green technological innovation, thereby advancing the low-carbon transition of resource-based cities.

Several policy implications can be drawn from the above results:

(1) Pilot Free Trade Zones deliver notable policy dividends in carbon abatement. Authorities should continue to advance FTZs development and deepen institutional innovation within existing pilot sites. Meanwhile, targeted policies supporting carbon reduction in resource-based cities ought to be rolled out to align local practices with environmental clauses embedded in high-standard international economic and trade agreements. Such arrangements can reconcile regional economic growth with low-carbon transition.

(2) Heterogeneous, region-tailored strategies are essential when leveraging FTZs to advance carbon reduction in resource-based cities. FTZs were launched in different batches across regions, and host cities diverge markedly in resource endowments and industrial comparative advantages. Accordingly, FTZs with different founding timelines and geographic locations require differentiated positioning. Each resource-based city should formulate plans suited to its local conditions, realize efficient resource allocation via refined functional division and sound spatial layout, and ultimately deliver the green development target of carbon emission reduction.

(3) Timely summarize and distill the reform and innovation achievements of pilot free trade zones in carbon reduction to enhance the feasibility and replicability of these outcomes. While fully considering

comprehensive factors such as the endowment of factors of production and the stage of development in cities where these practices are to be promoted, actively extend proven carbon reduction policies to other cities that are not pilot free trade zones. In this way, we can promote the green development of resource-based cities, effectively safeguard regional "green security" during the economic development process, and achieve long-term carbon reduction goals.

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