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Research Article

How Does Market-Oriented Environmental Regulation Affect Carbon Emission Performance? A Quasinatural Experiment Based on the Pilot Policy of Energy-Use Rights Trading

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In order to evaluate the effect of market-oriented environmental management measures on regional carbon emission intensity in the pilot areas better, this paper adopts a quasinatural experiment of energy-use rights trading (EURT) policy by using the difference-in-difference method from the perspective of cities in China from 2006 to 2019. The results show that the policy of EURT can significantly reduce regional carbon emission intensity, which varies in different regions and different scales of cities. The main goal of implementing the policy is to reduce regional carbon emission intensity by improving the energy consumption structure and promoting the improvement of industrial structure and green innovation. In addition, the spatial impact of the EURT pilot project is demonstrated by its ability to not only reduce local carbon emission intensity but also decrease carbon intensity in and around the designated areas.

1. Introduction

Integrating market regulatory mechanisms into environmental governance policies is another key strategy for China to accelerate the achievement of its "dual-carbon" goals. Currently, the environmental situation in China remains severe [1]. According to the International Energy Agency's (IEA) "2022 Carbon Dioxide Emissions Report," China's CO_2 emissions reached 12.1 billion tons in 2022, still ranking first in the world. The total carbon emissions accounted for 32.88% of the global emissions, far exceeding those of other major carbon-emitting countries. In this context, the Chinese government has promulgated and implemented a series of environmental governance policies, including command-and-control environmental regulations such as low-carbon pilot city policies, comprehensive demonstration areas for energy conservation and emission reduction fiscal policies, and public-participation-based environmental regulations such as environmental courts and environmental information disclosure policies. However, due to the limitations of command-and-control and public-participation-based environmental regulations, the asymmetry of information among the government, the public, and enterprises in pollution emissions and governance cannot be effectively addressed. This often leads to market failures such as environmental agency problems and moral hazards, resulting in limited actual effectiveness in environmental emission reduction and continued severity of pollution emissions.

In contrast, market incentive-based environmental regulations, such as pollutant discharge rights trading pilots, carbon emission rights trading pilots, environmental taxes, and energy-use rights trading (EURT), utilize market mechanisms to price pollutants and guide enterprise emission behaviors through price signals. Ultimately, by incentivizing polluters to actively participate in pollution control, these market-based regulations are aimed at achieving selfregulation of emission activities [2]. Theoretically, compared to command-and-control and public-participation-based environmental regulations, market-based environmental regulations can effectively address various market failures caused by information asymmetry between the government, the public, and enterprises, thereby promoting substantial emission reductions in China [3, 4]. However, the majority of existing market-based environmental regulations, such as pollutant discharge rights trading pilots and carbon emission rights trading pilots, primarily focus on end-of-pipe approaches to eliminate carbon emissions. Although this approach can to some extent address market failures in the environmental dimension, it fails to curb carbon emissions at the source. On the other hand, the EURT system sets the total energy consumption and intensity control targets during the “13th Five-Year Plan” period, emphasizing addressing environmental issues at the source. Therefore, a precise assessment of the emission reduction effects and mechanisms of the energy rights trading pilot implementation is essential. It can both effectively validate the advantages of market-based environmental regulations in strengthening emission reduction, providing guidance for future environmental governance policy formulation in China, and offer front-end governance solutions based on market mechanisms to accelerate the achievement of China’s “dual-carbon” goals. Moreover, existing literature on market incentive-based environmental regulations focuses on discussing the carbon emission reduction effects of policies such as carbon emission rights trading pilots, nitrogen oxide emission trading pilots, and sulfur dioxide emission trading pilots [5–9]. Literature directly related to EURT pilot policies predominantly concentrates on the impact of EURT pilot implementation on regional green development efficiency and energy consumption intensity factors [10, 11], with limited direct research on the impact of EURT pilot policy implementation on carbon emissions.

In this regard, based on data from 283 prefecture-level cities in China from 2006 to 2019 (prefecture-level city-level data was chosen because China has accurate carbon emission data at this level compared to other levels), this study treats the EURT pilot policy as a quasinatural experiment. It employs a multiperiod difference-in-difference model to empirically investigate the impact of the EURT pilot policy implementation on carbon emissions. The marginal contributions of this study are as follows: (1) This study accurately evaluates the emission reduction effects of the EURT pilot policy using an advanced multiperiod difference-in-difference model, effectively confirming the superiority of market-based environmental regulations over traditional command-and-control environmental regulations in addressing environmental market failures and promoting substantial carbon reduction in China. The research results are universally applicable. (2) The mechanistic test results demonstrate that fully leveraging the role of the market in energy resource allocation to drive China’s achievement of its “dual-carbon” goals provides a front-end governance solution based on market mechanisms, effectively mitigating the dilemma of traditional market-based environmental regulations’ inability to curb carbon emissions at the source. (3) This study not only accurately evaluates the emission reduction effects of the EURT pilot in pilot areas but also further examines the spillover effects of this policy implementation on emission reduction in neighboring areas, greatly enriching the research perspective of the article.

2. Literature Review

This paper is closely related to two aspects of research: one is the impact of market-based environmental regulation policies on carbon emissions. Market-based environmental regulation policies refer to local governments pricing pollutants based on market conditions, using price signals to guide corporate pollution behavior, and ultimately encouraging polluters to actively invest in pollution control through incentives, so as to achieve the goal of self-control of pollution behavior [2]. It not only promotes the development of energy saving and emission reduction but also strengthens green sustainable development and promotes environmental ecological governance. Market-based environmental regulation policies can stimulate enterprises to engage in green technology innovation, thereby improving carbon emission reduction performance [3, 4]. Xie et al. [9] pointed out that carbon emission trading policies have improved the power technology structure, promoted the use of low-emission power technology projects, and reduced regional carbon emissions. Scholars have also studied nitrogen oxide emission trading in the United States. Farrell et al. [7] used a dynamic, lenient mixed integer linear programming model for nitrogen oxide quota markets to show that market-driven environmental measures can enhance green technology innovation, reduce carbon emissions, and produce short-term Porter effects [6, 8, 12]. Chen et al. [5] empirically evaluated the SO_2 emission trading policy using a double-difference model and found that it significantly reduced industrial SO_2 emission intensity in pilot areas. Tang et al. [13] used the PSM-DID method to study the impact of emission trading policies on enterprise innovation and productivity and found that emission trading policies have a significant promoting effect on enterprise innovation, but no significant impact on enterprise productivity. The above studies show that the implementation of market-based environmental regulation policies can effectively reduce regional pollution emissions. Obviously, using EURT pilot policies as a typical representative of market-based environmental regulation, theoretically, can also reduce regional carbon emissions.

The second aspect is to explore the comparison between market-based environmental regulation, traditional command-and-control environmental regulation, and EURT pilot policies in terms of emission reduction effectiveness. Some scholars used data envelopment analysis (DEA) methods to establish interprovincial production models to simulate the impact of emission reduction policies on carbon emission cost savings and carbon emission intensity reduction and compared different types of emission reduction measures. They concluded that market-based emission reduction policies were more effective than command-and-control policies [14, 15]. First, high levels of economic development and technological endowment can promote low-carbon emission reduction, not only helping to reduce carbon emissions but also improving resource utilization and achieving sustainable development [16–18]. Second, as the population size continues to shrink, the effect of reducing energy consumption intensity on carbon emissions is becoming increasingly obvious. This is because when the population size is small, people are more likely to use energy more effectively, thereby reducing carbon emissions, and the amount reduced will also be greater. In addition, when the population size is small, people can better utilize resources, thereby reducing pollution and damage to the environment [19, 20]. Furthermore, although market-based environmental regulation policies can reduce pollution emissions caused by market failures in the environmental sector compared to command-and-control environmental regulation policies, existing research mainly focuses on the impact of market-based environmental regulation policies on emission reduction from the "back-end" governance link [5–9]. However, such environmental regulation policies cannot effectively control carbon emissions from the source. EURT pilot policies emphasize cutting off pollution sources from the front-end by optimizing energy consumption allocation, thereby improving regional pollution reduction levels. However, there are limited empirical studies discussing the carbon emission reduction effects of EURT pilot policies.

In summary, previous research has shown that the implementation of market-based environmental regulation policies can effectively reduce carbon emissions, and market-based environmental regulation policies perform better in emission reduction effectiveness than traditional command-and-control environmental regulation. However, market-based environmental regulation policies that focus on incorporating market mechanisms into the back-end governance link have failed to effectively control carbon emissions from the source. Although the EURT pilot policy is a typical market-based environmental regulation policy that incorporates market mechanisms into the front-end governance link, there are limited articles exploring the carbon emission reduction effects of this policy. Therefore, empirically studying the carbon emission reduction effects of the EURT pilot policy has some theoretical and practical significance. On the one hand, it can effectively supplement the shortcomings of such research; on the other hand, it can effectively verify the superiority of market-based environmental regulation policies, especially those based on front-end governance, in carbon emission reduction effects. This provides ideas and solutions for the country's further promotion of market-based environmental regulation policies.

3. Policy Background and Research Hypothesis

3.1. Policy Background. China began market-oriented environmental controls in the early 1980s to address the country's carbon emissions [8]. Since 2007, the Chinese government department has actively conducted a nationwide pilot project of paid use with a total investment of 522 million RMB. In 2021, with the implementation of the carbon market for the first time, China will see the first compliance period for the aboriginal assortment of power companies, and the "national carbon market," which has been in the making for more than a decade, will be further improved on this basis. The experimental results of the above market types have good reference value for China to establish a perfect environmental resource charging system.

Energy-use rights trading refers to the practice of trading energy rights indicators among energy consumers and other trading entities, facilitated by provincial energy-use rights trading agencies, within the framework of controlling regional energy consumption levels and intensity. Under the energy-use rights trading system, excessive energy consumption is subject to compensation. This internalizes the external costs associated with a firm's energy usage, contributing to the rational allocation of energy resources. The evolution of energy-use rights trading policies can be traced back to China's 13th Five-Year Plan in 2016, which introduced the idea of establishing a comprehensive system for the initial allocation of energy rights, water rights, pollution rights, and carbon emission rights. In July 2016, the National Development and Reform Commission released the "Pilot Program for the Paid Use and Trading of Energy Rights," launching energy-use rights trading pilot projects in Henan, Zhejiang, Sichuan, and Fujian. These pilots received official approval for their specific implementation plans in 2017. As of the end of 2019, all four pilot provinces had initiated paid use and trading of energy rights, achieving positive outcomes. This not only resulted in energy conservation but also enhanced the efficiency of energy utilization.

3.2. Research Hypothesis

3.2.1. Energy-Use Rights Trading Policy and Carbon Emissions. Environmental rights trading policies, as important market-based environmental regulatory policies, have been a hot topic in academic research. Existing studies have essentially confirmed the positive effects of environmental rights trading policies. Previous literature has demonstrated that market-based environmental trading systems such as emission trading, carbon emission trading, and energy-use rights trading can create Porter effects, inducing businesses to achieve progress in green technologies and consequently reduce high-carbon energy consumption [21]. Pollution rights trading policies can improve industrial total factor productivity by incentivizing technological advancement and optimizing resource allocation [22, 23]. Montgomery [24] further validated the cost-effectiveness of emission trading systems. Research by Carlson et al. [25] showed that the U.S. sulfur dioxide emission trading system significantly reduced abatement costs. In addition, carbon emission trading systems significantly reduce regional carbon dioxide emissions [26], promoting the progress and development of low-carbon technologies [27]. Shao et al. [28], focusing on China's carbon emission trading policy, investigated its synergistic governance effects on smog pollution and sulfur dioxide. Carbon emission trading policies affect green production performance [29]. They also have a substantial impact on green technology innovation in businesses [30].

Hu et al. [31] found that carbon emission trading reduced energy consumption in regulated industries in pilot areas by 22.8% and decreased CO_2 emissions by 15.5%. Wu et al. [15], based on their evaluation of emission trading pilot policies, concluded that this policy can reduce pollutant emissions at the macrolevel.

As an initial exploration of energy market reform, the energy rights policy is similar to the white certificate system proposed by the European Union in 2011. Di Santo et al. [32] pointed out that the white certificate system significantly promoted industrial energy efficiency in Italian regions. Furthermore, this system significantly reduced household energy consumption and further improved energy efficiency [33]. Giraudet et al. [34] demonstrated the carbon reduction effects of the white certificate system. In contrast, China's energy-use rights trading policy places constraints on the energy consumption of regulated enterprises, which creates an exogenous price increase in energy. On the one hand, under the price mechanism, enterprises that maintain their existing technologies incur additional production costs by purchasing energy usage rights quotas, potentially increasing their productive investments for green technological advancements [35]. On the other hand, the pilot program explicitly emphasizes increased government support for enterprise energy efficiency improvements. The compensatory effects generated by green technologies attract enterprises to adopt green technological advancements as a long-term development strategy [10]. Therefore, the energy-use rights trading pilot policy promotes the progress of clean energy technologies, energy-saving and emission reduction technologies, and other green technologies. Through peer effects and economies of scale, it facilitates the transition from high-carbon to low-carbon regions. Based on this, we propose research Hypothesis 1.

Hypothesis 1. The energy-use rights trading pilot policy contributes to reducing carbon emissions.

3.2.2. The Mechanisms of Energy Trading Policies for Carbon Emissions. Firstly, considering geographical location, the eastern regions, owing to their relatively higher economic development, often lead in terms of institutional innovation. They serve as experimental grounds and demonstration areas for numerous environmental policies. As a result, they have more advanced energy-efficient and environmentally friendly technologies and cleaner industrial structures. Even without the implementation of market-oriented environmental regulations, these provinces have already achieved relatively low-carbon emission levels [36]. In contrast, the central and western regions, with comparatively less favorable resource endowments and lower levels of energy-saving technologies, still have considerable room for improvement in terms of enhancing energy efficiency and reducing regional carbon emissions [37]. Specifically, high price targets will drive enterprises to adjust their production patterns, resulting in a shift towards lower use of energy-intensive sources [38–40]. Energy-intensive industries are slowly fading away in favor of greener, cleaner industries. However, because China's economy is a crude country, dominated by fuels such as fossil and coal, their combustion will directly increase the emission of polluting gases such as carbon dioxide and sulfur dioxide, which will further worsen environmental pollution [40]. The optimization of the structure will therefore contribute not only to reducing carbon emissions but also to improving energy efficiency and environmental quality for sustainable development [16, 20, 41, 42].

Secondly, emission trading systems can directly or indirectly impact industrial structure upgrades [31]. Empirical data from the European Union suggests that carbon emission trading significantly promotes industrial structure upgrades [43]. Wang [44], using a comprehensive control approach and a difference-in-difference method, demonstrated that China's emission trading policy has driven regional industrial structure optimization. Research by Xie et al. [9] also indicates that emission trading policies have significantly improved energy efficiency through industrial structure upgrades. Additionally, the paid utilization of energy rights and the resulting increase in internal production costs can lead to factor shifts. Simultaneously, the sale of allocation quotas can generate additional benefits, incentivizing local businesses to innovate production technology and adjust their internal structures. This, in turn, compels the industrial structure to move towards a more advanced level [31]. Industrial structure upgrading is a crucial factor for low-carbon development in cities. By breaking away from the reliance on energy consumption, it achieves sustainable growth. Typically, this involves transitioning from energy-intensive industries to those with lower energy inputs and reduced carbon emissions, such as the service sector and high-tech industries. This shift in the industrial structure leads to a transformation, ultimately resulting in carbon emission reduction [21, 45–47].

Thirdly, as a market-based environmental regulatory policy, environmental equity trading markets can leverage market mechanisms to transmit price signals for energy factors. Considering that energy factor prices are one of the key drivers for inducing technological innovation [48, 49], Liu and Sun [50] employed provincial panel data in China and found that carbon emission trading pilot policies effectively elevate the level of low-carbon technologies in pilot regions. Their findings align with the empirical research conclusions of Yang et al. [29] and support the "Porter Hypothesis." Calel and Dechezleprêtre [27] investigated the incentivizing effect of emission trading policies on green technology innovation within businesses. The pilot program for emission rights trading explicitly states that the government will continue to increase financial support and tax subsidies to alleviate the financial pressure on enterprises for energy-saving transformations. This, in turn, enhances the efficiency of green R&D in enterprises [29, 51]. Robust infrastructure and advanced technical equipment serve as the foundation for enterprises to innovate in green technologies. Increased R&D funding contributes to improving these hardware conditions and enhancing the sophistication of technical equipment. Consequently, the level of green technology also sees significant improvement [31]. Green technology innovation itself serves a societal function for environmental protection and energy conservation, further supporting the achievement of "dual carbon" goals and effectively promoting low-carbon development [21, 31].

Hypothesis 2. The EURT system is able to curtail regional carbon emissions by advancing the structure of energy consumption, optimizing the modernization of the industrial structure, and developing the level of green innovation.

In addition, the repercussion of market-incentivized regulation on carbon emissions may also be extraordinarily heterogeneous based on regional differences and governmental awareness of environmental protection in China [31, 42, 52]. Firstly, considering geographical location, the eastern regions, owing to their relatively higher economic development, often lead in terms of institutional innovation. They serve as experimental grounds and demonstration areas for numerous environmental policies. As a result, they have more advanced energy-efficient and environmentally friendly technologies and cleaner industrial structures. Even without the implementation of market-oriented environmental regulations, these provinces have already achieved relatively low-carbon emission levels [36]. In contrast, the central and western regions, with comparatively less favorable resource endowments and lower levels of energy-saving technologies, still have considerable room for improvement in terms of enhancing energy efficiency and reducing regional carbon emissions [37]. Second, in terms of city size, the large cities in the pilot areas have well-developed resource endowments and generally have high levels of energy-use efficiency, so the potential for energy saving is low, and the increase in energy-saving costs will continue to reduce the room for improving energy-use efficiency and further reducing carbon emissions [19]. Therefore, the implementation of the energy trading pilot policy may have a relatively poor effect on the emission reduction of large cities. Conversely, economic development in small- and medium-sized cities tends to lag behind, with outdated technological equipment and less comprehensive environmental policies. The overall level of energy-saving technologies is relatively low, indicating significant untapped potential for energy conservation [53]. The implementation of an energy-use rights trading system plays a vital role in enhancing local energy utilization efficiency, thereby harnessing the institutional advantages to effectively reduce regional carbon emissions. Finally, from the government's perspective, the government's primary objective is to significantly reduce regional carbon dioxide emissions, which is reflected in the government's moderate regulatory attention to compensate for the shortcomings of the trade market mechanism, overcome the inefficiency of the market mechanism, and reduce regional carbon dioxide emissions by continuously improving the market system of environmental regulation and increasing environmental awareness [42, 52, 54, 55].

Hypothesis 3. There is a momentous capriciousness in the abatement of carbon emissions in the EURT policy, with implementation cities in distinctive regions, distinctive sizes, and distinctive levels of government consideration.

In addition, China has actualized a number of pilot policies that have effectively contributed to the accelerated advancement of the economy [17, 56]. A common feature of these pilot policies is that they were first set up in certain cities, then replicated in other cities to form a chain, and finally realized a region-wide extension [37, 57]. Due to the spatial dependence on pollutant emissions, local pollution reduction efforts are influenced by the policy effectiveness of neighboring cities [58]. Research by J. Li and S. Li [51] also indicates the presence of spatial spillover effects in China's carbon emissions, wherein local carbon emissions lead to an increase in carbon emissions in adjacent regions. As one of the environmental equity trading policies, the pilot energy-use rights trading policy not only impacts economic and environmental performance within the designated pilot regions but also bears the responsibility of catalyzing improved economic and environmental performance in non-pilot areas [37]. Furthermore, due to carbon dioxide emissions being a form of atmospheric pollution, such pollution is subject to interference from factors such as wind direction, leading to the formation of cross-regional spillover effects. As a result, carbon emissions can be influenced by both local environmental pollution and the environmental pollution in neighboring areas [59]. Therefore, while reducing carbon emissions in the local area, it can also indirectly decrease carbon emissions in neighboring regions [60].

Hypothesis 4. In terms of spatial effects, energy trading has spatial spillover effects on reducing regional carbon emissions.

The research framework is shown in Figure 1.

4. Research Design

4.1. Setting of the Measurement Model. The double-difference method is a method of evaluating policy effects that calculates the difference between the incremental outcomes of an experimental group and a control group under a policy intervention in a natural experiment when the experimental and control groups satisfy the hypothesis of parallelism of trends. Therefore, based on the above theory, this section adopts the double-difference method to investigate the effect of the EURT system on regional carbon emissions [42, 61]. In the sample of the article, four provinces, Zhejiang, Fujian, Henan, and Sichuan, launched the pilot EURT system in 2016, which provides a good "quasinatural experiment" for the article. Specifically, the four provinces of Zhejiang, Fujian, Henan, and Sichuan constitute the treatment group, while the remaining provinces without pilot EURT systems constitute the control group. Quasinatural experiments were grouped according to whether or not EURT pilot work was carried out in the region, and the experimental and control groups were divided according to the timing of policy impact and purpose. The specific model of double difference (DID) is as follows.

$$\mathrm{rco}_2 = \beta_0 + \beta_1(\mathrm{treat}_i \times \mathrm{post}_t) + \beta x_{it} + \nu_i + \mu_t + \varepsilon_{it}, \quad (1)$$

where the interpretive variable is provincial carbon emission and the more considerable the CO_2 emissions, the more

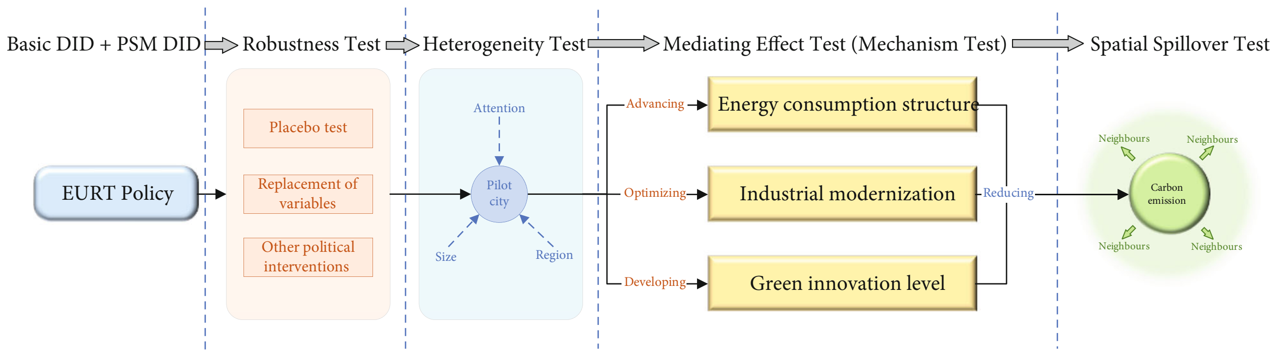

Figure 1: Research framework.

considerable the carbon emissions. $treat_i$ is the regional grouping variable; if the region is included in the pilot EURT, then $treat_i$ takes the value of 1, and vice versa, the $treat_i$ The value is 0. $post_t$ is a time dummy variable. Drawing from the methodology in Wang et al.'s [12] study, if a province implements energy trading pilot policies in the current year, it takes the value of 1 for that year and all subsequent years; otherwise, it takes the value of 0. x_{it} is the set of control variables, including the level of financial development, real utilization of foreign capital, the level of economic growth, education expenditure, government expenditure, science and technology expenditure, and the share of secondary industry in GDP; i and t represent the city and year, respectively. ε_{it} represents the random error terms, and the v_i and μ_t denote city and year fixed effects, respectively. In the above mathematical statement, the β_1 is the estimated coefficient of interest for the article, and if β_1 is incomparably negative, this demonstrates that the EURT system can extremely diminish regional carbon emissions.

4.2. Data Description and Variable Selection. Based on data availability and completeness, annual data from 283 provincial cities in mainland China from 2006 to 2019 were selected as a study sample to study regional indicators related to energy trade of CO_2 emissions. Unless otherwise stated, the data are obtained from the China City Statistical Yearbook and the China Energy Yearbook.

(1) Dependent variable (regional carbon emissions (rco2)): in this study, we use per capita carbon emissions (in ten thousand tons) as the measure of regional carbon emissions. In order to avoid the unitary indicator of the explained variable, this paper also calculates the relative value of the total regional carbon emission and the carbon emission per unit GDP, respectively, as the substitute variable of the robustness test. Firstly, we employ city-level carbon emissions (lnco2), represented as the natural logarithm of annual urban carbon emissions (in ten thousand tons). Secondly, we utilize city-level carbon emission intensity (uco2), denoted as the ratio of annual urban carbon emissions (in ten thousand tons) to the regional GDP (trillion yuan)

(2) Independent variable (EURT system (didyn)): in setting the variable, the value is assigned to each province according to the "Pilot Program of Energy Use Right Paid Use and Trading System" issued by the State Council, and the value is assigned to 1 if the province carries out the pilot EURT system in the year; otherwise, the value is assigned to 0

(3) Control variables: due to the multiple factors affecting regional carbon emissions, in order to control the influence of other variables on the experimental results and mitigate endogeneity issues caused by omitted variable bias, the following indicators are selected as control variables in this study: industrial structure (indus), which is measured by the ratio of value added from the secondary industry to GDP. Regions with a more developed secondary industry tend to have higher carbon intensity; actual utilization of foreign direct investment (fdi) is represented by the ratio of actual utilized foreign investment to GDP. Foreign direct investment may accelerate industrialization and urbanization processes, which could increase energy consumption and carbon emissions, or promote the introduction of more advanced and cleaner production technologies and equipment, thereby improving energy efficiency and reducing carbon emissions; level of financial development (fina) is measured by the logarithm of the balance of RMB loans from financial institutions. Higher levels of financial development in a region may enable enterprises to obtain more financing for environmental improvement, which is conducive to reducing regional carbon emissions; level of technological expenditure (tech) is represented by the ratio of total technological expenditure to GDP. Regions with higher technological levels may use clean and environmentally friendly production equipment to improve regional carbon emissions; and level of economic growth (lngdp) is represented by the logarithm of per capita GDP. According to the environmental Kuznets curve, regions with higher levels of economic development often have more serious environmental pollution issues; the level of education expenditure (edu) is measured by the ratio of educational expenditure to GDP. Regions with higher levels of education tend to have residents with

Table 1: Descriptive statistics.

Variable	Units	Obs	Mean	Std. dev.	Min	Max
rco2	Ten thousand tons per 10,000 people	3962	2.665	4.753	0.030	94.24
lnco2	Ten thousand tons	3962	6.130	1.193	2.019	9.533
uco2	Ten thousand tons per trillion	3962	0.544	0.610	0.023	9.612
fdi	Trillion per trillion yuan	3962	9.472	2.623	0.000	14.941
indus	Trillion per trillion yuan	3962	3.839	0.254	2.460	4.511
lngdp	Trillion yuan	3962	10.416	0.724	4.595	13.056
edu	Trillion per trillion yuan	3962	3.549	1.313	0.000	7.051
gov	Trillion per trillion yuan	3962	0.180	0.099	0.035	1.027
fina	Trillion yuan	3962	0.885	0.560	0.075	9.622
tech	Trillion yuan	3962	9.822	1.606	3.526	15.529
industry	—	3962	6.447	0.354	5.517	7.836
estru	Ten thousand tons per ten thousand tons	3962	4.295	1.201	0.739	8.347
patentappl	Pieces	3962	2.284	1.755	0.000	8.828

stronger environmental awareness, which can effectively reduce regional carbon emissions; government expenditure (gov) is represented by the ratio of government expenditure to GDP. Higher government expenditure in a region often means more transfer payments for environmental governance, which helps improve pollution emission issues

(4) Mechanism variables: industrial structure upgrading (industry) is assessed using an index of industrial structure rationalization. The energy consumption structure (estru) is represented by the ratio of total coal consumption (in ten thousand tons) to total energy consumption (in ten thousand tons). Green innovation (patentappl) is measured by the number of green patents. The descriptive statistics are shown in Table 1

5. Analysis of the Empirical Results

5.1. Baseline Regression Analysis. Based on the previous abstract analysis, this article significantly analyzes the consequences of the implementation of the EURT pilot project on urban carbon emissions, and the conclusions of the baseline regression are presented in Table 2.

Columns (1) and (2) describe the meanings of the establishment of the EURT pilot on regional carbon emissions without and with the inclusion of control variables, appropriately. Obviously, we can identify from the values and significance levels that the establishment of EURT pilot sites incomparably dwindles regional carbon emissions at the 1% level, regardless of whether control variables are included in the model. The regression coefficients in columns (1) and (2) indicate that the average treatment effect of the energy-use rights trading pilot policy on carbon emissions is 0.635 and 0.0516, respectively, for the dummy variables. Appropriately, research Hypothesis 1 is corroborated. This conclusion is consistent with the conclusions of the Liu and Wang [62], Qi and Han [63], and Pan and Dong [2] studies.

Table 2: Baseline regression results.

	(1) rco2	(2) rco2
didyn	-0.635*** (-3.31)	-0.516*** (-2.66)
lngdp		-1.772*** (-6.88)
indus		0.413 (0.98)
edu		0.169 (0.95)
gov		-4.144*** (-3.89)
tech		-0.090 (-1.13)
fina		0.365*** (2.87)
fdi		0.060* (1.73)
Control	No	Yes
Year FE	Yes	Yes
City FE	Yes	Yes
Constant	1.758*** (13.68)	16.969*** (7.51)
Observations	3,962	3,962
R-squared	0.149	0.167

Note: t-statistics in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

5.2. Model Set-Up Validity Test. On the basis of reference regression conclusions, more robust test of observational evidence is needed to improve the certainty of observational conclusions. In this paper, the empirical evidence strength test must be divided into two parts to achieve the most realistic experimental results: a model frame validity test and an empirical result validity test. Since empirical results are based on a model unit, empirical results from the model can only be reliable if the model unit is valid. Therefore, the validity of the model component should be tested first when testing the robustness of the empirical results. For the model with a double difference, two model validity tests are performed to obtain a reliable model setup: one is a trend repetition test and the other is a sample selection test.

5.2.1. Parallel Trend Test. The parallel trend hypothesis is one of the most important determinant assumptions of the double-difference model to achieve accurate estimation, so

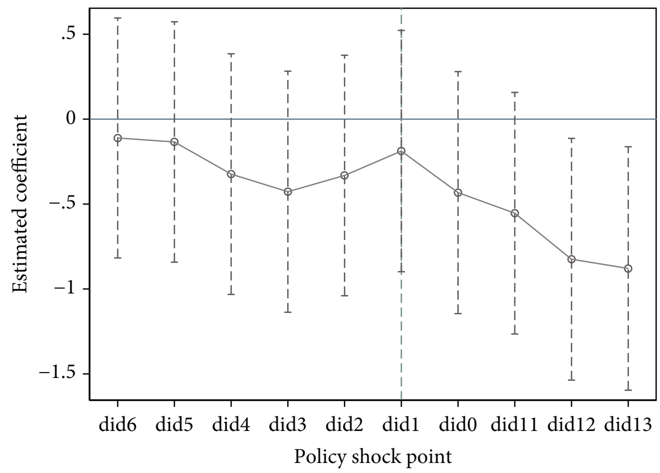

Figure 2: Parallel trend test.

it will be tested in this paper by referring to the measurement research method proposed by Xue and Zhou [64]. And the following event study graph is drawn. Figure 2 demonstrates the results of the parallel tendency, and it is apparent from the graph that the estimated coefficients of the experimental and control groups before the start of the policy are not significant, which illustrates that there is no considerable difference between experiments and control groups, and the model with a double difference corresponds to the parallel trend test. Contrariwise, imitation variable ratios decrease over time, and the estimated ratios are significantly negative from year 3 onwards, effectively demonstrating that trading in pilot energy-use rights can significantly reduce regional carbon intensity. However, this emission reduction effect has caused some political delays.

5.2.2. PSM-DID Test. The implementation of the EURT system is aimed at controlling energy to reduce environmental pollution. However, skewed considerations in selecting cities as front-runners attributed to differences in geographical advantages, economic bases, and rewarding city resources can lead to distorted paradigms and valid political values. On this basis, the performance of the PSM-DID model will be further investigated by observations and the proximity of carbon 1 : 1 will be compared with an empirical approach [11]. Table 3 shows the results of the regression with the PSM-DID and the experimental results that the implementation of energy trade policies still leads to significant reductions in carbon emissions in cities according to the regression analysis with the PSM-DID. Figure 3 of the propensity score matching effect shows that the covariate values in the match are distorted around 0, indicating that the propensity score matching effect is better. In conclusion, there is no material choice bias when selecting cities as pilot cities for EURT, and the reference model is correct.

Table 3: PSM-DID (1 : 1 caliper nearest neighbor matching).

	(1) rco2	(2) rco2
didyn	-0.718*** (-3.65)	-0.532*** (-2.68)
lngdp		-2.174*** (-6.79)
indus		0.465 (0.94)
edu		0.156 (0.84)
gov		-4.187*** (-3.15)
tech		-0.090 (-1.03)
fina		0.538*** (3.37)
fdi		0.067* (1.81)
Control	No	Yes
Year FE	Yes	Yes
City FE	Yes	Yes
Constant	1.800*** (13.70)	20.530*** (7.82)
Observations	3,813	3,813
R-squared	0.149	0.170

Note: *t*-statistics in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

5.2.3. Robustness Test of the Empirical Results

(1) Placebo Test. To verify again that the change in the trend between the search and organization after the introduction of EURT affects the implementation of EURT cooperation, which was not influenced by any other or random policy, therefore the paper uses an opportunistic test to validate the results of double variation in order to ensure the strength of the products. Spot testing was conducted by randomly assigning areas where the policy was implemented. In fact, four cities randomly selected as intervention groups from 283 cities were considered host cities, and the remaining cities were the control group. The random sample ensured that the didyn variable did not affect CO_2. 500 samples were randomly taken, and regression was performed on the basis of the baseline regression model. Figure 4 explains the average values of the estimated coefficients after 500 random assignments and the distribution of the estimated coefficients and the associated p values. The consequences show that originally, the distribution of the estimated 500 coefficients all revolves around the value of 0. Further, observation of the distribution of p values indicates that most estimated p values exceed 0.1. The above results suggest that the observational estimates are unlikely to be due to unrequited factors in the urban years.

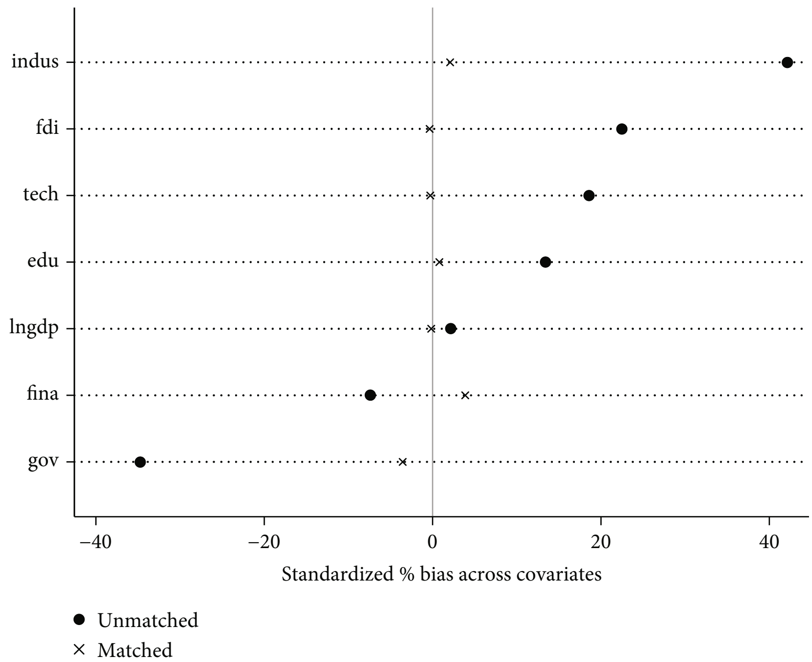

Figure 3: Matching effect.

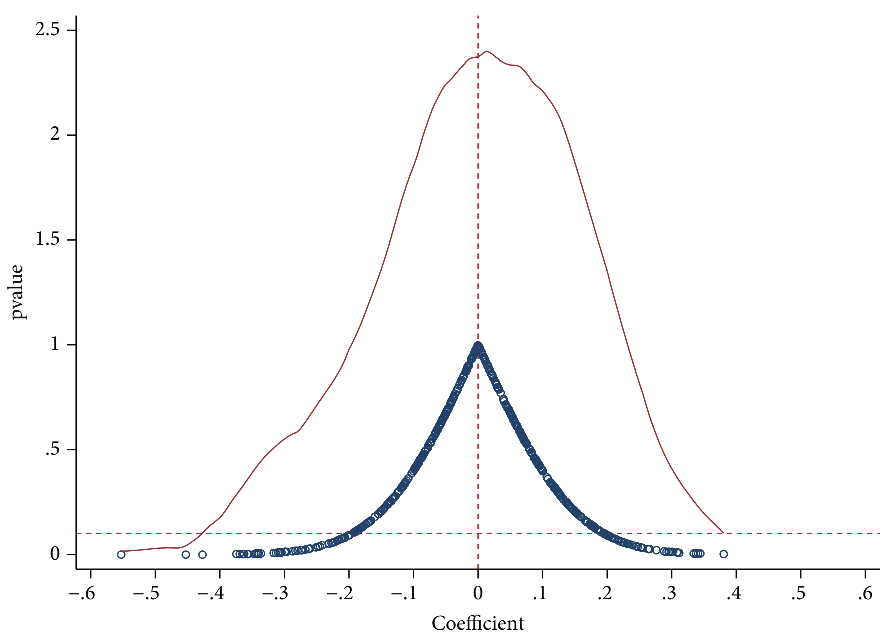

Figure 4: Placebo test.

(2) Replacement of Dependent Variables. To avoid an excess of individual explanation variables and to improve the affluence of explanation variables and the authenticity of the experimental results, this document also estimates the effect of EURT on regional carbon emissions, using the logarithm of total carbon emissions and the ratio of total carbon emissions to GDP as dependent variables. The empirical results are shown in Table 4. Columns (1)-(4) report the impact of EURT on urban carbon emissions, where the dependent variables are the ratio of total carbon emissions to GDP, the logarithm of total carbon emissions, and the control variables are excluded and included, respectively. This interpretation further demonstrates the robustness of the conclusion that the EURT significantly reduced urban carbon emissions and increased modelling, regardless of whether variable carbon is the share of total carbon emissions to GDP or the logit of total carbon emissions.

(3) In Addition to Other Political Interventions. China has implemented a string of strategic policies aimed at improving its environmental protection efforts to meet the carbon compliance and carbon neutral goals proposed by the

Table 4: Replacement of dependent variables.

	(1) uco2	(2) uco2	(3) lnco2	(4) lnco2
didyn	-0.113*** (-3.76)	-0.076** (-2.48)	-0.051 (-1.53)	-0.107*** (-3.27)
lngdp		-0.145*** (-3.60)		0.373*** (8.58)
indus		0.067 (1.01)		0.169** (2.39)
edu		0.042 (1.50)		0.127*** (4.21)
gov		1.011*** (6.07)		0.629*** (3.50)
tech		-0.039*** (-3.09)		0.028** (2.09)
fina		0.040** (2.01)		-0.019 (-0.88)
fdi		0.020*** (3.62)		0.011* (1.88)
Control	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Constant	0.762*** (37.75)	1.719*** (4.86)	5.574*** (252.73)	0.592 (1.55)
Observations	3,962	3,962	3,962	3,962
R-squared	0.151	0.174	0.596	0.617

Note: t-statistics in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

United Nations. These environmental protection policies encompass the Low-Carbon City Pilot Program, planned in 2010, and the manufacture of a demonstration space prior to ecological civilization in 2014. Among those who indirectly propose environmental protection conditions are smart cities and the air quality standard. The implementation of these policies will have a greater or lesser impact on reducing urban carbon emissions. Based on this, in order to eliminate the interference of these policies on the empirical conclusions and significantly improve the robustness of the empirical conclusions, the effects of EURT on regional carbon emissions are considered under the influence of smart city pilot (zh), low-carbon city pilot (dt), ecological civilization city construction pilot (st), and air quality standard (kq) on the empirical results, respectively. The empirical results are shown in Figure 5, from top to bottom, the corresponding regression results of the baseline regression results (br), excluding the smart city pilot (zh), low-carbon city pilot (dt), ecological civilization city construction pilot (st), and air quality standard (kq), respectively, and it can be found that the coefficients of the interaction term remain significant; i.e., after considering the above policies, the EURT system still has a significance. The coefficients of the interaction terms are still significant; after considering the above policies, the EURT system still has a significant negative impact on regional carbon emissions.

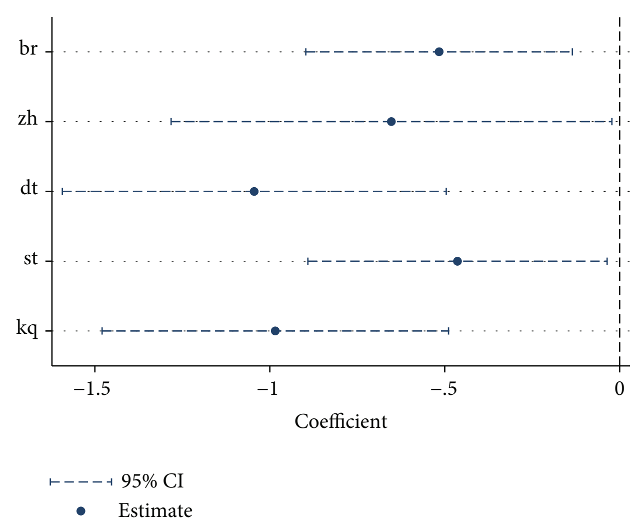

Figure 5: Other policy disruptions.

(4) Other Strength Tests.

(1) Polynomial interaction of control variables with time and time, respectively

The aforementioned parallel trend test is actually a test of the ex ante trend, and we cannot observe and test if the experimental and control groups maintain the same preexisting trends. Therefore, here we further put the control variables affecting the trend of the experimental and control groups into the model with time and the cross-product term of the time polynomial as control variables for regression. This ensures that the reference variables influencing the development trends of the experimental and control groups do not change over time or exclude the impact of policy implementation on the development trends of the experimental and control groups due to the reference variables. In turn, it makes it possible to further satisfy the ex post parallel trends while the parallel trends are satisfied. The endogeneity problem is eliminated as much as possible on the experimental results to ensure the robustness of the experimental results. From Table 5, column (1) and column (2) are the test results of control variables with time interaction and control variables with time polynomial interaction terms, respectively; the results are significantly negative at the 1% level; therefore, it can be proved that EURT can

Table 5: Other robustness tests.

	(1) Control variables interact with time	(2) Control variables interact with time polynomials	(3) Shortened sample intervals	(4) Data tailing
didyn	-0.531*** (-2.89)	-0.557*** (-3.03)	-0.406* (-1.85)	-0.290** (-2.53)
lngdp	2.754*** (5.14)	-1.940*** (-5.39)	-2.520*** (-6.07)	-1.261*** (-6.89)
indus	1.423** (2.24)	-0.470 (-0.72)	1.662*** (2.65)	0.264 (1.03)
edu	-0.050 (-0.22)	0.161 (0.81)	0.614** (2.18)	0.264** (2.45)
gov	-0.331 (-0.14)	-0.197 (-0.06)	-3.610** (-2.01)	-2.507*** (-3.55)
tech	-0.494*** (-3.16)	0.572*** (3.93)	-0.028 (-0.24)	0.069 (1.43)
fina	0.529*** (2.87)	-0.485 (-1.24)	0.090 (0.59)	0.149 (1.35)
fdi	-0.201*** (-2.68)	0.442*** (6.42)	0.018*** (3.01)	0.036* (1.76)
Control	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Constant	-23.833*** (-4.14)	14.093*** (4.43)	19.919*** (4.66)	11.390*** (7.38)
Observations	3,962	3,962	2,547	3,962
R-squared	0.316	0.286	0.181	0.290

Note: t-statistics in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

incomparably reduce regional carbon emissions, further verifying the robustness of the carbon emission reduction results of EURT policy in the aforementioned empirical results.

(2) Shorten the sample interval

In 2016, the National Development and Reform Commission (NDRC) declared that it would carry out a pilot project of paid use and EURT in four provinces, namely, Zhejiang, Fujian, Henan, and Sichuan, while the sample interval selected in this paper is located in 2006-2019, and since the time span of 2006 according to 2016 is too long and other policies not considered before the policy implementation may interfere with the empirical results, it is considered necessary to shorten the sample interval and then perform an equivalent benchmark regression. Based on the empirical results in column (3), it is shown that EURT can significantly reduce regional carbon emissions at the 10% level.

(3) Data tailing processing

In addition to considering selective bias and other political or other interference with events, the presence of extreme values may have an effect on experimental results. To reduce the effect of certain extreme values in the data on the empirical results, this experiment applies an upper and lower 1% extreme value tailoring treatment to the variables except for the policy dummy variables. From column (4), the EURT still significantly reduces urban carbon emissions at a significant level of 5% after a 1% tailoring of the data.

5.2.4. Heterogeneity Analysis

(1) Regional Heterogeneity. To determine the EURT effects on carbon extinction in cities in different regions for Hypothesis 3 tests, this article also divides the entire sample in eastern, central, and western China and uses subcity panel data from 2006 to 2019 to estimate and compare the regression coefficient of three subregions.

In the three regressions using different samples, the estimation results of the three groups of samples are compared. In the regression with the eastern region as the sample, the coefficient of the independent variable didyn is significantly positive, indicating that the EURT system does not have a suppressive effect on carbon emissions in the economically developed eastern cities; meanwhile, the regression results with the central and western regions as the sample show that the coefficient of the independent variable didyn is significantly negative. The coefficient of the independent variable didyn is significantly negative, demonstrating that the EURT system can significantly curtail the carbon emissions of cities.

(2) City Size Heterogeneity. Depending on the size of a city, its energy-saving potential varies, and the difference in energy-saving potential may lead to city size heterogeneity in the effect of the EURT system, and the influence of the EURT system on carbon emission reduction is marginally decreasing. Large cities carry out high-tech industries with less pollution intensity, while energy saving and emission reduction work start earlier, with a high level of industrial structure cleanliness, and even if they do not carry out EURT system, they can already control carbon emissions well and have relatively low energy-saving potential. Other cities focus on areas of heavy industry; with high-intensity carbon emissions, as well as backward technology and imperfect regulations and systems to save energy and reduce emissions, there is more space to improve carbon reduction in these areas, with the potential energy-saving potential higher. That is, small- and medium-sized cities with higher energy-saving potential will gain more from the EURT system than large cities with lower energy-saving potential [52, 60]. Columns (4) and (5) in Table 6 show that for small-

Table 6: Heterogeneity test.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Regional heterogeneity			City scale heterogeneity		Government attention	
	East	Medium	West	Large cities	Small- and medium-sized cities	High fiscal spending	Low fiscal spending
didyn	0.783*** (4.30)	-0.371*** (-4.30)	-2.538*** (-4.50)	0.009 (0.03)	-0.753*** (-3.06)	-0.520*** (-3.11)	-0.505* (-1.80)
lngdp	-0.337 (-1.32)	0.182 (0.99)	-4.601*** (-7.47)	-0.776** (-2.10)	-2.391*** (-7.26)	-0.508*** (-3.10)	-2.303*** (-4.88)
indus	-0.593 (-1.43)	-0.053 (-0.20)	1.114 (1.04)	-1.147* (-1.85)	0.686 (1.31)	-0.192 (-0.80)	0.973 (1.18)
edu	-0.327** (-1.97)	0.255*** (2.85)	-0.511 (-0.99)	-0.223 (-0.68)	-0.053 (-0.25)	0.022 (0.20)	0.334 (1.09)
gov	-3.779*** (-3.32)	-1.315 (-1.46)	-9.183*** (-3.87)	-4.474*** (-2.64)	-5.483*** (-4.14)	-0.648 (-1.12)	-6.666** (-2.05)
tech	0.267*** (3.72)	-0.190*** (-4.68)	-0.514** (-1.97)	0.241** (2.41)	-0.245** (-2.32)	-0.089* (-1.74)	-0.111 (-0.82)
fina	0.446*** (2.79)	-0.088* (-1.71)	0.464 (1.45)	0.737*** (4.46)	0.370** (2.25)	0.057 (0.88)	1.032*** (3.57)
fdi	0.000 (0.00)	0.002 (0.09)	0.117 (1.60)	-0.098* (-1.69)	0.089** (2.11)	0.087*** (4.73)	0.037 (0.50)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	7.033*** (2.92)	0.117 (0.08)	45.290*** (7.50)	14.953*** (4.38)	22.764*** (7.82)	6.106*** (4.44)	20.411*** (4.64)
Observations	1,680	1,120	1,162	1,134	2,828	1,512	2,450
R-squared	0.317	0.510	0.212	0.257	0.169	0.374	0.158

Note: *t*-statistics in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

Table 7: Mechanism test.

	(1)	(2)	(3)	(4)	(5)	(6)
	Industrial structure upgrading		Energy consumption structure		Green innovation	
didyn	0.045*** (6.02)	0.045*** (6.23)	-0.049* (-1.77)	-0.079*** (-2.80)	0.221*** (4.56)	0.176*** (3.70)
lngdp		0.126*** (13.17)		0.180*** (4.82)		-0.268*** (-4.24)
indus		-0.303*** (-19.33)		0.139** (2.29)		-0.019 (-0.19)
edu		0.030*** (4.51)		0.052** (2.01)		0.110** (2.53)
gov		0.048 (1.22)		-0.082 (-0.53)		-2.349*** (-9.01)
tech		0.006** (2.17)		0.026** (2.26)		0.280*** (14.27)
fina		0.003 (0.56)		0.064*** (3.46)		0.051 (1.62)
fdi		0.001 (0.96)		0.009* (1.72)		0.006 (0.76)
Control	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	6.291*** (1,256.87)	6.084*** (72.32)	3.726*** (199.62)	1.003*** (3.06)	1.013*** (31.23)	1.492*** (2.70)
Observations	3,962	3,962	3,962	3,962	3,962	3,962
R-squared	0.731	0.759	0.533	0.545	0.707	0.730

Note: *t*-statistics in parentheses. ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

and medium-sized cities, the EURT system to a great extent reduces urban carbon emissions, while for large cities, the results are positive and insignificant; it not only does not reduce carbon emissions but also promotes the increase of carbon emissions.

(3) Heterogeneity of Government Attention. The difference in governmental attention affects the effect of policy implementation [52, 61], and the performance of governmental attention is more reflected in fiscal expenditure, i.e., financial support. High fiscal expenditure can provide more financial guarantee for policy implementation and urban innovation and help to make up for the defects of the market mechanism of EURT and overcome the failure of the market mechanism, so that the EURT system can be carried out smoothly, promote the improvement of urban green technology and improve the green productivity of cities, and improve the environmental protection awareness of the public to reduce regional carbon emissions by continuously improving the EURT system. On the contrary, low fiscal expenditures are not sufficient to meet the R&D costs of urban innovation and cannot successfully complete the transformation of enterprises, resulting in a significantly smaller inhibitory effect on urban carbon emissions than in regions with high fiscal expenditures, and the empirical results, in turn, verify that Hypothesis 3 holds.

5.2.5. Mediating Effect Test. Based on the theoretical consultation in the study, the implementation of EURT policy principally reduces urban carbon emissions and advances energy consumption structure and develops green innovation. Is this the case in practice? In this paper, we further refer to Song et al. [65] and construct a mediating effect model by introducing industrial structure upgrading, energy consumption structure, and green innovation as mediating variables [47, 65], to empirically test the correctness of the theoretical mechanism. Among them, improved industrial structures, energy consumption structures, and vet innovation were measured by increasing the industry structure and industrial reasoning, the ratio of total coal consumption total energy consumption, and volume of vet arrivals, respectively.

The specific models are as follows.

$$\mathrm{rco}_2 = \beta_0 + \beta_1(\mathrm{treat}_i \times \mathrm{post}_t) + \beta x_{it} + \nu_i + \mu_t + \varepsilon_{it}, \quad (2)$$

$$R_{it} = \beta_0 + \theta(\mathrm{treat}_\mathrm{i} \times \mathrm{post}_t) + \beta x_{it} + \nu_i + \mu_t + \varepsilon_{it}, \quad (3)$$

where in the model (4), the R_{it} is the ensemble of mediating variables, including industrial structure upgrading, energy consumption structure, and green innovation. The other variables remain consistent with model (1). Table 7 reports the results of the mediating effects of the three types of mediating variables, among which columns (1)-(6) report the effects of energy trading on industrial structure upgrading, energy consumption structure, and green innovation, respectively, and the results show that the implementation of EURT policy promotes industrial structure upgrading, improves energy consumption structure, and enhances green innovation at 1% significance level. In summary, reducing carbon emissions from euro policy performance comes mainly from improving the industrial structure, improving energy consumption metals, and improving green innovation. The research Hypothesis 2 has been confirmed.

6. Expand Research

Existing studies show that there is a strong spatial correlation between pollution emissions in various regions of China, and ignoring this spatial correlation effect is likely to cause biased experimental results. Therefore, under the condition of the spatial spillover effect of pollution emissions, a spatial panel model of the EURT system and carbon

Table 8: Spatial spillover effects.

	(1)	(2)	(3)	(4)
	SAR		SDM	
	rco2	rco2	rco2	rco2
Main DID	-0.644*** (0.182)	-0.530** (0.184)	-0.542** (0.194)	-0.896*** (0.207)
W-DID			7.987 (5.263)	-44.457*** (10.312)
Spatial rho	-1.314*** (0.219)	-1.349*** (0.221)	-1.336*** (0.219)	-0.829** (0.292)
Direct DID	-0.641*** (0.188)	-0.526** (0.190)	-0.567** (0.195)	-0.790*** (0.205)
Indirect DID	0.364*** (0.110)	0.300** (0.111)	3.732* (2.191)	-24.465** (7.814)
Total DID	-0.277** (0.086)	-0.226** (0.085)	3.166 (2.242)	-25.255** (7.893)
Control variables	No	Yes	No	Yes
Urban fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
N	3962	3962	3962	3962
R^2	0.002	0.195	0.028	0.197

Note: t-statistics in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

dioxide emissions is constructed to investigate the impact of environmental policies on carbon dioxide emissions in a region and its neighboring regions. The spatial econometric model is designed as follows.

$$\begin{aligned} \text{rco2} = \delta_0 + \rho_0 W_{ij}\text{rco2} + \beta_1(\text{treat}_i \times \text{post}_t) \\ + \theta_x W_{ij} x_{it} + \beta x_{it} + \nu_i + \mu_t + \varepsilon_{it}, \end{aligned} \quad (4)$$

where W_{ij} is the spatial weight matrix of the model and the spatial distance matrix is used in this paper. θ_x is the spatial regression coefficient of the control variables, and ρ_0 is the spatially lagged coefficient to be estimated for the dependent variables, and the other parameters are consistent with the definition of the model (1).

The empirical results are shown in Table 8, where columns (1) and (2) are the regression results of SAR under the selected spatial distance matrix and columns (3) and (4) are the regression results of SDM under the selected spatial distance matrix. In addition, to verify the fitting effect of spatial panel model selection, the Wald test and LR test are conducted on the basis of two spatial models, and the results show that the SDM model has a better fitting effect in exploring energy-use rights trading on carbon emission reduction.

The results show that firstly, the negative coefficient of W-DID in the spatial Durbin model shows a significant spatial spillover effect of the implementation of the EURT system on the improvement of carbon emission reduction performance; i.e., the construction of the energy trading system effectively reduces carbon emissions in the pilot region. Second, the coefficients of the core interaction term (main DID) are significantly negative at the 5% and 1% levels for the SAR and SDM models, respectively. This result shows that, based on spatial effects, the construction of the EURT system still effectively improves carbon emission reduction performance.

7. Discussion

This paper treats the pilot policy of EURT as a quasinatural experiment and employs a multiperiod difference-in-difference approach combined with a balanced panel dataset of 283 prefecture-level cities from 2006 to 2019 to empirically examine the carbon emission reduction effect of the implementation of the EURT pilot policy. The results of this study indicate that the implementation of the EURT pilot policy can reduce regional carbon emissions by improving energy consumption structure, promoting industrial structural upgrading, and increasing government attention. Moreover, this effect is more pronounced in western cities and small- to medium-sized cities. Furthermore, the implementation of this policy not only effectively reduces carbon emissions in the pilot areas but also radiates to neighboring areas, resulting in decreased carbon emission levels.

However, existing literature on market-based environmental regulation mainly focuses on discussing the carbon emission reduction effects of market-based environmental regulation policies that target end-of-pipe carbon emissions, such as carbon emission trading pilots, nitrogen oxide emission trading pilots, and sulfur dioxide emission trading pilots [5–9]. Literature directly related to the EURT pilot policy primarily focuses on the impact of the implementation of the EURT pilot on regional green development efficiency, energy consumption intensity, and other factors [10, 11]. There is limited research specifically examining the impact of the EURT pilot policy on carbon emissions. The few existing studies mainly employ synthetic control methods to empirically examine the carbon emission reduction performance of the EURT pilot policy [63]. Alternatively, some studies focus on exploring the interactive effects of the EURT pilot policy and other regulatory policies on regional carbon emissions [2]. Existing research has not thoroughly discussed the mechanisms and regional heterogeneity of the EURT pilot policy in reducing regional carbon emissions, nor has it examined the radiative effects of the implementation of the EURT pilot policy on adjacent areas. This paper provides a detailed theoretical and empirical analysis of these issues.

In addition, this study has certain limitations. Firstly, it only focuses on the macrolevel carbon emission reduction effects of EURT policies in urban areas, overlooking the microlevel perspective of carbon emission reduction effects within enterprises. Secondly, it only considers the impact of EURT policies on carbon emissions, without examining the effects of these policies on different pollutants. In the future, studying the effects of energy trading on enterprise-level carbon emissions and various pollutant emissions from a microlevel perspective will be of great significance. Moreover, exploring the effects of EURT on carbon emissions from different dimensions such as market size and market dynamics can provide further insights.

8. Conclusions and Policy Recommendations

This study employs the energy-use rights trading pilot policy as a quasinatural experiment, based on panel data from 283 prefecture-level cities across China for the years 2006-2019. It employs the difference-in-difference and spatial econometric methods to investigate the impact effects and mechanisms of energy-use rights trading pilot policies on regional carbon emission performance. The research findings indicate the following: First, energy-use rights trading pilot policies significantly reduce carbon emissions in the pilot cities. This conclusion remains robust after a series of tests, including placebo tests, propensity score matching, and additional robustness checks. Second, energy-use rights trading policies primarily reduce regional carbon emissions through three main pathways: optimizing energy consumption structure, promoting industrial structure upgrading, and enhancing green technology levels. Third, heterogeneous analysis reveals that the carbon reduction effects of energy-use rights trading pilot policies vary among different regions, scales, and cities with varying levels of government attention. Specifically, the carbon reduction effects are significant in western regions and small- to medium-sized cities, while they are not significant in eastern regions and large cities. Fourth, the study identifies significant spatial spillover effects of energy-use rights trading policies on adjacent regions. This policy not only significantly reduces carbon emissions in the pilot areas but also exerts a significant spatial suppression effect on carbon emissions in neighboring regions.

At present, China's environmental issues remain severe, and sustainable development is still a distant goal. How to effectively combine market regulatory mechanisms and formulate reasonable and effective environmental regulations to reduce carbon emissions is a necessary condition for China's economic sustainable development. This article explores the implementation of market-based environmental regulations from the perspective of front-end governance and empirical evidence of the carbon reduction effects of EURT pilot policies. The research conclusions provide the following policy recommendations.

Firstly, further improve the market-based environmental regulatory policy guidelines based on front-end governance and actively expand related regulatory types to curb regional carbon emissions from the source of pollution. Introduction and Literature Review of this paper show that the implementation of market-based environmental regulatory policies based on front-end governance can not only solve the market failure caused by traditional command-and-control environmental regulatory policies but also address the shortcomings of most market-oriented environmental regulations that cannot control pollution emissions from the source. The benchmark empirical results of this article demonstrate that market-based environmental regulations based on front-end governance can significantly reduce regional carbon emissions. This result effectively confirms the relative superiority of front-end governance-type environmental regulatory policies and also inspires us to further examine factors such as regional social development level and stage, industrial structure and layout, energy-saving potential, and resource endowment to develop scientifically reasonable energy rights indicators, promote the compensated use of energy units, and improve the trading market and create a fair and orderly market environment to effectively promote the rational allocation of regional energy consumption and improve the energy efficiency of energy-using units, thus fully exerting the carbon reduction effect of the EURT pilot policy. In addition, based on the excellent properties of this type of market-incentive environmental regulation in promoting regional carbon emission reduction, the government should further expand this type of market-based environmental regulation and strengthen the front-end governance mechanism to effectively control regional carbon emissions.

Secondly, further support and strengthen the role of EURT pilot policies in reducing regional carbon emissions, fully exert the decisive role of the market in energy resource allocation, and effectively reduce regional carbon emissions to promote sustainable economic development. The mechanism results of this article show that the implementation of EURT pilot policies mainly reduces regional carbon emissions by improving energy consumption structure, promoting industrial structure upgrading, and improving green innovation level. This conclusion suggests that to fully exert the carbon reduction effect of EURT pilot policies, we need to start with policy implementation schemes and consciously formulate specific plans that help improve regional energy consumption structure, promote industrial development, and enhance green innovation level. Firstly, it is necessary to reasonably increase the proportion of low-pollution fossil energy or renewable energy quotas, guide enterprises and residents to use energy with relatively small pollution for production and life, improve the regional energy consumption structure, and reduce pollution emissions. Secondly, it is necessary to appropriately reduce the compensated use of energy fees in high-tech industries or national key supported industries and guide the upgrading of the industrial structure towards cleanliness, and finally, it is necessary to increase green fiscal expenditures to stimulate the improvement of regional green innovation level.

Thirdly, it further enhances policy implementation fairness and promotes the positive attitude of various regions to pollution reduction. The findings in this article reveal significant variations in the effectiveness of carbon emission reduction resulting from EURT implementation across cities, indicating notable differences based on regional disparities, scale differences, and varying levels of government attention. The influence of the EURT system on carbon emission reduction has different effects on different regions and scales of cities. The carbon emission reduction effect is significant in western regions and small- and medium-sized cities but not significant in the eastern regions and large cities. This result suggests that when formulating energy trading pilot policies, the government should pay attention to policy fairness issues, avoid energy quotas biased towards specific regions or industries, discard the government's biased thinking mode, promote policy implementation fairness, and stimulate the enthusiasm of various regions to reduce their emissions. In addition, further analysis results of this article show that the EURT system can not only reduce carbon emissions within the region but also have a "cross-border" impact on neighboring regions. This result suggests that we need to give full play to the exemplary role of EURT pilot areas, strengthen communication and cooperation with neighboring regions, and enhance the radiation-driven effect of EURT pilot policies on emission reduction.

Nomenclature

EURT:	Energy-use rights trading policy
DID:	The difference-in-difference method
PSM-DID:	Propensity score matching difference-in-difference method
CO_2:	Carbon emissions
RMB:	Chinese yuan
GDP:	Gross domestic product
rco2:	Per capita carbon emission
lnco2:	Carbon emission pair value
uco2:	Carbon emission intensity
indus:	Industrial structure
fdi:	Foreign direct investment
fina:	Financial development level
tech:	Science and technology expenditure level
lngdp:	The value of the gross national product
edu:	Education expenditure level
gov:	Fiscal expenditure
industry:	Industrial structure upgrading
estru:	Energy consumption structure
patentappl:	Green innovation
didyn:	The core explanatory variable of energy-use rights trading policy
br:	The baseline regression results
zh:	Smart city pilot
dt:	Low-carbon city pilot
st:	Ecological civilization city construction pilot
kq:	Air quality standard
SAR:	Spatial lag model
SDM:	Spatial Durbin model
NUM:	Observed value
i:	City
t:	Year
post_t:	A time dummy variable
treat_i:	The regional grouping variable
X_{it}:	The set of control variables
ε_{it}:	The random error terms
ν_i:	City fixed effects
μ_t:	Year fixed effects
β_1:	The estimated coefficient of interest for the article
R_{it}:	The ensemble of mediating variables
W_{ij}:	The spatial weight matrix of the model
$\boxtimes_x$:	The spatial regression coefficient of the control variables
ρ_0:	The spatial lagged coefficient to be estimated for the dependent variables.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Authors' Contributions

Yang Li, Xuan Wang, and Jiachao Peng conceived and designed the experiments. Yang Li and Jiachao Peng performed the experiments. Yilin Wang, Jiachao Peng, and Shaofeng Chen analyzed the data and wrote the manuscript. All authors read and approved the final manuscript.

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