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Evaluation of Environmental Governance Effects and Effectiveness of Carbon Emission Trading System Based on RDD-DID Model

-- A Case Study of Typical Pilot Cities in the First Batch of Carbon Emission Trading Markets

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ABSTRACT

This paper takes China's first batch of carbon emission trading pilot cities (Shanghai, Beijing, Tianjin, Chongqing) as the research objects. Based on the carbon emission and nitrogen oxide emission data from 2011 to 2023, it comprehensively uses the Regression Discontinuity Design (RDD) and the Generalized Difference-in-Differences Model (RDD-DID) to systematically evaluate the environmental governance effects and pollutant emission reduction effects of the carbon emission trading system. The study finds that after the implementation of the "Guiding Opinions on Further Promoting the Pilot Work of Paid Use and Trading of Emission Rights" in 2015 in Shanghai, the coefficient of the policy treatment term is significantly negative (estimated value -0.572, $p<0.01$), indicating that the carbon emission trading system has significantly reduced nitrogen oxide emissions, and control variables such as economic development level (GDP), population density, and foreign direct investment (FDI) have a positive synergistic effect on emission reduction. However, due to the relatively mature carbon trading system in Beijing, the policy incentive effect is not significant. The RDD-DID model extended to the four municipalities directly under the Central Government shows that the overall emission reduction effect of the policy is significant (YPost coefficient -4.45, $p<0.01$), but the interaction term coefficient between the activity of carbon emission trading and the policy is significantly positive (0.238, $p<0.01$), revealing that resource crowding, side effects of technical substitution, and market mechanism fragmentation may weaken the synergistic governance effect of multiple pollutants. The study suggests integrating the market rules of carbon emission rights and emission permits, strengthening the local environmental assessment mechanism, and optimizing the differentiated pricing strategy to improve the synergistic efficiency of environmental policies and provide theoretical support for the construction of a national unified environmental rights market.

KEYWORDS

Carbon emission trading system; Emission rights; Environmental governance benefits; Regression Discontinuity Design

1. LITERATURE REVIEW

The article "Research on the Incentive Effect of Emission Rights Trading Policy Evolution on Haze Governance Based on RDD-DID Method" is the key reference for us. This article aims to explore the impact of changes in the initial allocation policy of emission rights on haze governance by using the RDD-DID method, selecting Hangzhou, a provincial capital city, as the representative region and using the panel data of Hangzhou from 2010 to 2019 [1].

This paper evaluates the inapplicability of mainstream policy effect evaluation methods - Difference-in-Differences (DID) and Dynamic Difference-in-Differences, and introduces the Regression Discontinuity Design (RDD), and describes its advantages in this study: it can identify the changes in haze concentration before and after the implementation of the paid use policy of emission rights in Hangzhou. At the same time, since the RDD method requires that the control variables do not jump around the breakpoint date, the RDD-DID method uses the differences in two dimensions: annual and monthly (or other combinations of two dimensions), and its identification assumption allows other covariates except the core explanatory variables to jump around the reform date.

Finally, the RDD study shows that the 2011 policy document on the paid use of emission rights in Hangzhou and the 2015 policy document on the paid use of emission rights issued by the State Council have completely different effects on haze governance [1]. Through comparing the treatment group and the control group, RDD-DID shows that the paid use policy of emission rights can promote the reduction of PM2.5 concentration, showing a good effect on haze governance.

"Study on the Emission Reduction Effect of Emission Rights Trading Policy - An Empirical Test Based on China's Provincial Data" uses a PSM-DID model. Aiming at the endogeneity problem in the selection of emission rights trading pilots, this study innovatively constructs a PSM-DID hybrid model: first, through Propensity Score Matching (PSM), it selects the control group matching the economic and environmental characteristics of the pilot provinces in the pre-policy base period (2004-2006), effectively alleviating the sample selection bias; then, it uses the Difference-in-Differences method (DID) to separate the net policy effect, and finds that the pilot policy significantly reduces the SO_2 emission intensity by 18.7% ($p<0.01$). This method provides a methodological model for evaluating the effects of heterogeneous regional environmental policies through the dual correction mechanism of "matching first and then differencing" [2].

"Fuzzy Comprehensive Evaluation of Emission Rights Trading Based on AHP-CRITIC - A Case Study of Jiangxi Province" adopts unique methods in the multi-dimensional evaluation of the effect of emission rights trading policies: first, through the AHP-CRITIC combined weighting model, it takes into account both policy orientation and data-driven, compressing the subjective and objective weight deviation rate to 17%, which is significantly better than the traditional entropy weight method (deviation rate > 40%) or the single expert scoring method [3]; second, it designs a dynamic calibration mechanism for fuzzy comprehensive evaluation, and uses the time-series adaptive threshold to solve the problem of evaluation benchmark drift caused by the adjustment of policy stage goals. The empirical study based on Jiangxi Province shows that this index system can effectively identify regional governance shortcomings (such as the obstacle degree of institutional maturity reaching 32.7%) and provide a quantitative basis for the design of cross-regional ecological compensation mechanisms. Future research can further integrate high-resolution remote sensing data to enhance the ability to evaluate non-point source pollution.

At the same time, other articles such as "Paid Use and Trading of Emission Rights in China: Index Construction and Measurement Analysis" show that the research on the progress and effect evaluation of emission rights trading pilot work mainly uses qualitative methods to evaluate the system design, policy implementation, organizational management and other aspects. These methods rely heavily on researchers' understanding of emission rights, and make insufficient use of transaction data, with strong subjectivity and large room for improvement. Based on this, this paper introduces a comprehensive evaluation index, combines with emission rights transaction data, designs a quantifiable emission rights transaction evaluation method, and conducts an empirical study, in order to provide a quantitative method for evaluating the current situation and transaction effect of emission rights trading work [6].

And "Research on the Application of Multi-Indicator Visualization Method in the Effect Evaluation of Provincial Emission Rights Trading Pilots - A Case Study of Fujian Province" constructs an evaluation index system, uses a combination of qualitative and quantitative methods to carry out the evaluation, and applies the constructed visualization tool map of emission rights transaction data governance to complete the "one map" of emission rights trading in Fujian Province. On the basis of multi-dimensionally displaying the activity, participation, liquidity, optimization, contribution and other aspects of emission rights trading in Fujian Province, it discusses the challenges and opportunities faced by emission rights trading in Fujian Province [7].

Overall, current domestic studies on the emission rights trading system mostly focus on environmental governance effects and effect evaluation. However, in China's emission rights trading pilots, different articles use different models and methods to evaluate emission rights, which also provides ideas and directions for our research. In view of this, this paper will identify and evaluate the environmental governance effect of the carbon emission trading system on local cities (taking Shanghai as the sample city and Beijing as the control city) from the perspective of pollutant (taking typical pollutant nitrogen oxide as an example) emission reduction. However, due to the lack and incompleteness of data, we choose to use the RDD-DID method for research.

2. DEVELOPMENT HISTORY OF CHINA'S CARBON TRADING

The system of paid use and trading of emission rights is a major and basic mechanism innovation in China's resource and environmental field, and an important part of the construction of ecological civilization system. The national level attaches great importance to the paid use and trading of emission rights. The "Opinions of the Central Committee of the Communist Party of China and the State Council on Comprehensively Promoting the Construction of a Beautiful China" proposes to improve the market-oriented allocation system of resource and environmental factors, include emission rights in the overall reform of market-oriented allocation of factors, and the paid use and trading of emission rights have been raised to an unprecedented height [4].

In the 1980s, China had the earliest batch of emission rights trading explorations, but before 2006, it was only limited to the simple "enterprise-enterprise" model. In October 2011, the National Development and Reform Commission issued the "Notice on Carrying out the Pilot Work of Carbon Emission Rights Trading", approving seven provinces and cities including Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong and Shenzhen to take the lead in launching the carbon emission rights trading pilot, marking the official breakthrough of China's carbon trading system [1].

From 2013 to 2014, pilot provinces and cities successively launched trading; in 2016, Fujian Province expanded to join, forming a "7+1" pilot pattern. Each pilot, combined with local economic structure, energy consumption and emission characteristics, includes high-emission and high-emission reduction potential industries such as power, transportation, construction and cement into control, and explores differentiated system design: quota accounting adopts three methodologies: benchmark method, historical total method and historical intensity method; the allocation mechanism is dominated by free allocation, and some pilots gradually introduce paid allocation; the trading category is centered on carbon quota spot, and Shanghai, Hubei and other places take the lead in trying carbon financial derivative innovation.

In December 2017, the National Development and Reform Commission issued the "National Carbon Emission Rights Trading Market Construction Plan (Power Generation Industry)", establishing the implementation path of "industry first, then expansion"; on July 16, 2021, the national carbon emission rights trading system was launched in Shanghai, and the registration and settlement system was settled in Wuhan, Hubei, forming a "two-city linkage" structure. Initially, the market focuses on the power generation industry, covering 2162 key emission control enterprises with annual carbon emissions of 26,000 tons of carbon dioxide equivalent or more, adopting the "benchmark + pre-issuance" intensity control quota allocation model, and implementing free allocation. Simultaneously, the certified emission reduction (CCER) offset mechanism is opened, allowing enterprises to use CCER to offset no more than 5% of the quotas to be paid. By the end of the first compliance cycle on December 31, 2021, the national carbon market had covered about 4.5 billion tons of carbon dioxide emissions, achieving a high compliance rate of 99.5%. This breakthrough marks a historic leap from regional pilots to a national unified system in China's carbon market, building a core policy tool for achieving the "dual carbon" goals.

3. CURRENT SITUATION OF EMISSION RIGHTS TRADING SYSTEM DEVELOPMENT

3.1. Continuous Expansion of Trading Coverage

In terms of regional dimension, the pilot work shows a in-depth development trend. Most pilot provinces take municipal administrative regions as the basic implementation unit, and some leading regions have begun to build provincial cross-regional trading mechanisms. By establishing regional emission rights transfer platforms, they effectively alleviate the mismatch of environmental capacity resources between regions. In terms of pollutant control, all regions generally include four major pollutants: sulfur dioxide, nitrogen oxides, chemical oxygen demand and ammonia nitrogen into the trading system. In terms of industry coverage, the trading scope has gradually expanded from key monitored industries to the entire industrial field, and some pilot areas are exploring the inclusion of agricultural non-point source pollution into the management system.

3.2. Continuous Improvement of Right Confirmation Mechanism

All pilot areas have built a three-in-one right confirmation system of initial emission rights, new emission rights and surplus emission rights, and strive to promote the collaborative linkage with environmental management systems such as emission permits and environmental impact assessment approval. The initial emission rights confirmation adopts a progressive expansion strategy, comprehensively using diversified accounting methods such as the three-core quantitative strict minimum method, the quota compliance method and the industry emission performance method. The new emission rights strictly implement the "environmental impact assessment approval + market trading" dual-track system to ensure the market-oriented allocation of environmental capacity resources for new projects. For surplus emission rights, a disposal mechanism parallel to government storage and market circulation has been formed, and Hubei, Hunan and other places have taken the lead in establishing a surplus emission rights verification and public announcement system. It is worth noting that the validity period of emission rights in most regions is synchronized with the five-year plan cycle of the national economy.

3.3. In-depth Promotion of Paid Use System

As the core system design of the emission rights trading system, the paid use mechanism is increasingly prominent in the basic role of environmental resource allocation. Pilot areas have gradually established a differentiated paid use fee collection system, and the pricing mechanism fully considers multi-dimensional factors such as regional environmental governance costs, ecological resource endowments, and industrial economic carrying capacity. The price formulation generally adopts a prudent strategy, cultivating the market by setting a lower initial price. Although the collection standards vary significantly across regions, they generally show a steady upward trend. This gradual pricing strategy not only ensures the operability of the system, but also reserves policy space for subsequent market development.

3.4. Improvement of Market-oriented Allocation Efficiency

The current trading market presents three significant characteristics: first, government-enterprise transactions still dominate, accounting for more than 60% of the total transaction volume, and the growth rate is significantly higher than that of inter-enterprise transactions; second, air pollutant transactions are active, and the transaction scale of sulfur dioxide and nitrogen oxides continues to take the lead; third, the price formation mechanism is gradually mature, effectively reflecting the scarcity of environmental resources through market supply and demand regulation. It is worth noting that through the implementation of innovative policy tools such as double replacement and industry access restrictions, environmental resource factors are moving towards advantageous enterprises and industrial clusters with advanced technology and outstanding benefits, and the leverage role of market mechanisms in industrial structure optimization is gradually emerging.

4. MODEL ESTABLISHMENT

4.1. Research Objectives

From the perspective of pollutant (taking typical pollutant nitrogen oxide as an example) emission reduction, identify the pollutant emission reduction effect of the implementation of the emission rights trading policy on local cities (taking Shanghai as the sample city and Beijing as the control city), and evaluate the environmental governance effect of the carbon emission trading system on the first batch of typical pilot cities with carbon emission trading markets: Shanghai, Beijing, Chongqing and Tianjin.

4.2. Main Research Data

Total carbon emissions of all sectors in Shanghai, Beijing, Tianjin, Chongqing and the whole China (annual: 2011-2023) - Wind database

Nitrogen oxide emissions of Shanghai, Beijing, Tianjin, Chongqing and the whole country (annual: 2011-2023) - National Bureau of Statistics - provincial data

Average transaction price, transaction volume and transaction amount of carbon emission rights in Shanghai, Beijing, Tianjin and Chongqing (annual: 2013-2021) - Wind database

Other variables: GDP, population, etc. - "China Statistical Yearbook", "Shanghai Statistical Yearbook", "Beijing Statistical Yearbook", "Tianjin Statistical Yearbook", "Chongqing Statistical Yearbook" and the National Bureau of Statistics

Note: To distinguish SHEA, BEA and CCER, simply put, SHEA and BEA are the carbon emission rights quotas (carbon allocation) allocated by the city government to enterprises, while CCER is the carbon emission rights quotas (carbon offset) created by enterprises through some emission reduction activities and approved by the government.

4.3. Research Methods

Use the RDD method to identify the changes in nitrogen oxide emissions before and after the implementation of Shanghai's paid use policy of emission rights, add Beijing as the control city for pollutant emission reduction before and after the implementation of the emission rights trading policy in Shanghai, and identify the pollutant emission reduction effect of the implementation of the emission rights trading policy with Shanghai and Beijing as units.

On the basis of the established RDD model, combine with the generalized DID model to expand the model, and use RDD-DID to evaluate the incentive effect of the carbon emission rights trading system on pollutant emission reduction governance in the first batch of typical cities with carbon emission trading markets: Shanghai, Beijing, Tianjin and Chongqing.

Reasons for selecting Beijing as the reference group: The two cities are both municipalities directly under the Central Government, and both are among the first batch of pilot cities (seven provinces and municipalities directly under the Central Government) to establish carbon emission rights trading, and they have similar GDP, population, industrial scale, etc. Because the carbon emission rights trading policy identified by the RDD method is a national impact policy, we need to use the generalized DID model to distinguish the different impact degrees of the policy on Shanghai, Beijing, Tianjin and Chongqing.

4.4. Model Construction

Variable Selection

(1) Select the annual nitrogen oxide emissions of Beijing, Shanghai, Chongqing and Tianjin and logarithmize them (lmean) as the explained variable to measure the pollution degree;

(2) The time dummy variable (YPost) is the explanatory variable in this paper, which is 1 after the implementation of the emission rights trading system policy and 0 before the implementation;

(3) intensityi represents the impact of the establishment of the carbon emission rights trading market system on different individuals, and uses the continuous variable of the logarithmized carbon emission rights transaction amount in the four regions to represent the activity of carbon emission rights trading, which also reflects the impact of the carbon emission rights trading policy on different individuals.

Control the following variables that may have an impact on haze pollution at the same time:

(1) Regional economic development level (lGDP), expressed by the logarithm of GDP of Beijing, Shanghai, Chongqing and Tianjin;

(2) Industrialization degree (indusgdp), expressed by the proportion of industrial added value in GDP of Beijing, Shanghai, Chongqing and Tianjin;

(3) Population density (mpeople), expressed by the number of people per unit area in Beijing, Shanghai, Chongqing and Tianjin;

(4) Degree of opening to the outside world (ltFDI), expressed by the logarithm of the actual amount of foreign capital utilized in Beijing, Shanghai, Chongqing and Tianjin.

(5) intensityi represents the impact of the establishment of the carbon emission rights trading market system on different individuals, and uses the continuous variable of the logarithmized carbon emission rights transaction amount in the four regions to represent the activity of carbon emission rights trading, which also reflects the impact of the carbon emission rights trading policy on different individuals.

RDD Model Construction:

$$lmean_{it} = \beta_1 YPost_{it} + \beta_2 (t-t_0) + \beta_3 YPost_{it}(t-t_0) + \beta_k X_{it} + \varepsilon_{it} \tag{1}$$

lmeanit represents the logarithm of the annual nitrogen oxide emissions of sample i in year t; YPost it is the policy treatment variable, which is 0 before the implementation of the policy and 1 after the implementation of the policy; t-t0 represents the standardized year time variable, and t0 is the policy implementation time point; εit is the random disturbance term; Xit is other variables. The coefficient of the policy term in the whole model is the object we focus on.

RDD-DID Model Construction:

$$lmean_{it} = \alpha + \beta_1 YPost_{it} + \beta_2 intensity_i + \beta_3 (t-t_0) + \beta_4 YPost_{it}(t-t_0) + \beta_5 intensity_i * YPost_{it} + \beta_k X_{it} + \varepsilon_{it} \tag{2}$$

lmeanit represents the logarithm of the annual nitrogen oxide emissions of sample i in year t; YPost it is the policy treatment variable, which is 0 before the implementation of the policy and 1 after the implementation of the policy; t-t0 represents the standardized year time variable, and t0 is the policy implementation time point; εit is the random disturbance term; Xit is other variables; intensityi represents the impact of the establishment of the carbon emission rights trading market system on different individuals, and uses the continuous variable of the logarithmized carbon emission rights transaction amount in the four regions to represent the activity of carbon emission rights trading, which also reflects the impact of the carbon emission rights trading policy on different individuals. The policy term coefficient and the interaction term coefficient in the whole model are the objects we focus on.

5. ANALYSIS OF EMPIRICAL RESULTS

5.1. Analysis of RDD Model Regression Results

Table 1. RDD Model Regression Results of Beijing and Shanghai

VARIABLES	RDD	RDD	RDD	RDD	RDD	RDD
	Beijing	Beijing	Beijing	Shanghai	Shanghai	Shanghai
	Estimate	pValue	Significance	Estimate	pValue	Significance
Intercept	33.26771812	0.155560439		12.61620154	0.00699636	**
YPost	0.115956899	0.55937252		-0.571992445	1.35951E-05	***
intensity	/	/		/	/	
time	0.269560268	0.380401378		-0.069421648	0.045270714	*
YPost_time	-0.154823636	0.4603221		0.117928924	0.001081293	**
intensity_YPost	/	/		/	/	
lGDP	-2.255898335	0.134618737		-1.14840517	0.005894344	**
indusgdp	0.643384888	0.90603618		-2.357900171	0.062926233	
mpeople	-0.005520259	0.496914605		0.001842226	0.002756717	**
ltFDI	-0.152050308	0.52136314		-0.763351355	0.003446915	**
Observations	13	13	13	13	13	13
freedom	5	5	5	5	5	5
RE	0.116	0.116	0.116	0.0185	0.0185	0.0185
R-squared	0.94	0.94	0.94	0.999	0.999	0.999
ad R-squared	0.856	0.856	0.856	0.998	0.998	0.998
F	11.2	11.2	11.2	1.12e+03	1.12e+03	1.12e+03
p-value	0.00857	0.00857	0.00857	1.12e-07	1.12e-07	1.12e-07

As shown in Table 1, through the regression results of the RDD single model for Shanghai and Beijing, it is found that there are great differences in the policy identification results of the two cities. The coefficient of the policy treatment term of the RDD model (Shanghai) is significantly negative, and pollutant emission reduction is also affected by control variables such as GDP, population density and FDI. Through the analysis of the regression results of the RDD single model for Shanghai, it can be found that the 2015 emission rights trading policy "Guiding Opinions on Further Promoting the Pilot Work of Paid Use and Trading of Emission Rights" has a very significant incentive effect on pollutant emission reduction in Shanghai, and with the improvement of Shanghai's GDP, population density and FDI, it also has a more significant incentive effect on local pollutant emission reduction in Shanghai.

On the other hand, through the analysis of the regression results of the RDD single model for Beijing, it can be found that the coefficients of all policy terms and control variable terms are not significant. Not only does the 2015 emission rights trading policy "Guiding Opinions on Further Promoting the Pilot Work of Paid Use and Trading of Emission Rights" have no incentive effect on pollutant emission reduction in Beijing, but it also indicates that the RDD model has not correctly identified the control variables that have a significant effect on pollutant emission reduction in Beijing.

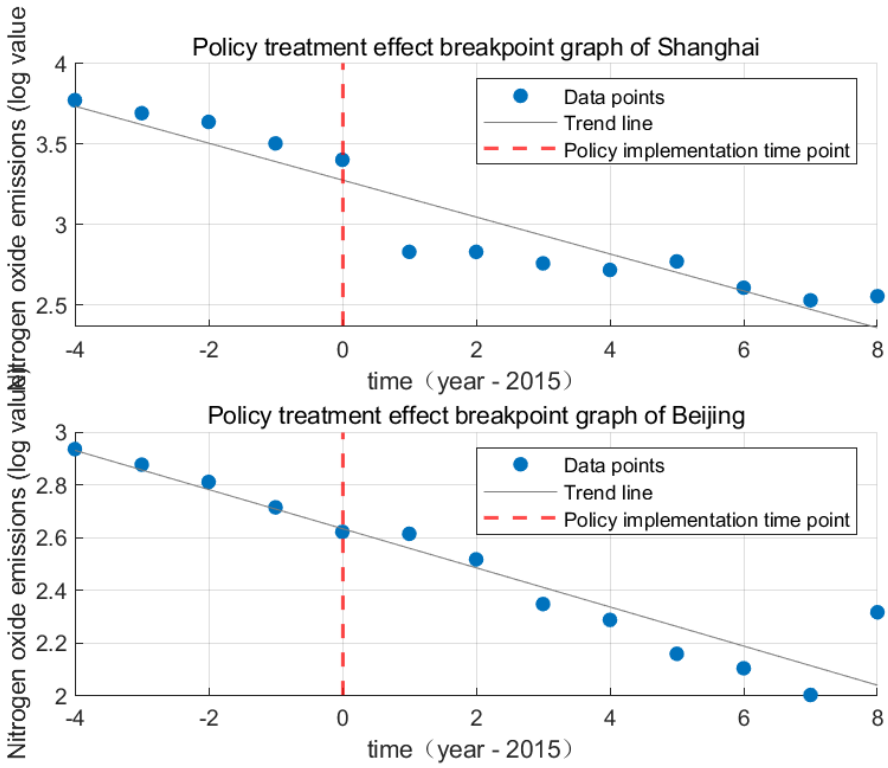

Figure 1. Policy treatment effect breakpoint graph

As shown in Figure 1 Breakpoint Plots of Policy Treatment Effects in Shanghai and Beijing, the RDD models of both Shanghai and Beijing conform to the basic assumption of parallel trends, and it can be more intuitively seen that the pollution degree in Shanghai has decreased to a greater extent after the implementation of the policy, while Beijing has not been significantly affected by the policy on the original downward trend before and after the policy treatment. Based on the above analysis, the reason why Beijing is not significantly affected by the policy is that Beijing, as the capital, has already established a relatively complete emission rights trading mechanism, so the "Guiding Opinions on Further Promoting the Pilot Work of Paid Use and Trading of Emission Rights" to promote the establishment of emission rights trading has little actual impact on pollutant emission reduction in Beijing.

5.2. Analysis of RDD-DID Model Regression Results

Table 2. RDD-DID Model Regression Results of Shanghai, Beijing, Tianjin and Chongqing

VARIABLES	RDD-DID	RDD-DID	RDD-DID
	Four Municipalities	Four Municipalities	Four Municipalities
	Estimate	pValue	Significance
Intercept	-7.004485669	0.00035374	***
YPost	-4.450472262	0.001265613	**
intensity	0.030420955	0.105250497	
time	-0.25378322	0.011935099	*
YPost_time	0.139168779	0.167029516	
intensity_YPost	0.238175735	0.002059361	**
lGDP	1.175981073	1.20436E-06	***
indusgdp	1.203019403	0.213449642	
mpeople	0.000260762	0.000230241	***
ltFDI	-0.716401503	2.86587E-08	***
Observations	52	52	52
freedom	42	42	42
RE	0.261	0.261	0.261
R-squared	0.764	0.764	0.764
ad R-squared	0.714	0.714	0.714
F	15.1	15.1	15.1
p-value	1.43e-10	1.43e-10	1.43e-10

Through the RDD single model policy identification regression experiment on Shanghai, it is found that the 2015 emission rights trading policy "Guiding Opinions on Further Promoting the Pilot Work of Paid Use and Trading of Emission Rights" did play a key role in emission reduction in Shanghai, but from the performance of the reference group Beijing, the coefficients of YPOST and control variables are not significant.

Therefore, based on the consideration of the robustness of the experiment, the sample is expanded to the four municipalities directly under the Central Government that are the first batch of pilot cities to establish carbon emission trading markets, and the RDD-DID model is established to identify the emission reduction effect of carbon emission trading on cities that have promoted the emission rights trading policy. The coefficients of YPOST and intensity*YPOST are our focus.

As shown in Table 2, in the RDD-DID model, the YPOST coefficient is significantly negative, while the intensity. YPOST coefficient is significantly positive. Based solely on this empirical result, it can be explained that the 2015 policy "Guiding Opinions on Further Promoting the Pilot Work of Paid Use and Trading of Emission Rights" did play a key incentive role in pollutant emission reduction in various cities, while the activity of carbon emission rights trading played a certain reverse role in pollutant emission reduction.

The reason why the interaction term coefficient is significantly positive is that it is considered that enterprises in regions with established carbon emission rights trading markets may hinder the promotion of the "Guiding Opinions on Further Promoting the Pilot Work of Paid Use and Trading of Emission Rights" to establish emission rights trading markets to a certain extent due to the existing carbon emission rights trading. In other words, the existing carbon emission rights trading markets will crowd out the emission rights trading markets, reduce enterprises' attention and transaction activity to emission rights, and thus inhibit pollutant emission reduction. The reasons for the above results will be explained in detail below:

(1) Resource Crowding and Priority Conflict

Enterprises have limited funds and human resources in emission reduction technology research and development, equipment upgrading or management optimization. When the carbon emission rights trading market is active, enterprises may invest main resources in carbon emission reduction fields (such as purchasing carbon quotas, developing low-carbon technologies), while ignoring investment in the governance of other pollutants (such as sulfur oxides, nitrogen oxides). If the economic incentives of the carbon emission rights trading policy are stronger (such as higher carbon prices, stricter penalties), enterprises will give priority to meeting carbon emission reduction requirements, leading to the marginalization of the emission rights trading policy.

(2) Side Effects of Technical Substitution

Some low-carbon technologies (such as coal-fired power plants switching to natural gas) may reduce carbon emissions, but may increase other pollutants (such as natural gas combustion may produce more nitrogen oxides). If enterprises adopt such technologies to meet the requirements of the carbon market, it will instead lead to an increase in other pollutant emissions. Enterprises may choose cheaper carbon emission reduction methods (such as purchasing quotas) instead of investing in multi-pollutant synergistic governance technologies (such as desulfurization and denitrification equipment) at the same time, resulting in unbalanced pollutant emission reduction.

(3) Fragmentation of Market Mechanism Design

The quota allocation rules (such as benchmark, free quota ratio) or covered industry scopes of the carbon emission rights market and the emission rights market are inconsistent, and enterprises may transfer emissions through "institutional arbitrage". For example, high-carbon industries purchase quotas in the carbon market to maintain production, while allowing other pollutants to be emitted due to insufficient constraints in the emission rights market. High carbon prices may attract capital to flow into the carbon emission reduction field, while low emission rights prices lead to enterprises' lack of motivation to reduce other pollutants, forming a market pattern of "one strong and one weak".

(4) Decentralization of Supervision and Execution Capabilities

Regulatory authorities may allocate more human and technical resources to the verification of carbon emission data (due to the active carbon market and large transaction volume), resulting in weakened monitoring of other pollutants and reduced actual execution effect of emission rights trading. Enterprises may choose "selective compliance" to cope with multiple environmental policies, that is, giving priority to meeting the requirements of the more strictly regulated (or more severely punished) carbon market, while reducing attention to the emission rights policy.

6. LIMITATIONS AND FUTURE PROSPECTS

Due to the serious lack of data such as monthly emissions, the scope of this study is expanded to four municipalities directly under the Central Government. In addition, differences in policy nodes and data limitations may affect the accuracy of the results. Future research can further find corresponding data and more pilot provinces, deeply explore the heterogeneous effects of the carbon emission rights trading system in regions with different economic structures, and provide more comprehensive empirical support for the construction of a national environmental rights market.

7. CONCLUSION

Based on the carbon emission and nitrogen oxide emission data of four first-batch carbon emission trading pilot cities (Shanghai, Beijing, Tianjin, Chongqing) from 2011 to 2023, this study uses Regression Discontinuity Design (RDD) and Generalized Difference-in-Differences Model (RDD-

DID) to systematically evaluate the incentive effect of the carbon emission trading system on pollutant emission reduction and its environmental governance effect.

The results of the RDD model show that after the implementation of the "Guiding Opinions on Further Promoting the Pilot Work of Paid Use and Trading of Emission Rights" in 2015 in Shanghai, the coefficient of the policy treatment term is significantly negative (estimated value -0.572, $p<0.01$), indicating that the carbon emission trading policy has significantly reduced nitrogen oxide emissions. However, the policy term coefficient in Beijing is not significant, which may be because as the capital, it already has a relatively mature carbon emission rights trading system, and the marginal incentive effect of the new policy is limited. In addition, control variables such as economic development level (GDP), population density and foreign direct investment (FDI) have a significant positive impact on the emission reduction effect in Shanghai, but there is no significant correlation in the Beijing model.

The extended analysis of RDD-DID shows that the carbon emission rights trading policy has a significant overall emission reduction effect on the four pilot cities (YPost coefficient -4.45, $p<0.01$), but the interaction term coefficient between the activity of carbon emission rights trading (intensity) and the policy is significantly positive (0.238, $p<0.01$). This indicates that the high activity of the carbon emission rights market may weaken the emission reduction incentive of the emission rights trading policy, due to resource crowding effect, side effects of technical substitution, market mechanism fragmentation and decentralized supervision resources.

This study suggests:

(1) Strengthen the multi-pollutant synergistic governance mechanism, integrate the market rules of carbon emission rights and emission permits, and avoid efficiency losses caused by policy fragmentation.

(2) Link central policy intervention with local assessment: incorporate environmental performance (such as nitrogen oxide emission reduction) into the assessment system of local officials to curb local implementation inertia.

(3) Optimize market incentive design: guide enterprises to invest in multi-field emission reduction technology research and development in a balanced way through differentiated carbon prices and emission rights pricing. Build and continuously improve the secondary market for emission trading, increase investment from enterprises and institutions, activate the market-oriented system of emission rights trading, optimize market allocation, ensure market-led transactions, operate the secondary trading market well, and give play to the competitive role of the market [5].

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