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The Impact of Carbon Emissions Trading on Urban Green Development

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Abstract

Under the background of China's "dual carbon" strategy (i.e., the goals of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060) and urban green transformation, carbon emissions trading, as a typical market-oriented environmental regulation policy, has become an important starting point for balancing economic development and ecological protection. This article takes the balanced panel data of prefecture-level cities in China from 2011 to 2024 as the research sample, and regards the pilot policy of carbon emissions trading as a quasi-natural experiment. Two-way fixed-effects difference-in-differences (DID) model is used to empirically test the overall impact and regional heterogeneity of carbon emissions trading on urban green development. Furthermore, the intermediary effect model is constructed to explore the transmission mechanism of green innovation between them. The results show that: First, carbon emissions trading policy can significantly improve the green development level of pilot cities. This conclusion is still valid after multiple robustness tests, such as lagging explanatory variables, random sampling samples, parallel trend test and placebo test. Second, the policy effect of carbon emissions trading has obvious heterogeneity of economic development level. Policies only play a significant role in promoting cities with high economic development level, but the effect is not significant in cities with low economic development level. Third, green innovation plays a significant intermediary role between carbon emissions trading and urban green development. Carbon emissions trading can indirectly promote the green development of cities by stimulating the output of green patents and enhancing the regional green innovation ability. Based on the research conclusion, this article puts forward policy suggestions from the aspects of perfecting the national carbon market construction, implementing differentiated regional policies, and strengthening green innovation incentives, with the aim of providing experience reference and decision-making basis for fully releasing the carbon emissions trading policy dividend and helping the green and high-quality development of cities.

Keywords

Emissions Trading; Urban Green Development; Difference-in-differences Model; Green Innovation; Mediation Effect.

1. Introduction

1.1. Research Background

Global warming has become an ecological challenge faced by all mankind. Controlling greenhouse gas emissions and promoting low-carbon transformation have become an important consensus in the economic and social development of all countries in the world. As the world's largest developing country and a big carbon emitter, China has successively put forward the strategic goals of peak carbon dioxide emissions and carbon neutrality, incorporated the development of low-carbon life into the national top-level development plan, and gradually built a diversified environmental governance system of "government guidance+market drive". Traditional mandatory environmental regulation has some defects, such as high implementation cost, insufficient flexibility and weak endogenous motivation of enterprises to reduce emissions, which makes it difficult to meet the needs of green and high-quality development in the new era. Carbon emissions trading relies on the market-oriented price mechanism to internalize the cost of carbon emissions, forcing market players to take the initiative to carry out emission reduction actions and become the core market-oriented tool to implement the goal of "dual carbon".

The pilot project of carbon emissions trading in China was officially launched in 2013, and has been carried out in Beijing, Shanghai, Tianjin, Chongqing, Guangdong, Hubei, Shenzhen and other provinces and cities, gradually forming an implementation pattern of promoting in batches and regions. In 2021, the national carbon emission trading market was officially put into operation, and the coverage and trading scale of the carbon market continued to expand. Cities are the main carrier of carbon emissions and the core unit of green development. The effect of low-carbon transformation at the city level directly determines the progress of the national "dual carbon" goal. Under this background, this article explores the actual impact, action path and regional differences of carbon emissions trading policy on urban green development, and clarifies the internal logic of policy operation. This can not only scientifically evaluate the implementation effect of the existing carbon trading pilot, but also provide practical support for the optimization and improvement of the national carbon market and the design of urban green transformation path.

At the same time, the current urban green development in China presents a significant regional imbalance. There is an obvious gap between the developed cities in the east and the underdeveloped cities in the central and western regions in terms of economic base, technical level, industrial structure and financial resources. Carbon trading policies may have differentiated effects in cities with different levels of development. As the core driving force of green development, whether green innovation can bear the policy impact of carbon trading and form a conduction chain of "carbon trading-green innovation-green development" is also a key issue that needs to be verified urgently. Based on this, this article focuses on the level of prefecture-level cities and studies the impact of carbon emissions trading on urban green development, which has important theoretical value and practical significance.

1.2. Significance of the Study

1.2.1. Theoretical Significance

The existing research mostly focuses on the carbon emission reduction effect of carbon emissions trading, the impact of enterprise performance and the single effect of green innovation. Although some studies have discussed the direct relationship between carbon trading and green development, there is little systematic analysis from three dimensions: overall effect, heterogeneity and intermediary mechanism. In this article, the double difference model and the intermediary effect model are combined to verify the intermediary transmission function of green innovation, which enriches the research on the mechanism of market-oriented environmental policies affecting urban green development. At the same time, according to the level of economic development, samples are divided to carry out heterogeneity analysis, which refines the research on the regional effect of carbon trading policy, makes up for the lack of consideration of urban development endowment differences in existing research, and expands the research boundary between environmental economics and green development theory.

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1.2.2. Practical Significance

Firstly, the implementation effect of the pilot carbon emissions trading policy from 2011 to 2024 was evaluated, and the actual promotion of the policy to urban green development was tested, which provided an empirical basis for the rule optimization and scope expansion of the national carbon market. Secondly, the policy adaptability of cities with different economic development levels is identified, which provides a reference for local governments to formulate differentiated low-carbon development policies and avoid "one size fits all" environmental regulations. Thirdly, the intermediary role of green innovation has been clarified, guiding local governments to leverage carbon trading policies to promote green technology research and development, breaking through the virtuous cycle of "policy incentives innovation upgrading green development", and helping cities achieve coordinated development of economy, ecology, and people's livelihood.

1.3. Review of the Literature

1.3.1. International Research

The theoretical foundation of emissions trading can be traced to property-rights theory. Coase (1960) [1] introduced the idea of environmental property rights, laying the groundwork for markets in pollution permits and carbon allowances. Montgomery (1972) [2] subsequently demonstrated the cost advantage of emissions trading over administrative regulation, showing that market-based exchange can reduce the aggregate social cost of abatement. Empirical research expanded as systems such as the European Union Emissions Trading System (EU ETS) and the US Regional Greenhouse Gas Initiative (RGGI) entered operation.

Porter and Van der Linde (1995) [3] formulated the classic Porter hypothesis, according to which well-designed market-based environmental regulation can induce technological innovation and yield both environmental and economic gains. Drawing on this argument, Calel and Dechezleprêtre (2016) [4] studied the EU ETS and found that emissions trading significantly increased firms' green R&D and patenting. Regarding regional heterogeneity, Martin et al. (2014) [5] showed that policy effectiveness depends strongly on local economic, industrial, and technological conditions: developed regions are better positioned to realize policy benefits, whereas less developed regions may incur adverse effects from abatement costs. International studies commonly apply quasi-experimental methods, including DID and propensity-score matching, to evaluate such policies, providing an important methodological reference for the present study.

1.3.2. Research in China

Following the launch of China's emissions-trading pilots in 2013, domestic research developed along three main lines. The first concerns emissions reduction. Using provincial panel data, Zhang et al. (2019) [6] found that emissions trading effectively reduced regional carbon intensity, whereas Shen and Zhou (2020) [7] documented substantial regional and sectoral heterogeneity in the abatement effect.

The second line examines emissions trading and green innovation. Wang et al. (2021) [8] argued that internalizing the cost of carbon induces firms to invest more heavily in green patents. Li and Zhang (2022) [9] further noted that underdeveloped financial systems and shortages of innovation inputs can constrain this incentive effect.

The third line focuses on emissions trading and urban green development. Liu and Peng (2022) [10] found that emissions trading generally advances the green transformation of cities. Taken together, however, the domestic literature [11-15] has largely tested only the direct relationship, with limited attention to mediating channels and the sources of heterogeneity; moreover, the samples commonly cover relatively short periods.

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Overall, prior research demonstrates close links among emissions trading, green innovation, and urban green development. Few studies, however, use a long prefecture-level-city panel covering 2011-2024 and incorporate the direct effect, economic heterogeneity, and mediation mechanism into a unified framework. The present study addresses this gap through a systematic set of empirical tests.

1.4. Research Content and Methods

1.4.1. Research Content

The paper is organized as follows. Section 1 introduces the background and significance of the study, reviews the literature, and presents the research content, methods, and contributions. Section 2 develops the direct, heterogeneous, and mediating mechanisms through which emissions trading may affect urban green development and proposes three hypotheses. Section 3 describes the data sources and sample-selection rules, defines the variables, and specifies the empirical models. Section 4 reports descriptive statistics, correlation and multicollinearity tests, and baseline regressions. Sections 5-7 present mechanism, heterogeneity, robustness, parallel-trend, and placebo tests and interpret the results. Section 8 concludes, proposes policy recommendations in light of China's urban-development conditions, and discusses limitations and directions for future research.

1.4.2. Research Methods

(1) Literature review. Relevant international and Chinese research on emissions trading, urban green development, and green innovation is reviewed to identify established findings and remaining gaps and to develop the theoretical framework.

(2) Quasi-natural experiment (difference-in-differences). Pilot cities constitute the treatment group and non-pilot cities the control group. A two-way fixed-effects DID model estimates the net effect of the policy on urban green development.

(3) Mediation analysis. Green innovation is introduced as the mediator to identify the transmission channel through which emissions trading affects urban green development.

(4) Statistical analysis. Descriptive statistics, correlation analysis, and multicollinearity diagnostics are used to characterize the sample and reduce statistical-modeling concerns. Robustness is assessed by lagging the explanatory variable, randomly resampling the observations, and conducting parallel-trend and placebo tests.

1.5. Contributions

This study contributes in three respects. First, it moves beyond single-effect analysis by placing the direct effect, heterogeneity by economic-development level, and the mediation mechanism of green innovation within one analytical framework. Second, it uses a 14-year balanced panel of Chinese prefecture-level cities for 2011-2024, which is better suited than a short sample to capturing the policy's longer-term dynamics. Third, it develops a layered testing strategy that combines several robustness checks with parallel-trend and placebo tests, subgroup analysis, and mediation analysis, thereby strengthening the credibility of the empirical results.

2. Theoretical Mechanisms and Research Hypotheses

2.1. Direct Mechanism

Urban green development is a comprehensive development model of economic growth, resource utilization, ecological environment and improvement of people's livelihood. Its core lies in solving the contradiction between economic development and ecological protection. As a market-oriented environmental regulation tool, carbon trading plays a role in urban green development from two dimensions: cost constraint and income incentive. From the perspective of cost constraint, carbon trading clarifies the property right attribute of carbon emissions, and

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enterprises need to purchase carbon emission quotas for excessive emissions. This directly increases the production cost of enterprises with high energy consumption and high emissions, and forces enterprises to reduce the scale of high-carbon production and optimize production processes, thereby reducing the overall carbon emission intensity of the city, improving the ecological environment and helping green development. From the perspective of income incentives, enterprises with remarkable low-carbon transformation and surplus carbon emission quotas can obtain additional income by selling quotas, forming positive incentives and guiding market players in cities to actively practice the low-carbon development model. At the same time, the carbon trading policy will guide local governments to optimize industrial layout, increase investment in environmental protection infrastructure, and promote the overall transformation of the city to green development. Accordingly, hypothesis 1 is put forward: carbon emissions trading can promote urban green development.

2.2. Heterogeneity Mechanism

The economic development level of different cities in China is quite different. The differences in economic base, technical reserves, financial strength and industrial structure will lead to the differentiation of the landing effect of carbon trading policies. The industrial structure of cities with high level of economic development is more diversified, with the tertiary industry accounting for a high proportion and the industries with high energy consumption accounting for a relatively low proportion. Such cities have strong financial strength, perfect scientific and technological innovation system and sufficient financial resources, and the financial strength of enterprises is strong. It can bear the cost of green technology transformation and emission reduction equipment renewal, respond to the price signal of carbon market quickly, and turn the pressure of emission reduction into transformation power, thus fully releasing the green development effect of carbon trading policy. Most cities with low economic development level rely on high energy-consuming industries to achieve economic growth, with heavy industrial structure and weak willingness of local governments and enterprises to reduce emissions. Enterprises in such cities generally have problems such as lack of funds and backward technology, and are unable to carry out substantive green transformation. They can only passively meet policy requirements by purchasing quotas or paying fines. This makes it difficult for carbon trading to play an incentive role and the policy effect is not significant. To sum up, the impact of carbon trading on urban green development will be different due to different levels of economic development, and accordingly hypothesis 2 is put forward: the impact of carbon emissions trading on urban green development is different at different levels of economic development.

2.3. Mediating Role of Green Innovation

Green innovation is the core bridge between carbon trading policy and urban green development. Carbon emissions trading raises the cost of carbon emissions, compresses the profit margin of high-carbon enterprises, and forces enterprises to shift resources from traditional high-carbon production to green technology research and development. This has promoted the output of innovative achievements such as green patents and green processes, thus enhancing the level of regional green innovation. With the improvement of green innovation level, on the one hand, green technology and green equipment can directly reduce energy consumption and carbon emissions of enterprises and improve urban ecological environment. On the other hand, green innovation will give birth to green emerging industries such as new energy, energy conservation and environmental protection, promote the transformation of urban industrial structure to advanced and green, realize the coordinated promotion of economic development and ecological protection, and finally promote the green development of cities. In short, carbon emissions trading policy can indirectly promote the green development of cities by improving the level of green innovation, that is, green innovation

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plays an intermediary role. Based on this, hypothesis 3 is put forward: green innovation plays an intermediary role in the influence of carbon emissions trading on urban green development.

3. Research Design

3.1. Data Sources and Sample Construction

The study uses a panel of Chinese prefecture-level cities covering 2011-2024. The raw data are drawn from the China City Statistical Yearbook, China Environmental Statistics Yearbook, China Financial Statistics Yearbook, statistical bulletins issued by individual cities, and the green-patent database of the China National Intellectual Property Administration.

To ensure data validity, the sample is processed as follows. First, municipalities directly under the central government, cities with substantial missing data, and cities subject to frequent administrative-boundary adjustments are excluded. Second, a small number of missing annual observations are imputed by linear interpolation. Third, statistical definitions are harmonized across variables. The final balanced panel contains 2433 city-year observations.

3.2. Variable Selection and Definition

Combined with the research topic and existing literature, four categories of variables are set up: explained variables, core explanatory variables, intermediate variables and control variables. The definitions, symbols and calculation methods of specific variables are shown in Table 1.

Table 1. Variable Definitions

Variable type	Variable	Symbol	Definition and measurement
Dependent variable	Urban green development	green	Composite prefecture-level green-development index constructed from the Green Development Indicator System, covering the green economy, resource use, environmental quality, and improvements in living standards
Key explanatory variable	Emissions-trading policy effect	DID	DID interaction term. Pilot cities form the treatment group and non-pilot cities the control group. The time indicator equals 1 in and after the year of implementation and 0 otherwise; its interaction with treatment status measures the policy effect.
Mediator	Green innovation	lngi	Total green patents granted in the city (10,000 patents), measuring regional green-technology output
Control variable	Economic development	lngdp	Natural logarithm of city GDP, used to reduce heteroskedasticity and control for economic scale
Control variable	Financial development	fin	Year-end balance of loans from financial institutions divided by city GDP, measuring credit availability and financial-resource allocation
Control variable	Industrial upgrading	ind	Value added of the tertiary sector divided by GDP (%), measuring the shift toward services and a more advanced industrial structure
Control variable	Internet development	lnint	Natural logarithm of the total number of internet users, measuring digital infrastructure and the digital economy

3.3. Model Specification

3.3.1. Baseline Difference-in-Differences Model

In this article, the double difference model of two-way fixed effect is used to test the direct impact of carbon emissions trading on urban green development. By controlling urban

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individual fixed effect and time fixed effect, the interference of urban heterogeneity and time trend can be avoided. The benchmark model is set as follows:

$$green_{it}=\beta_0+\beta_1 DID_{it}+\gamma X_{it}+\delta_i+\mu_t+\varepsilon_{it}$$

where i represents cities and t represents years; $green_{it}$ denotes the level of green development of city i in year t; DID_{it} represents the interaction term of the carbon emissions trading policy (the core explanatory variable); X_{it} is the set of control variables; δ_i represents city fixed effects; μ_t represents time fixed effects; and ε_{it} is the random disturbance term. The coefficient β_1 is the core coefficient of interest. If β_1 is significantly positive, it indicates that the carbon emissions trading policy can promote urban green development.

3.3.2. Mediation Model

To examine the mediating role of green innovation, this study adopts the two-step mediation approach proposed by Jiang Ting to construct the mediation effect model. Based on the baseline model, the level of green innovation (lngi) is introduced as the dependent variable in the regression equation, and the specific models are constructed as follows:

Model 1 (total effect; identical to the baseline regression):

$$green_{it}=\beta_0+\beta_1 DID_{it}+\gamma X_{it}+\delta_i+\mu_t+\varepsilon_{it}$$

Model 2 (effect of the policy on the mediator):

$$lngi_{it}=\alpha_0+\alpha_1 DID_{it}+\theta X_{it}+\delta_i+\mu_t+\varepsilon_{it}$$

Test logic: If the DID coefficient β_1 in Model 1 is significantly positive, and the DID coefficient α_1 in Model 2 is also significantly positive, it indicates that green innovation plays a significant mediating role.

4. Empirical Analysis

4.1. Descriptive Statistics

Firstly, descriptive statistics are made for all variables, and the overall distribution, dispersion degree and range of sample data are analyzed. The results are shown in Table 2.

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
green	2433	0.277	0.05	0.164	0.669
DID	2433	0.136	0.343	0	1
fin	2433	10634.071	6406.807	1179.761	96229.102
lngdp	2433	7.412	0.968	5.033	10.674
ind	2433	42.236	10.145	10.1	83.5
lnint	2433	13.749	1.511	9.21	21.795

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As can be seen from Table 2, the observed values of all variables are 2433, and the sample matching degree is good, which meets the requirements of panel data analysis. The specific analysis is as follows:

(1) Explained variable (green): The average value of urban green development level is 0.277, and the standard deviation is only 0.05, so the data distribution is centralized. This shows that the overall green development of the sample cities is at a medium and low level. The minimum value is 0.164, and the maximum value is 0.669, which is a big range, which directly reflects the obvious regional imbalance characteristics of urban green development in China. The level of green development in a few cities is significantly higher than the national average.

(2) Core explanatory variable (DID): the average value is 0.136, indicating that 13.6% of the observed values in the sample belong to the pilot cities after the implementation of the policy. This is in line with the implementation characteristics of China's carbon trading in batches and regions. The standard deviation is 0.343, which shows that there are significant differences in time and space dimensions of policy shocks, which meets the grouping and exogenous requirements of double difference model.

(3) Control variable (fin): The average value of financial development level is 10634.071, the standard deviation is as high as 6406.807, and the extreme value gap is wide. This shows that the scale of financial credit and the distribution of financial resources in different cities are extremely uneven, and the regional financial development is obviously divided.

(4) Control variable (lngdp): The level of economic development adopts the logarithmic form of GDP, with an average value of 7.412 and a standard deviation of 0.968. The data distribution is smooth, and the logarithmic processing effectively alleviates the heteroscedasticity problem, which shows that the difference of urban economic scale is in a reasonable range.

(5) Control variable (ind): The average value of industrial structure upgrading is 42.236%, indicating that the whole sample city is in the transition stage from industrialization to service. The standard deviation is 10.145% and the range of values is 10.1%–83.5%. Some cities have formed a leading pattern of service industry, while some cities are still dominated by industry, and the industrial structure is significantly differentiated.

(6) Control variable (lnint): The development level of the Internet adopts the logarithmic form of the number of users, with an average of 13.749 and a standard deviation of 1.511. The data distribution is stable, which reflects the gradient popularization characteristics of digital infrastructure among cities, and the difference is reasonable.

4.2. Correlation Analysis

In order to avoid multicollinearity, the correlation analysis of variables is carried out before regression analysis to test the degree of linear correlation between variables. The results are shown in Table 3.

Table 3. Correlation Matrix

	green	DID	lngdp	ind	lnint
green	1				
DID	0.203***	1			
lngdp	0.611***	0.253***	1		
ind	0.665***	0.158***	0.426***	1	
lnint	0.552***	0.245***	0.645***	0.493***	1
*** p<0.01, ** p<0.05, * p<0.1					

The results of correlation analysis show that: Firstly, the correlation coefficient between the core explanatory variable DID and the explained variable green is 0.203, which is significantly

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positive at the level of 1%, indicating that there is a positive correlation between carbon emissions trading and urban green development; Secondly, the correlation coefficients of all variables are less than 0.7, and most of them are less than 0.6, which shows that the linear correlation between variables is low and there is no serious multicollinearity problem. In addition, the level of economic development, industrial structure and Internet development are significantly positively correlated with the level of green development, which is in line with theoretical expectations.

4.3. Multicollinearity Test

In order to test multicollinearity more accurately, variance expansion factor (VIF) was used for analysis. It is generally believed that when VIF<10, there is no serious multicollinearity between variables. The test results are shown in Table 4.

Table 4. Multicollinearity Diagnostics

Variable	VIF	1/VIF
ind	1.994	0.502
lnint	1.919	0.521
lngdp	1.785	0.560
fin	1.644	0.608
DID	1.113	0.898
Mean VIF	1.691	-

It can be seen from Table 4 that the VIF values of all variables are far less than 10, and the average VIF is only 1.691, which proves that there is no serious multicollinearity between the selected core explanatory variables and the controlled variables, and the selection of variables is reasonable, so the benchmark regression analysis can be continued.

4.4. Hausman Test

In order to further test the rationality of the model setting, Hausman test is used to compare the fixed effect model with the random effect model. If the test results are significant, it shows that the key assumptions of the random effect model are not valid, and the fixed effect model is more suitable. The test results are shown in Table 12.

Table 5. Hausman Test Results

Test statistic	Statistic
chi2	123.347
Degrees of freedom	16
p-value	0.000

It can be seen from Table 12 that the chi2 statistic of Hausman test is 123.347, and the P value is close to 0, which is significant at the level of 1%, indicating that the random effect model should be rejected and the fixed effect model should be adopted. The results show that the fixed effect model used in this article is reasonable, and further enhance the reliability of the benchmark regression conclusion.

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4.5. Baseline Regression

In this article, the double difference model with two-way fixed effect is used for benchmark regression, and the results of two groups of regression with and without control variables are reported in turn. All regression controls the fixed effect of urban individuals and the fixed effect of time, and the specific results are shown in Table 5.

Interpretation of the regression results:

(1) Column (1), without controls. The DID coefficient is 0.017 and is positive at the 1% significance level. In the absence of the additional controls, the pilot policy is associated with a significant improvement in green development among participating cities. The R-squared is 0.276, and the significant F-statistic indicates that the specification is jointly informative.

(2) Column (2), with all controls. After controlling for economic and financial development, industrial structure, and internet development, the DID coefficient falls to 0.006 but remains positive at the 1% level. The policy effect is thus robust to these observable factors. On average, implementation of the pilot raises the composite green-development index of participating cities by 0.006 units.

(3) Control variables. The coefficients on economic development (lngdp), financial development (fin), and industrial upgrading (ind) are all significantly positive, indicating that economic expansion, access to finance, and structural upgrading support urban green development. The coefficient on internet development (lnint) is significantly negative. One possible explanation is that the early diffusion of internet services entails additional digital-infrastructure construction and electricity consumption, which may exert a modest adverse effect in the short run.

(4) Model fit. Adding the controls raises the R-squared from 0.276 to 0.646, showing that they explain a substantial share of variation in urban green development. The sharp increase and significance of the F-statistic also indicate strong overall model fit.

Table 6. Baseline Regression Results

	(1) green	(2) green
DID	0.017***	0.006***
	(6.439)	(3.127)
lngdp		0.026***
		(24.625)
fin		0.000***
		(12.203)
ind		0.001***
		(15.281)
lnint		-0.007***
		(-6.968)
_cons	0.275***	0.108***
	(294.365)	(11.937)
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
N	2433	2433
R^2	0.276	0.646
F	41.459	523.135
***p<0.01,**p<0.05,*p<0.10		

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Based on the comprehensive benchmark regression results, hypothesis 1 is verified: Carbon emissions trading can significantly promote urban green development.

5. Mediation Test: Green Innovation

In order to test the mediating effect of green innovation, regression analysis is carried out based on the mediating effect model set forth above, and the results are shown in Table 8. Among them, column (1) is the total effect regression (consistent with the benchmark regression), and column (2) is the regression result of carbon emissions trading on the intermediary variable green innovation (zl, namely lngi).

Table 7. Mediation Test Results

	(1) green	(2) zl
DID	0.006***	0.044***
	(3.127)	(7.348)
lngdp	0.026***	0.066***
	(24.625)	(20.400)
fin	0.000***	0.000***
	(12.203)	(5.870)
ind	0.001***	0.003***
	(15.281)	(10.256)
lnint	-0.007***	-0.007**
	(-6.968)	(-2.298)
_cons	0.108***	-0.498***
	(11.937)	(-17.756)
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
N	2433	2433
R^2	0.646	0.460
F	523.135	363.809
***p<0.01,**p<0.05,*p<0.10		

5.1. Interpretation of Results

(1) Step 1: total effect. In column (1), the DID coefficient is 0.006 and is significantly positive at the 1% level. Emissions trading therefore has a significant total effect on urban green development, satisfying the first condition for mediation.

(2) Step 2: effect on the mediator. In column (2), the DID coefficient is 0.044 and is significantly positive at the 1% level. The policy thus increases urban green innovation; following implementation, the number of green patents granted in pilot cities rises by an average of 0.044 ten-thousand patents.

Under Jiang's two-step criterion, the significance of both the total effect and the effect on the mediator supports a significant mediating role for green innovation. H3 is therefore supported.

5.2. Interpretation of the Mediating Mechanism

Carbon emission trading increases the carbon emission cost of enterprises by means of market-oriented mechanism, changes the cost-benefit structure of enterprises, and forces enterprises to reduce the investment in high-carbon production. This will shift capital, talents and other resources to green technology research and development, directly promote the output of

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innovation achievements such as green patents and green processes, and improve the overall level of green innovation in the city. Green innovation promotes urban green development through two paths: First, green technology and equipment can reduce the carbon emission intensity and energy consumption of enterprises and directly improve the urban ecological environment; Second, green innovation has spawned green emerging industries such as energy conservation, environmental protection and new energy, promoted the transformation of urban industrial structure to green and high-end, and realized the coordinated development of economic growth, ecological protection and improvement of people's livelihood. Thus, a complete transmission chain of "carbon emissions trading → green innovation promotion → urban green development" is formed.

5.3. Supplementary Test of the R&D Investment Channel

In addition to green innovation, the potential transmission path of carbon emissions trading affecting urban green development is further investigated from the perspective of R&D investment. Carbon emissions trading may prompt enterprises and local governments to increase R&D investment by increasing carbon emission costs and strengthening emission reduction constraints, and then promote urban green development through technological progress and transformation of production methods. Based on this, the R&D input variable (lnrd) is constructed based on the R&D internal expenditure at the city level, and the supplementary mechanism is tested. The results are shown in Table 9.

Table 8. Test of the R&D Investment Channel

	(1)	(2)
	green	lnrd
DID	0.006***	0.089**
	(3.127)	(1.068)
lngdp	0.026***	1.660***
	(24.625)	(36.528)
fin	0.000***	0.000**
	(12.203)	(2.282)
ind	0.001***	-0.002
	(15.281)	(-0.556)
lnint	-0.007***	0.015
	(-6.968)	(0.331)
_cons	0.108***	-0.738*
	(11.937)	(-1.882)
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
N	2433	2433
R2	0.646	0.610
F	523.135	745.270

It can be seen from Table 9 that the DID coefficient in column (1) is 0.006, which is still significantly positive at the level of 1%, indicating that the promotion of carbon emissions trading to urban green development is still valid. In column (2), the coefficient of DID to R&D input variable lnrd is 0.089, which is significant at the level of 5%. This shows that within the scope of this sample, carbon emissions trading has a very significant direct driving effect on urban R&D investment.

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6. Heterogeneity by Level of Economic Development

In order to verify hypothesis 2, the whole sample is divided into two groups according to the level of economic development, and the results are shown in Table 7.

Table 9. Heterogeneity by Economic-Development Level

	(1)	(2)
	Higher economic development	Lower economic development
DID	0.012***	-0.001
	(4.438)	(-0.248)
lngdp	0.042***	0.023***
	(20.489)	(8.362)
fin	0.000***	0.000**
	(6.864)	(2.222)
ind	0.001***	0.001***
	(6.470)	(7.472)
lnint	-0.007***	0.002**
	(-5.066)	(2.311)
_cons	-0.004	0.046**
	(-0.251)	(2.204)
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
N	1065	1355
R^2	0.642	0.905
F	298.515	22.672

6.1. Interpretation of Results

(1) Higher-development group. The DID coefficient is 0.012 and is positive at the 1% level, indicating a pronounced favorable effect of emissions trading on green development in more economically developed cities.

(2) Lower-development group. The DID coefficient is -0.001, with a t-statistic of -0.248, and is not statistically significant. No discernible effect is therefore found for less developed cities.

The difference between the two subsamples supports H2: the effect of emissions trading on urban green development varies substantially with the level of economic development.

6.2. Sources of Heterogeneity

(1) More developed cities. These cities possess established innovation systems, stronger fiscal capacity, and higher-quality corporate resources, allowing them to respond rapidly to carbon-price signals. Well-capitalized firms can proactively retrofit equipment and undertake technological R&D, converting abatement pressure into an incentive to innovate. Local governments also have the capacity to introduce complementary environmental measures and improve low-carbon infrastructure. Carbon-market benefits can therefore be more fully realized.

(2) Less developed cities. Growth in these cities often depends heavily on traditional energy-intensive industries, and the industrial structure is relatively rigid. Local firms generally have less capital and weaker technology and cannot readily bear the high cost of green transformation. They may therefore comply by purchasing allowances or paying penalties rather than by undertaking substantive abatement and innovation. Local governments may also

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fear adverse effects of strict carbon constraints on output, fiscal revenue, and employment. These conditions weaken the implementation and effectiveness of emissions trading.

6.3. Regional Heterogeneity

Based on the analysis of the heterogeneity of economic development level, the sample is further divided into the eastern region, the central and western regions and other regions according to the region of the city, so as to investigate whether there are spatial differences in the effects of carbon emissions trading policies. The eastern region has a high degree of marketization, a good industrial base, and concentrated innovation resources, and its policy implementation and enterprise response ability are usually stronger. There are differences in industrial structure, technical conditions and resource allocation between the central and western regions and other regions, and the policy effect may be different. The regression results are shown in Table 10.

Table 10. Regional Heterogeneity Results

	(1)	(2)
	Eastern region	Central, western, and other regions
DID	0.015***	-0.013***
	(5.678)	(-4.373)
lngdp	0.030***	0.020***
	(18.392)	(14.443)
fin	0.000***	0.000***
	(7.695)	(10.616)
ind	0.002***	0.001***
	(11.026)	(7.029)
lnint	-0.006***	-0.006***
	(-3.682)	(-4.535)
_cons	0.021	0.163***
	(1.424)	(14.656)
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
N	1025	1408
R2	0.702	0.595
F	334.589	145.701

As can be seen from Table 10, the DID coefficient in the eastern samples is 0.015, which is significantly positive at the level of 1%. This shows that carbon emissions trading can significantly promote the green development of eastern cities. The DID coefficient in the samples of the central and western regions and other regions is -0.013, which is significantly negative at the level of 1%, indicating that there are obvious differences in policy effects among different regions. The reason may be that the eastern region has a better market mechanism, technical foundation and industrial support, which can transform carbon trading constraints into green transformation power faster. Some cities in the midwest and other regions are still under great pressure of industrial transformation. In the short term, carbon trading constraints may increase the cost of enterprises, thus weakening the performance of green development.

7. Robustness and Endogeneity Tests

7.1. Parallel-Trend Test

The hypothesis of parallel trend is the core premise of the establishment of the double difference model, which requires that the explained variable (green development level) of the

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treatment group (pilot city) and the control group (non-pilot city) keep the same changing trend before the policy is implemented. This article takes the previous period of policy implementation as the benchmark period to test the dynamic effects of multiple periods before and after policy implementation, and the results are shown in the figure.

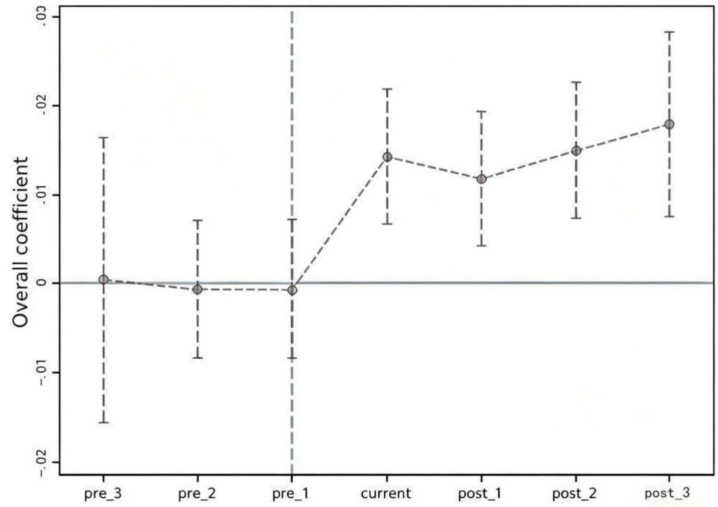

Figure 1. Dynamic Effects Before and After Policy Implementation

(1) Pre-policy period. The coefficients for three years, two years, and one year before implementation are all close to zero, their 95% confidence intervals include zero, and none is statistically significant. Thus, no systematic difference in pre-policy green-development trends is observed between pilot and non-pilot cities. The parallel-trend assumption is satisfied, supporting the DID specification.

(2) Year of implementation and post-policy period. The coefficient becomes significantly positive in the year of implementation, indicating an immediate policy effect. It then generally increases, reaching approximately 0.018 three years after implementation. The green-development effect is therefore not merely short-lived; it persists and strengthens as the policy matures.

The parallel-trend test provides further support for the validity of the baseline estimates.

7.2. Placebo Test

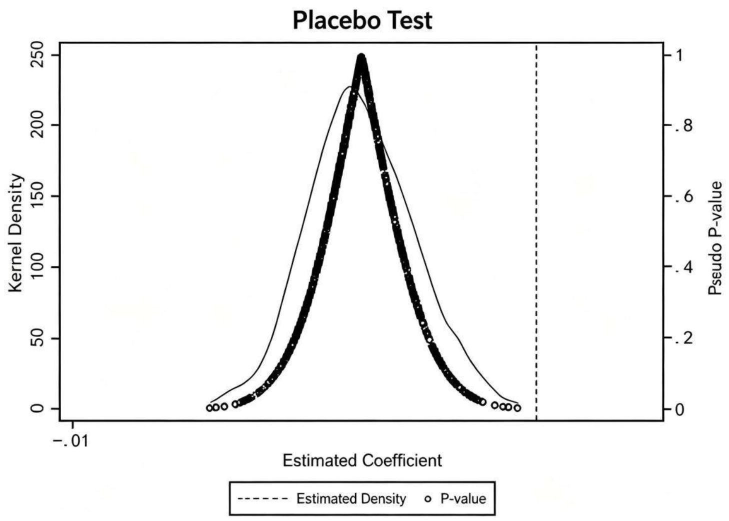

Figure 2. Placebo Test Results

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In order to eliminate the interference of missing variables and unobservable random factors on the regression results, the placebo test was carried out by randomly allocating the treatment groups: Cities with the same number as the real pilot cities were randomly selected as the false treatment groups, and false DID interactive items were constructed, and the regression was repeated for 500 times to observe the distribution characteristics of false coefficients. The results are shown in the figure.

The test yields the following findings:

(1) The 500 placebo estimates are concentrated around zero and approximate a normal distribution. Randomly assigned carbon-market treatment therefore has no systematic effect on urban green development.

(2) The actual baseline coefficient of 0.006 lies at the far right of the placebo distribution and differs clearly from the simulated estimates.

(3) The p-values associated with nearly all placebo coefficients exceed 0.1; only a very small number of random samples produce significant estimates.

The placebo evidence indicates that the positive effect of emissions trading is unlikely to be an artifact of omitted variables or chance.

7.3. Robustness Tests

In order to eliminate the interference of endogenous and sample selection bias on the benchmark regression conclusion, two methods, one-stage lag explanatory variables and random sampling of 80% samples, are used for robustness test, and the results are shown in Table 6.

Table 11. Robustness Tests

	(1) One-period lag	(2) Random 80% sample
DID	0.017***	0.008***
	(6.439)	(3.828)
lngdp		0.026***
		(22.011)
fin		0.000***
		(12.020)
ind		0.001***
		(12.798)
lnint		-0.008***
		(-6.834)
_cons	0.275***	0.120***
	(294.365)	(11.783)
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
N	2433	1946
R^2	0.276	0.653
F	41.459	422.121
***p<0.01,**p<0.05,*p<0.10		

7.3.1. One-Period Lag of the Explanatory Variable

The key explanatory variable is lagged by one period to mitigate potential reverse causality, such as the possibility that cities with stronger green-development performance are more likely

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to be selected as pilots. The coefficient on lagged DID is 0.017 and is significantly positive at the 1% level, identical in direction and significance to column (1) of the baseline regression. The result suggests that the favorable policy effect is not driven by evident reverse causality and persists over time.

7.3.2. Random 80% Subsample

The model is re-estimated on a random 80% of the observations (1,946 city-year observations) to determine whether the findings depend on a particular sample composition. The DID coefficient is 0.008 and significantly positive at the 1% level, close to the baseline estimate of 0.006 in column (2). The signs and significance of all controls remain consistent with the baseline results. The model R^2=0.653, which is basically the same as the benchmark regression, and the f value is significant. This proves that the research conclusion is not affected by sample selection bias and has good sample representativeness.

To sum up, the two kinds of robustness tests confirm that the benchmark regression conclusion is robust and reliable, and the core conclusion that carbon emissions trading promotes urban green development is established.

7.3.3. Excluding Municipalities Directly under the Central Government

Considering the differences between municipalities directly under the central government and ordinary prefecture-level cities in administrative levels, resource allocation capacity, industrial base and policy implementation, it may have an impact on the estimation results. In order to eliminate the interference of special city samples, this article makes a regression analysis after excluding the samples of municipalities directly under the central government, and the results are shown in Table 12.

Table 12. Robustness Test Excluding Centrally Administered Municipalities

	(1) green
DID	0.006***
	(3.230)
lngdp	0.026***
	(24.599)
fin	0.000***
	(12.664)
ind	0.001***
	(13.992)
lnint	-0.007***
	(-6.654)
_cons	0.105***
	(11.422)
City fixed effects	Yes
Year fixed effects	Yes
N	2395
R2	0.630
F	452.172

It can be seen from Table 11 that the DID coefficient is still 0.006 after excluding municipalities, and it is significantly positive at the level of 1%, which is consistent with the benchmark regression results. This shows that the conclusion is not driven by cities with special administrative levels such as municipalities directly under the central government, and the

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conclusion that carbon emissions trading promotes urban green development has good robustness.

8. Conclusion, Policy Recommendations, and Outlook

8.1. Main Conclusion

Taking the balanced panel data of 2433 prefecture-level cities in China from 2011 to 2024 as the sample, this study regards the carbon emissions trading pilot as a quasi-natural experiment, and tests the impact, heterogeneity and transmission mechanism of carbon emissions trading on urban green development by using the two-way fixed effect double difference model and the intermediary effect model. Combining descriptive statistics, multiple robustness test, parallel trend test and placebo test, the following four main conclusions are drawn:

(1) Overall effect. The emissions-trading pilots significantly promote urban green development. The result remains robust after controlling for economic and financial development, industrial structure, and internet development and after lagging the explanatory variable, resampling the data, and conducting parallel-trend and placebo tests. As a market-based environmental instrument, emissions trading generates complementary environmental and developmental benefits overall.

(2) Dynamic effect. Green-development trends in pilot and non-pilot cities are comparable before implementation, supporting the model specification. The effect emerges in the implementation year and becomes stronger over time, indicating a lasting rather than transitory influence.

(3) Heterogeneity. The policy effect varies significantly with the level of economic development. Emissions trading has a clear favorable effect in more developed cities but no significant effect in less developed cities, where industrial structure, finance, technology, and local development priorities constrain its operation.

(4) Mediation mechanism. Green innovation plays an important mediating role. Emissions trading stimulates green patent output and strengthens cities' green-innovation capacity; the resulting innovation further improves environmental performance and supports industrial upgrading.

8.2. Policy Recommendations

Based on the empirical conclusion and the present situation of China's urban green development and carbon market construction, this article puts forward policy suggestions from three dimensions: national carbon market perfection, regional differentiation policy and green innovation incentive:

8.2.1. Continue Improving the National Carbon Market

First, the coverage of the national carbon market should be expanded gradually. More prefecture-level cities and energy-intensive industries can be included in an orderly manner so that a broader range of market participants face market-based carbon constraints. Second, allowance allocation and carbon-price formation should be improved to stabilize price expectations and prevent excessive volatility from weakening incentives. Supervision should be strengthened to deter irregular trading and data falsification and to safeguard orderly market operation. Third, complementary institutions should be improved by aligning the carbon market with environmental regulation and fiscal and tax policy, thereby creating a coordinated policy mix.

8.2.2. Adopt Differentiated Regional Policies

Carbon-reduction policy should be adapted to cities' levels of economic development rather than applied uniformly.

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(1) More developed cities. Their technological, financial, and industrial strengths should be used to establish leading carbon-market demonstration areas. These cities should increase investment in green-technology R&D, explore links between emissions trading, green finance, and the digital economy, and disseminate effective practices nationally.

(2) Less developed cities. High-intensity carbon constraints should be phased in gradually. The central government can increase fiscal transfers to support the retirement of inefficient, energy-intensive capacity and the upgrading of environmental equipment. Developed regions can provide technological assistance, facilitate suitable industrial cooperation, and coordinate carbon allowances to help close financial and technological gaps. Low-carbon industries suited to local conditions should also be cultivated to create a viable foundation for the policy.

8.2.3. Strengthen Incentives for Green Innovation

Carbon-market policy should be used to reinforce the transmission chain from emissions trading to green innovation and green development. First, complementary subsidies, tax relief, and fiscal support can lower the cost borne by firms conducting green-patent R&D and low-carbon technological retrofits. Second, collaborative platforms linking universities, research institutes, and urban firms can accelerate the commercialization and application of green patents and technologies. Third, stronger protection of green intellectual property can safeguard legitimate returns and create durable internal incentives for market participants to innovate.

8.2.4. Improve Industrial Structure and the Allocation of Financial Resources

Cities should continue to upgrade and decarbonize their industrial structures, strictly control new energy- and emissions-intensive projects, and accelerate the green transformation of conventional industry. These measures can reduce the underlying emissions base and improve the conditions under which emissions trading operates. Financial institutions should simultaneously expand green lending and green-bond finance, giving priority to low-carbon firms and green-innovation projects and directing more capital toward green activities.

8.3. Limitations and Future Research

8.3.1. Limitations

First, the heterogeneity analysis is limited to economic-development groups and does not further distinguish geographic location, city size, or dominant industry. Second, green innovation is the only mediator considered, although industrial structure, the energy mix, and household green consumption may also transmit policy effects. Third, the analysis relies on city-level aggregate data and does not incorporate firm-level evidence, limiting the ability to identify changes in corporate behavior.

8.3.2. Directions for Future Research

Future research could extend heterogeneity analysis across eastern, central, and western regions; large, medium, and small cities; and industrial and tourism-oriented cities. It could also incorporate several mediators, including the energy mix, green finance, and industrial upgrading, within a multi-channel framework. Combining city-level and firm-level data would permit the policy to be studied from both macro and micro perspectives and would clarify the behavioral foundations of abatement and innovation. As the national carbon market develops, updated data can be used to evaluate the unified market and provide further evidence for sustained progress toward China's carbon-peaking and carbon-neutrality goals.

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