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The Impact of Carbon Emission Trading Pilots on Regional Innovation

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Abstract: To investigate the driving effects of market-based environmental regulation on regional innovation, this study uses China's carbon emissions trading pilot programs as a quasi-natural experiment. Drawing on panel data from 227 prefecture-level and higher cities from 2005 to 2020, we employ a multi-period difference-in-differences (DID) model to empirically examine the impact of these pilot programs on regional innovation and to investigate the moderating roles of government intervention and the degree of marketization. The results indicate that carbon emissions trading pilot programs significantly promote regional innovation. This conclusion holds even after a series of robustness tests, including parallel trends tests, exclusion of pandemic-affected samples, exclusion of special cities, and PSM-DID analysis. Both government intervention and the level of marketization exert significant positive moderating effects, effectively amplifying the promotional role of carbon emissions trading pilot programs on regional innovation. Mechanism analysis reveals that carbon emissions trading pilot programs drive regional innovation by internalizing the external costs of carbon emissions, creating incentives for emission reductions, and generating technology spillover effects, while effective government intervention and a well-developed market environment can further amplify the policy's impact. The findings of this study provide empirical evidence and policy references for deepening the development of the national carbon market and integrating the "dual carbon" goals with the innovation-driven development strategy.

Keywords: Carbon emissions trading pilot, regional innovation, multi-period difference-in-differences.

1. Research Background

Exploring the sources of sustainable economic growth has always been one of the most crucial and central themes in economic research. With the rapid development of the global economy and the continuous advancement of industrialization, labor-intensive production models have driven high economic growth while also triggering a series of severe environmental issues. Among these, climate pollution caused by carbon emissions is particularly prominent and has become a global focus of attention. As one of the world's largest developing countries, China inevitably faces the reality of high carbon emissions during its rapid economic development. This not only places significant pressure on the domestic ecological environment but has also sparked widespread discussion within the international community.

To fundamentally transform the model of economic development and alleviate environmental pollution caused by traditional development patterns, the Chinese government has put forward the five major development concepts of "innovation, coordination, green development, openness, and sharing," establishing "green" development as the fundamental principle and key direction for economic and social progress. This concept aims to achieve a win-win outcome for economic growth and environmental protection through optimizing industrial structures, improving resource utilization efficiency, and promoting the application of clean energy. To further advance the green development strategy, the Chinese government made a solemn commitment at the 75th session of the United Nations General Assembly in 2020: to enhance the ambition of its Nationally Determined Contributions (NDCs), adopt more proactive and effective policies and measures, strive to reach peak carbon dioxide emissions by 2030, and work toward achieving carbon neutrality by 2060. This commitment not only demonstrates China's sense of responsibility in global climate governance but also charts a clear course for the country's domestic green and low-carbon transition.

In terms of practical implementation, the carbon emissions trading mechanism has become one of the key tools for China to promote green and low-carbon development. This mechanism utilizes market-based approaches to allocate and trade carbon emission allowances as a scarce resource, thereby incentivizing enterprises to reduce carbon emissions and improve energy efficiency. In the specific implementation of carbon emissions trading, the goal of enhancing regional innovation levels aligns with the core principles of green development and is organically integrated with the innovation-driven development strategy. Through technological and institutional innovation, regions can cultivate new economic growth points while reducing carbon emissions, thereby achieving coordinated development of economic growth and environmental protection. This innovation-driven development model not only helps address current environmental challenges but also lays a solid foundation for future sustainable development.

2. Theoretical Analysis and Research Hypotheses

2.1. Direct Effects of Carbon Emission Trading Pilots on Regional Innovation

The carbon market is a classic example of using the Coasean property rights approach to address environmental pollution. The logic behind the carbon market's internalization of the external costs of carbon emissions is primarily based on a cap-and-trade system. Specifically, by allocating initial carbon allowances, the system imposes a cap

on corporate carbon dioxide emissions, thereby creating pressure for companies to reduce emissions. However, enterprises retain autonomy in meeting these cap requirements: they may reduce total carbon emissions through optimized resource allocation or technological upgrades, or they may purchase carbon allowances on the market to satisfy the cap requirements.

On the one hand, from the perspective of economic incentives, market-based environmental regulation such as carbon emissions trading helps enterprises identify more effective production management strategies. Through technological innovation, enterprises can achieve sustainable development, not only enjoying policy benefits but also enhancing their market competitiveness, which greatly promotes their investment in innovation resources. On the other hand, from the perspective of compliance pressure, carbon emissions trading controls regional carbon emission totals and constrains corporate production behavior, thereby accelerating the innovation process of enterprises in the region. Under the pressure of internalized pollution costs in the carbon market, enterprises typically have three behavioral options: first, maintaining their existing production scale and purchasing excess emission allowances in the carbon market; second, reducing output to comply with total emission control requirements; and third, optimizing resource allocation, improving production processes, and pursuing technological innovation to reduce carbon intensity per unit of output by increasing production efficiency, thereby achieving emission reduction targets. As organizations seeking to maximize profits, enterprises do not passively accept environmental regulatory pressures but are more inclined to adopt the third behavioral option: improving production efficiency to reduce carbon intensity per unit of output. This approach enhances product competitiveness in the market while simultaneously meeting the total emissions cap requirements under the emissions trading mechanism. Furthermore, given that enterprises in pilot regions achieve emissions reductions through technological innovation, coupled with clear government policy guidance and the sensitivity of relevant industry enterprises, technological spillover effects can further drive regional innovation.

Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 1: Carbon emissions trading pilot programs have a positive impact on regional innovation.

2.2. Indirect Effects of Carbon Emission Trading Pilots on Regional Innovation

In studies on the effectiveness of government intervention, Pang and Guan (2018) conducted an empirical analysis of data from enterprises in Zhongguancun [1]. The results indicate that government intervention can effectively regulate corporate innovation activities, helping to maintain corporate vitality and drive business development. Given the inherent flaws in market mechanisms, the government intervenes in innovation activities by formulating innovation policies to address market failures in the allocation of innovation resources. Government-led and government-participated R&D in foundational knowledge and general-purpose technologies creates a favorable knowledge environment for enterprises to conduct business and engage in applied research, thereby playing a significant role in promoting regional innovation.

The degree of marketization has a certain impact on contract formation and market transaction costs, which may influence the pathways through which carbon emissions trading affects green innovation. When market mechanisms are underdeveloped, issues such as an opaque institutional environment, weak awareness of property rights protection, and the proliferation of corruption are likely to arise, ultimately producing direct negative effects on contract formation and market transaction costs. Therefore, when the level of marketization lags behind, the vitality of corporate technological innovation will be weakened. Conversely, when the level of marketization increases and price mechanisms become more refined, they can swiftly reflect market supply and demand dynamics and provide enterprises with precise guidance, thereby accelerating technological and product innovation. Simultaneously, the acceleration of information flow and enhanced market transparency enable enterprises to better grasp industry trends, facilitating their R&D efforts and helping them avoid being eliminated from the market. As a market-based environmental regulatory tool, the efficiency of carbon emissions trading is directly influenced by the level of marketization; a well-developed market environment is more conducive to the realization of innovation effects.

Based on the above analysis, this paper proposes the following hypotheses:

Hypothesis 2: Government intervention exerts a positive moderating effect on the relationship between carbon emissions trading pilot programs and regional innovation.

Hypothesis 3: An increase in the degree of marketization will strengthen the impact of carbon emissions trading pilot programs on regional innovation in pilot areas.

3. Data Description and Research Design

3.1. Variable Description

Explanatory Variables: The difference-in-differences (DID) variable is the core explanatory variable in this study, defined as $treat_i \times post_{it}$. This study employs a difference-in-differences model to analyze the regional innovation effects of carbon emissions trading pilot programs. Here, $treat_i$ represents the policy dummy variable, and postit represents the time dummy variable. In this study, $treat_i = 1$ if region i is a carbon emissions trading pilot city; otherwise, $treat_i = 0$. $post_{it} = 1$ if region i is Beijing, Shanghai, Tianjin, or Guangdong and $t \geq 2013$; or if region i is Hubei or Chongqing and $t \geq 2014$; or if region i is Fujian and $t \geq 2016$; otherwise, $post_{it} = 0$.

Dependent variable: City Innovation Index (inno). Data compiled by the research team led by Professor Kou at Fudan University.

Control Variables: Drawing on the research by Song (2017)[2] , Chen et al. (2010)[3] , and Zhao et al. (2020)[4] , we introduce the following control variables: Economic Development Level (pgdp), defined as the logarithm of per capita regional GDP; Educational level (edu) is defined as the ratio of education expenditure to general government expenditure; technological level (tech) is defined as the ratio of science and technology expenditure to general government expenditure; industrial structure (indus) is defined as the share of tertiary sector value added in regional GDP; and financial development level (finance) is defined as the ratio of year-end deposit and loan balances of financial institutions to regional GDP.

Moderating variables: Degree of government intervention (gi) is defined as the ratio of general government expenditure

to regional GDP; level of marketization (market) is calculated using the method proposed by Fan et al. (2003) [5] , which involves a weighted estimation of the level of marketization based on the relationship between government and the market, the development level of the non-state-owned economy, the development level of products, the development level of factors of production, the development level of intermediary organizations, and the legal and institutional environment.

Data sources and definitions are as follows: First, the data used are drawn from the China Urban Statistical Yearbook, statistical bulletins of various provinces, autonomous regions, and counties, and other sources. Second, to ensure the quality and comparability of the sample data, this study excluded sample cities where administrative divisions changed during the sample period and those with severe data missingness. Third, to eliminate the impact of price fluctuations on the estimation results, all price-related variables in this study were adjusted using 2005 as the base year. Fourth, a small number of missing values were imputed using linear interpolation. Descriptive statistics for the variables are presented in Table 1.

Table 1. Descriptive Statistics

Variable		Sample Size	Mean	Median	Standard Deviation	Minimum	Maximum
Explanatory variable	Carbon Emissions Trading Pilot (DID)	4432	0.07	0	0.26	0	1
Dependent variable	Regional Innovation Index (inno)	4432	15.95	1.313	83.34	0.01	2,384.00
Control variable	Level of economic development (GDP)	4432	10.38	10.42	0.75	4.595	13.06
	Education level (edu)	4432	0.18	0.18	0.04	0.00	0.49
	Technology Level (tech)	4432	0.01	0.00	0.02	0.007	0.21
	Industrial Structure (indus)	4432	0.40	0.39	0.10	0.000	0.84
	Level of financial development (finance)	4,432	2.24	1.93	1.14	0.508	21.30
Moderating variable	Government intervention (gi)	4432	0.17	0.15	0.10	0.04	1.94
	Level of Marketization (marke)	4432	10.40	10.35	2.90	2.72	19.69

3.2. Specification of the Econometric Model

This study uses prefecture-level and higher-level cities in pilot regions as the treatment group and prefecture-level cities in non-pilot regions as the control group, selecting the period from 2005 to 2020 as the sample interval. This ensures that there is at least a three-year window period before and after the implementation of each carbon emissions trading pilot program. We examine the impact on regional innovation within the 227 prefecture-level and higher-level cities selected after screening to assess the policy's regional innovation effects. A two-way fixed-effects model is constructed as shown in Equation (1):

$$\text{inno}_{it} = \beta_0 + \beta_1 treat_i \times post_{it} + \rho X_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (1)$$

Where i denotes the city, t denotes the time period, and the dependent variable is the regional innovation index (inno_{it}), reflecting a region's level of regional innovation. treat is a policy dummy variable indicating whether a city is a carbon emissions trading pilot city, and post_{it} is a time dummy variable reflecting the implementation period of the pilot program. $\text{treat}_i \times \text{post}_{it}$ represents the interaction term between the policy dummy variable and the time dummy variable, which is the core explanatory variable of focus in this study. β_0 is the intercept term, and β_1 is the coefficient to be estimated, representing the net effect of the carbon emissions trading pilot program on regional innovation. X_{it} is the matrix of control variables, including economic development level (pgdp), education level (edu), technological level (tech), industrial structure (indus), and financial development level (finance).

To further explore the mechanism through which carbon emissions trading affects regional innovation, this paper analyzes how government intervention and the degree of marketization moderate the regional innovation effects of carbon emissions trading pilot programs from both government and market perspectives. Accordingly, a moderation model is constructed as shown in Equation (2):

$$\text{inno}_{it} = \beta_0 + \beta_1 treat_i \times post_{it} + \beta_2 treat_i \times post_{it} \times M_{it} + \beta_3 M_{it} + \rho X_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (2)$$

Where M_{it} is the moderator variable, primarily examining the potential moderating effects from the perspectives of government intervention and the degree of marketization. The sign of the moderating effect is determined by the regression coefficient β_2 of the interaction term ($\text{treat}_i \times \text{post}_{it} \times M_{it}$). A positive sign indicates a positive moderating effect, while a negative sign indicates a weakening moderating effect.

4. Empirical Results and Analysis

4.1. Baseline Regression Results

The baseline regression results are presented in Table 2. Column (1) considers only the core explanatory variables. It can be seen that, without including any fixed effects or control variables, the estimated coefficient of DID is significantly positive. Upon progressively adding regional and annual fixed effects, as well as control variables, the results shown in columns (2) and (3) indicate that although the coefficient of DID has decreased somewhat, it remains significantly positive. Following the implementation of carbon emissions trading, pilot regions imposed caps on total carbon emissions and imposed constraints on the production behavior of economic entities. By assisting enterprises in identifying more efficient production management methods, this system promoted the harmonization of economic growth and environmental protection, thereby fostering an increase in regional innovation levels.

Table 2. Baseline Regression Results

Variables	(1)	(2)	(3)
did	78.97*** (18.43)	60.87*** (13.12)	52.05*** (11.29)
pgdp			-37.47*** (-6.97)
edu			259.38*** (7.14)
tech			1063.07*** (10.76)
industrial			-163.91*** (-6.55)
finance			4.53*** (2.62)
_cons	10.23*** (2.94)	1.08*** (0.32)	354.59*** (6.43)
Regional fixed	No	Yes	Yes
Year Fixed	No	Yes	Yes
N	4432	4432	4432
R^2	0.07	0.11	0.16

Note: *** and ** indicate significance at the 1% and 5% levels, respectively; values in parentheses are t-values or z-values.

4.2. Parallel Trends Test

The construction of a difference-in-differences model requires the assumption of homogeneity, meaning that the treatment group and the control group must exhibit consistent development trends prior to the implementation of the pilot policy. In this study, this is reflected in the fact that the trends in regional innovation levels in pilot and non-pilot cities were broadly consistent prior to the impact of the pilot policy. Therefore, before conducting the baseline regression, this study follows the approach of Rao et al. (2019) [6] to construct the following model for the parallel trends test.

$$\text{inno}_{it} = \alpha + \sum_{t=0}^{3} \beta_{-t} pre_{it} + \beta_0 current_{it} + \sum_{t=0}^{4} \beta_t post_{it} + \rho X_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (3)$$

Here, pre_{it} denotes the year t prior to the carbon emissions trading pilot; $current_{it}$ denotes the year the pilot was implemented; and $post_{it}$ denotes the year t following the pilot. For the specific study year, the value is set to 1; otherwise, it is set to 0. If the coefficient of the pre-pilot dummy variable pre_{it} is not significant, it indicates that regional innovation did not undergo systematic changes prior to the policy shock. The significance levels of the coefficients for $current_{it}$ and $post_{it}$ reflect the regional innovation effects of the policy in the year of implementation and its subsequent lasting impact.

This paper conducts a parallel trends test to examine the impact of the carbon emissions trading pilot program on regional innovation. The resulting dynamic effects are shown in Figure 1. It can be observed that the estimated coefficients prior to the pilot did not pass the significance test, whereas the estimated coefficients for the pilot year and the post-pilot period were both significantly positive. Furthermore, the impact showed a trend of gradually expanding over time, preliminarily indicating that this exogenous shock—the carbon emissions trading pilot—exerts a sustained positive influence on regional innovation.

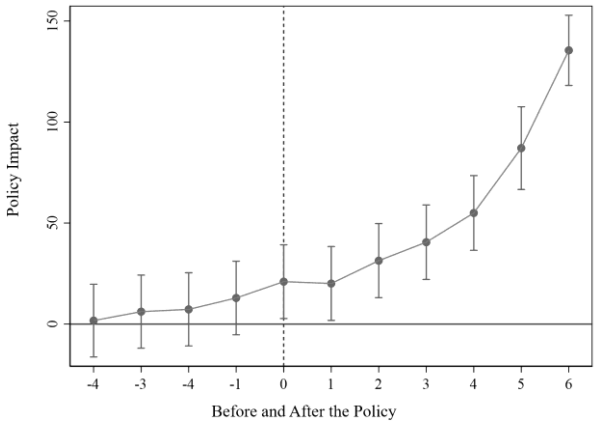

Figure 1. Parallel Trends Test Results

4.3. Robustness Tests

The COVID-19 pandemic that erupted in late 2019 dealt a massive blow to the global economy and had a severe negative impact on market entities, namely enterprises (Tang et al; 2020) [7]. To avoid potential interference from the COVID-19 pandemic on regional innovation, the 2020 samples were excluded, and the impact of the carbon emissions trading pilot program on regional innovation was re-examined. Column 1 of Table 3 reports the regression results. After excluding the 2020 samples, the regression coefficient for DID was 48.19, which was significant at the 1% level, indicating that the carbon emissions trading pilot program can promote regional innovation.

Among the seven carbon market pilot regions designated in 2011, Beijing, Shanghai, and Shenzhen rank among China's top three cities in terms of economic strength. In addition to the carbon market pilot policies, these three cities may have implemented other stringent energy conservation and emission reduction policies during the 12th Five-Year Plan period, which could potentially confound the identification of the effects of the carbon market pilot policies. We exclude them to further test the robustness of the baseline regression results. The regression results are shown in the second column of Table 3: after excluding the aforementioned special samples, the regression coefficient of the dummy variable "did" remains significantly positive at the 1%–5% level, further validating the robustness of the baseline regression results in this paper.

Furthermore, we employed Propensity Score Matching (PSM) to re-match the treatment group samples with the control group to mitigate sample selection bias. Specifically, we used a kernel matching method to ensure no systematic differences between the treatment and control groups. After excluding a small number of unmatched samples, we ultimately obtained 4,411 observations; the regression results are shown in the third column of Table 3. The regression coefficient for did was significantly positive at the 1% level, with a value of 52.97. This indicates that, after controlling for selection bias, carbon emissions trading stimulated regional innovation effects across various regions, consistent with the direction of the baseline regression.

Table 3. Results of Robustness Tests

Variables	(1) Excluding 2020 data	(2) Excluding data from Beijing, Shanghai, and Shenzhen	(3) PSM-DID
DID	48.19*** (11.92)	5.71*** (3.07)	52.97** (11.41)
_cons	223.44*** (4.41)	163.76*** (0.32)	348.87*** (5.24)
Control variables	Yes	Yes	Yes
Time is fixed	Yes	Yes	Yes
Fixed individual	Yes	Yes	Yes
N	4155	4384	4411
R^2	0.15	0.31	0.16

Note: *** and ** indicate significance at the 1% and 5% levels, respectively; values in parentheses are t-values or z-values.

5. Further Research

5.1. Moderation Effect Test

To further investigate the mechanism through which carbon emissions trading pilot programs influence regional innovation, this study incorporates the degree of government intervention and the level of marketization as proxy variables into the model. The interaction term between these two variables and the carbon emissions trading dummy variable is included to test the indirect impact mechanism of the pilot programs on regional innovation. Column (1) of Table 4 reports the regression results for the moderating effect of the degree of government intervention. The regression results indicate that the coefficient of the interaction term between government intervention (gi) and carbon emissions trading (did) is 431.85, passing the significance test at the 1% level. Furthermore, the coefficient is positive, suggesting that government intervention plays a positive reinforcing role in the mechanism through which the carbon emissions trading pilot program influences regional innovation, thereby validating Hypothesis 2.

Table 4. Moderation Test Results

Variables	(1) Government Intervention	(2) Level of Marketization
did	-17.29 (11.92)	215.77*** (9.54)
gi	-69.61*** (-3.70)	
market		11.46*** (-3.69)
did × gi	431.85*** (6.72)	
did×market		13.36*** (7.39)
_cons	19.78 (0.47)	37.61 (1.00)
Control variables	Yes	Yes
Time-fixed	Yes	Yes
Fixed individual	Yes	Yes
N	4432	4432
R^2	0.16	0.24

Note: *** and ** indicate significance at the 1% and 5% levels, respectively; values in parentheses are t-values or z-values.

Column (2) of Table 4 reports the regression results for the moderating effect of the level of marketization. The regression results indicate that the coefficient of the interaction term between the level of marketization (market) and carbon emissions trading (did) is 13.36. This coefficient passed the significance test at the 1% level and is positive, suggesting that under the positive moderating effect of marketization, healthy competition fully unleashes corporate market vitality. To avoid being eliminated by the market, enterprises actively innovate to adapt to the green economy, thereby further enhancing the promotional role of carbon emissions trading pilot programs in regional innovation, which validates Hypothesis 3.

6. Research Conclusions and Policy Recommendations

This paper uses 227 prefecture-level and higher cities in China from 2005 to 2020 as a sample. By employing a difference-in-differences model, it empirically examines the impact of carbon emissions trading pilot programs on regional innovation and investigates the moderating effects of government intervention and the degree of marketization. The main conclusions are as follows: First, carbon emissions trading pilot programs significantly promote regional innovation. By internalizing the external costs of carbon emissions, creating compliance pressures, and providing economic incentives, carbon trading compels enterprises to engage in technological innovation and optimize resource allocation, while generating technological spillover effects that significantly enhance the innovation levels in pilot regions. Second, the policy effects satisfy the parallel trends assumption, and the conclusions are robust and reliable. The parallel trends test indicates that the policy shock is exogenously effective; robustness tests—excluding pandemic years, specific cities, and employing PSM-DID—all confirm that the positive effect of carbon trading on regional innovation is consistently present. Third, both government intervention and the level of marketization play positive moderating roles. Government intervention can address market failures and strengthen support for innovation, while increased marketization helps optimize pricing mechanisms and reduce transaction costs; both significantly enhance the innovation-driven effects of carbon trading pilot programs. Overall, as a market-based environmental regulatory tool, carbon trading can effectively achieve synergy between emission reduction constraints and innovative development. Under effective government guidance and a high level of marketization, the policy's innovative efficacy can be fully unleashed.

Based on this, this paper proposes the following policy recommendations:

Steadily expand the coverage of the carbon market and improve institutional operating mechanisms. Building on the

achievements of the pilot programs, systematically expand the geographical and sectoral scope of carbon trading, optimize systems for quota allocation, trading, compliance, and supervision, enhance market liquidity and pricing efficiency, and strengthen market-based emission reduction and innovation incentive mechanisms.

Strengthen targeted government support and improve the green innovation system. Increase fiscal investment in low-carbon technology R&D, refine relevant policies such as green finance and tax incentives, establish collaborative innovation platforms among industry, academia, and research institutions, promote the commercialization of green technology outcomes, and provide institutional and resource guarantees for the innovative development of the carbon market.

Enhance marketization and optimize the policy implementation environment. Deepen market-oriented reforms of production factors, strengthen property rights protection and market supervision, reduce the institutional costs of carbon trading and innovation activities, and leverage market competition mechanisms to stimulate enterprises' green innovation vitality.

Integrate the "dual carbon" goals with innovation-driven development to promote coordinated regional development. Incorporate carbon reduction and innovative development into local planning, promote the low-carbon upgrading of industries and the diffusion of green technologies, narrow regional innovation gaps, and achieve the coordinated advancement of low-carbon transformation and high-quality development.

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