

Original Research

The Impact of Carbon Emissions Trading System on Regional Green Innovation: A Perspective of Foreign Investment Agglomeration

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Abstract

Climate change is a critical global concern, and China's carbon emissions trading system (ETS), which was introduced in 2011, has significantly contributed to fostering green innovation. Based on the panel data of 284 cities in China from 2006 to 2020, the study examines the impacts and mechanisms of ETS on green innovation using difference in differences method (DID), mechanism testing models, and moderating effect models, and explores the spillover effects of the policy with the help of spatial Durbin models. The study finds that overall, ETS can significantly promote green innovation, with a more significant incentive effect observed for eastern and western cities and resource cities. In terms of the mechanism of action, ETS promotes green innovation by reducing the scale of foreign investment and improving the quality of foreign investment. Additionally, government environmental attention can significantly and positively regulate the relationship between ETS and green innovation. From a spatial spillover perspective, ETS can significantly enhance green innovation in local cities, but it may also inhibit green innovation in neighboring cities. The findings of this study hold significant implications for expediting the transition towards a green economy and promoting sustainable development.

Keywords: carbon neutrality, carbon emissions trading system, green innovation, quality of foreign investment, government environmental attention, economic transformation

Introduction

Under the pressure of increasingly severe natural resource constraints and continuous changes in climate risks, countries around the world have sought circular and low-carbon green development paths. One of the core policy tools for carbon emission reduction is carbon ETS, which originated from the concept of emissions trading put forward by economists in the 1990s [1]. As of December 31, 2022, there are 23 operational carbon trading systems worldwide. Among these systems, the European Union Emissions Trading System (EU ETS) stands out as the largest one. It encompasses 28 EU member States, along with Norway, Liechtenstein, and Iceland, making it an extensive and inclusive carbon trading platform. Notably, the EU ETS involves the participation of over 18,000 industrial and energy enterprises, making it a significant player in the global efforts to reduce carbon emissions. Carbon emissions trading in China commenced with a local pilot program in October 2011 [2]. Since June 2013, an ETS has been implemented in several regions including Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, Shenzhen, and Fujian. This system covers seven greenhouse gases and more than a dozen industries, with a cumulative turnover of 15.263 billion yuan over the past decade. The successful establishment of the ETS market has played a crucial role in driving greenhouse gas emission reduction among enterprises and raising awareness of low-carbon development across all sectors of Chinese society. It serves as an important tool and guarantee for China to achieve its “dual-carbon” goal.

Promoting green innovation is crucial for facilitating the country’s green transformation and upgrading. It has become a key priority in the development of a robust ETS and the subsequent nationwide implementation [3]. The ETS plays a crucial role in promoting green and low-carbon technological innovations by providing economic incentives and directing funds towards industrial enterprises with high emission reduction potential [4]. It serves as a catalyst for the transformation of cutting-edge green technological innovation breakthroughs, facilitating the development and adoption of sustainable technologies. However, the ETS in China continues to face constraints in mitigating emission reductions and promoting green innovation. These constraints include the low degree of standardization of green products, weak replication of innovative products, unbalanced regional development, and the exclusion of key industrial sectors such as petrochemicals, iron and steel, non-ferrous metals, paper, chemicals, and building materials from the Chinese carbon market. Additionally, a significant number of enterprises and emissions have not been included in the compliance assessment process. Furthermore, the role of foreign investment in driving green innovation through the ETS cannot be underestimated. Foreign investment agglomeration serves as an important channel for the transfer of green technologies [5]. Therefore, effectively integrating

foreign investment within the ETS framework and leveraging its potential for promoting green innovation is crucial for China’s economy to achieve true high-quality development.

To synthesize the above analysis, the study constructs a difference in differences model, a mechanism testing model and a spatial econometric model based on the panel data of 284 prefectural-level cities in China from 2006 to 2020, empirically examines the relationship between ETS and green innovation, as well as the role played by foreign capital agglomeration in the relationship between the two, and tries to answer the following questions: Can ETS promote green innovation? Is there regional and resource endowment heterogeneity? Is foreign capital agglomeration an effective path for ETS to promote green innovation? Are there spatial spillovers from the impact of ETS on green innovation? By providing empirical evidence on the relationship between the ETS and green innovation, as well as the role of foreign capital agglomeration, this study offers valuable insights for the nationwide promotion of the ETS in China. Moreover, the findings of this research have broader implications for optimizing low-carbon emission reduction and sustainable development paths, not only in China but also worldwide. The study’s results can inform policy decisions and strategies aimed at achieving environmentally sustainable economic growth and addressing climate change challenges on a global scale.

This study makes several notable contributions:

Firstly, this study provides a theoretical clarification of the underlying mechanism through which the ETS promotes green innovation. By examining the relationship between market-oriented environmental regulation and its impact on both the environment and the economy, the study addresses a major practical concern in China. Specifically, it offers insights into whether the implementation of the ETS can effectively achieve a win-win situation for both environmental sustainability and economic growth.

Secondly, this study empirically examines the relationship between the ETS and green innovation from the perspectives of market mechanisms and government intervention using a double difference model. Additionally, it investigates the heterogeneous factors such as geographic location and resource endowment that affect the effects of the policy. This approach effectively identifies the causal effects of the policy and captures its long term effects.

Finally, this study examines the mechanism of action by considering the influence of the scale and quality of foreign investment on the ETS and green innovation. It also estimates the spatial spillover effect of the ETS from a spatial perspective. These findings provide valuable guidelines for China to actively attract and utilize foreign investment in the future. Additionally, they offer insights on how to optimize the construction of the ETS and leverage its spatial radiation effect. This spatial perspective contributes to a better understanding

of how to maximize the policy's impact and promote sustainable development.

Theoretical Framework

ETS and Green Innovation

The ETS, implemented by the Chinese government in 2011, represents a significant institutional innovation aimed at employing market mechanisms to regulate and mitigate greenhouse gas (GHG) emissions across industries such as building materials, non-ferrous metals, iron and steel, petrochemicals, chemicals, paper, aviation, and others. Its primary objective is to foster green and low-carbon development. On the one hand, the ETS has a "cost effect." The implementation of the ETS has introduced a carbon price, which serves as a market-based mechanism to regulate the overall level of pollution emissions [6]. As a result, highly polluting enterprises and other relevant emitters are compelled to adopt greener production technologies [7], optimize their green logistics and distribution practices [8], and reform their management approaches. These actions are taken to avoid the cost increase and decrease in profitability that would arise from purchasing excessive carbon emission rights or reducing the total level of production [9]. In other words, the ETS promotes green innovation by compelling emitters to undergo a green transition in order to achieve economic performance.

On the other hand, there is an "innovation compensation effect" within the ETS. Unlike other common environmental regulatory instruments in China, the ETS offers potential benefits such as financial compensation to encourage relevant emitters to proactively transition towards greener practices [10]. This provides business managers with a stronger incentive to invest in green capital, upgrade production technologies, and develop environmentally friendly products as part of their overall green development strategies [11]. As a result, the ETS effectively promotes green innovation. After completing the transition, the relevant entities can effectively reduce their carbon emissions, allowing them to generate additional revenue through the trading of their remaining emission rights in the carbon market [12]. This revenue can then be used for research and development of green and low-carbon technologies. In essence, the ETS incentivizes emission subjects to engage in green innovation, creating a self-reinforcing cycle of revenue generation that promotes further green innovation.

As a result, this study proposes hypothesis H1: ETS can promote green innovation.

Heterogeneous Effects of ETS on Green Innovation

Considering historical factors, national development strategies, and variations in resource endowments,

cities located in different geographical regions exhibit substantial differences in terms of economic and social development, as well as industrial structure [13]. Consequently, these disparities may lead to heterogeneous effects on the relationship between the ETS and green innovation. Cities located in the eastern region of China possess considerable comparative advantages in terms of economic development, governance principles, infrastructure development, and talent reserves when compared to cities in the central and western regions [14]. These advantages can further enhance the concentration of green factors, such as green research and development and low-carbon expertise, in the implementation of the ETS. Additionally, they can strengthen the market mechanism of the ETS and fully utilize the mobilization potential of market resources to facilitate the transition towards green innovation. This further amplifies the impact of ETS implementation in consolidating green elements such as green R&D and the development of low-carbon talent. It also bolsters the market mechanism of the ETS, allowing for the full utilization of its potential to mobilize market resources towards the advancement of green innovation. Despite the substantial disparity in terms of economic and industrial foundations between cities in western China and those in the eastern and central regions, recent years have witnessed robust support and guidance from the state. Moreover, the western region's prevalence of traditional high-carbon industries may create favorable conditions for the ETS to assume a pioneering role in innovation [15].

It is worth noting that beyond geographical variations, discrepancies in urban resource endowments may also yield heterogeneous effects on the relationship between the ETS and green innovation. In resource-based cities, the urgency of sustainable transformation becomes more pronounced as the potential for resource development shifts from large to depleted to decoupled stages. Consequently, these cities exhibit strong incentives to reform their production models, industrial structures, and overall economic development. They strive for the intensive utilization of factors and aim to minimize ecological damage in order to achieve higher economic returns. This favorable context makes it more feasible for the ETS to effectively promote green innovation in resource-based cities.

As a result, hypotheses H2 and H3 are proposed in this study:

H2: The promotional effect of ETS is more significant for green innovation in eastern and western cities.

H3: The facilitating effect of ETS on green innovation in resource-based cities is more significant.

Mechanisms of ETS Influence on Green Innovation

Since the implementation of China's historic decision of "reform and opening up", China's market has brought a strong "gravitational pull" to international capital

through continuous opening up, and has become a new space for international investment cooperation [16]. During the initial phase of China's reform and opening up, the market faced a dearth of financial support and lacked a favorable technical environment. As a result, the country relied heavily on export processing and gradually integrated into the global industrial economy division of labor system. China's competitive advantage in labor-intensive industries was underpinned by low labor costs, an open policy environment, and a vast market potential [16]. However, this development trajectory led to a rudimentary economic model, wherein China prioritized attracting capital without enforcing stringent environmental control standards. The distinctive advantage of lower labor costs has expedited the establishment of low value-added foreign funded industries in China. This, in turn, has hastened the exploitation of the country's natural resources and resulted in the production of goods with higher pollution intensity. Consequently, China has, to some extent, become a destination for the transfer of polluting industries from developed countries, earning the moniker of a "pollution paradise" [18].

Following the implementation of the ETS, the introduction of carbon trading mechanisms and the establishment of carbon prices will elevate environmental standards and intensify environmental regulations. As a consequence, the production costs of foreign firms engaged in polluting activities will rise, consequently diminishing their productivity. In line with the "pollution refuge" hypothesis, this phenomenon is expected to impede their R&D investments, erode their comparative advantage, and diminish their relative competitiveness, ultimately resulting in a decline in foreign investment inflows [19]. In the course of this transition, high quality foreign funded enterprises with advanced technology and substantial capital are expected to gain prominence in the market. These enterprises typically adhere to standardized environmental protection measures in their production and business operations. They possess extensive experience in environmental management and demonstrate a strong commitment to utilizing green technology and producing environmentally friendly products [20]. As foreign investment levels decrease and the quality of foreign investment improves, a production substitution effect and technology spillover effect come into play. This attracts high-end, low-carbon, and environmentally conscious talents, along with other green production factors. This, in turn, triggers a momentum for industrial upgrading, expedites the introduction of environmentally friendly technologies and products in the Chinese market, and fosters competition among local manufacturers. Consequently, local manufacturers are compelled to increase their investments in research and development to effectively respond to market competition.

In conclusion, this study finds that the implementation of the ETS has the potential to decrease the overall inflow of foreign investment while simultaneously

enhancing its quality. This, in turn, serves as a catalyst for promoting green innovation. Furthermore, the study highlights that the intensity of environmental regulation plays a positive moderating role in shaping the impact of the ETS on green innovation (As shown in Fig. 1). As a result, hypotheses H3 and H4 are proposed in this study:

H4: ETS promotes green innovation by reducing the scale of foreign investment and improving the quality of foreign investment.

H5: Government environmental attention positively moderates the impact of ETS on green innovation.

Material and Methods

Model Construction

In order to progressively establish a domestic carbon emissions trading market and facilitate the adoption of market mechanisms to achieve the "double carbon" objective at a reduced cost, the Chinese government introduced and implemented the carbon ETS in 2011. The selection of pilot regions was based on their declarations and the foundation of their efforts. To accurately evaluate the policy effects of the ETS, it is crucial to ascertain the causal pathway of its implementation [21]. The DID method is extensively employed to evaluate the treatment effects of policies. It effectively captures the dual individual and time-series differences resulting from exogenous policy interventions, thereby mitigating the common issue of endogeneity in the model [22]. Considering ETS as a quasi-natural experiment, the study utilizes DID to explore the impact of ETS on green innovation based on the panel data of 284 cities in China from 2006 to 2020, and constructs the following model:

$$\text{Innovation}_{i,t} = \alpha + \beta \text{Treat} * \text{Time}_{i,t} + \gamma X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

In Equation (1), $GF_{i,t}$ denotes the green innovation of city i in year t . If $\beta > 0$, it indicates that ETS implementation can significantly promote green innovation in pilot cities, and otherwise significantly inhibit green innovation in pilot cities. If $\beta = 0$, it means that the effect of ETS implementation on green innovation in pilot cities is insignificant. , that is, the interaction term between the grouping dummy variable ($Treat$) and the time dummy variable ($Time$). If city i is set up as ETS pilot area during the sample period, $Treat = 1$, otherwise $Treat = 0$. If province i is set as a pilot region in the current year and thereafter, $Time = 1$, otherwise $Time = 0$. $X_{i,t}$ denotes the set of control variables used in the study. u_i represents the regional fixed effect, λ_t represents the time fixed effect, and $\varepsilon_{i,t}$ is the random error term.

Second, in order to examine whether the policy effect is characterized by heterogeneity due to differences in

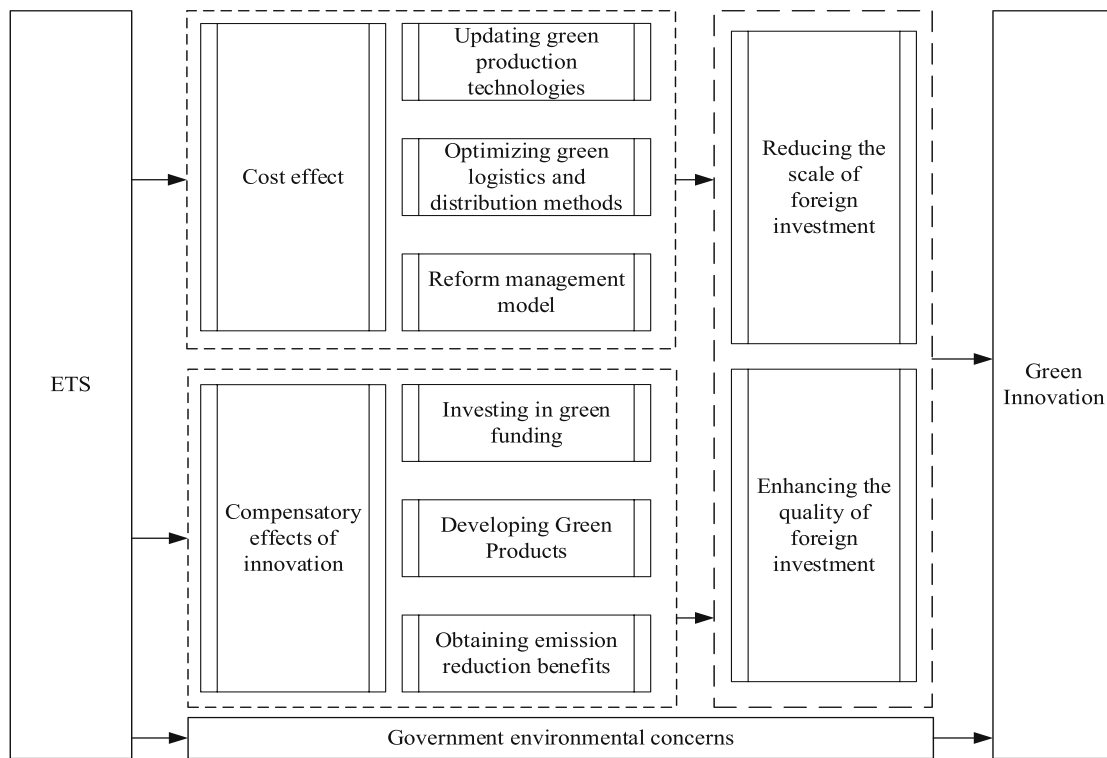


Fig. 1. Influence mechanisms.

urban geographic location and resource endowment, the following model is constructed:

$$\begin{aligned} \text{Innovation}_{i,t} = & \alpha + \beta_1 \text{Treat} * \text{Time}_{i,t} \\ & + \beta_2 \text{Group}_{i,t} + \beta_3 \text{Group}_{i,t} * \text{Treat} * \text{Time}_{i,t} \\ & + \gamma X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \end{aligned} \tag{2}$$

In Equation (2), $\text{Group}_{i,t}$ denotes the subsample that divides the sample according to the difference in the geographical location (resource endowment) of the city, respectively. The coefficient β_3 reflects the influence of urban geographical location (resource endowment) on ETS effect. The other variables have the same meaning as in Equation (1).

Third, to examine whether ETS implementation affects green innovation by promoting foreign investment concentration.

$$\text{Fdi}_{1,i,t} = \alpha + \beta_4 \text{Treat} * \text{Time}_{i,t} + \gamma X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \tag{3}$$

$$\text{Fdi}_{2,i,t} = \alpha + \beta_5 \text{Policy}_{i,t} + \gamma X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \tag{4}$$

In Equations (3, 4), and $\text{Fdi}_{1,i,t}$ and $\text{Fdi}_{2,i,t}$ represent the scale and quality of foreign investment, respectively. The other variables have the same meaning as in Equation (1). In order to circumvent the measurement error and modeling bias, the study mainly explains

the effect of ETS on $\text{Fdi}_{1,i,t}$ and $\text{Fdi}_{2,i,t}$ by combing the economic theories and the existing literature. Combined with Equation (1), if the coefficients β and β_4 are both greater than 0, it is considered that the mechanism of the ETS to promote green innovation in the pilot cities by increasing the scale of foreign investment in real use in the cities is established. If the coefficients β and β_5 are both greater than 0, it is considered that the mechanism of the ETS to promote green innovation in the pilot cities by increasing the quality of foreign investment in real use in the cities is established.

Further, to examine the moderating effect of environmental regulation intensity on green innovation in the ETS, the following model is constructed:

$$\begin{aligned} \text{Innovation}_{i,t} = & \alpha + \beta_6 \text{Regulation}_{1,i,t} * \text{Treat} \\ & * \text{Time}_{i,t} + \gamma X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \end{aligned} \tag{5}$$

In Equation (5), $\text{Regulation}_{1,i,t}$ represents the government environmental attention of city i in year t . The other variables have the same meaning as in Equation (1). If β_6 is greater than 0, it indicates that government environmental attention has a positive strengthening effect on the relationship between ETS and green innovation, and the other side has no positive strengthening effect.

Finally, to examine the spatial spillover effects of ETS on green innovation, these two and the control variable spatial interaction term are introduced into Equation (1),

and the following spatial panel measurement model is constructed:

$$\begin{aligned} \text{Innovation}_{i,t} = & \alpha + \rho W \text{Innovation}_{i,t} + \beta_1 \text{Treat} \\ & * \text{Time}_{i,t} + \beta_2 W \text{Treat} * \text{Time}_{i,t} + \gamma_1 X_{i,t} \\ & + \gamma_2 W X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \end{aligned} \quad (6)$$

$$\begin{aligned} \text{Innovation}_{i,t} = & \gamma + \rho W \text{Innovation}_{i,t} \\ & + \gamma_3 \text{Treat} * \text{Time}_{i,t} + \theta X_{i,t} + u_i + \lambda_t \end{aligned} \quad (7)$$

Equation (6) represents the SDM model and Equation (7) represents the SAR model. Where, ρ is the spatial autocorrelation coefficient. Since ρ does not fully represent the true elasticity, the study utilizes the decomposition of direct and indirect effects to determine the spatial correlation. Of these, the direct effect measures the impact of the ETS on the city's own green innovation. The indirect effect (spatial spillover effect) measures the impact of ETS on green innovation in other cities. β_2 and γ_2 are the elastic coefficients of the interaction terms of the core explanatory variable and the control variable, respectively. The other variables have the same meaning as in Equation (1). W denotes the corresponding spatial weight matrix. Drawing on Lu et al. (2021) [23] to construct the economic geographical distance weight matrix, which can be expressed as:

$$W = \frac{1}{|\text{GDP}_i - \text{GDP}_j|}, i \neq j \quad (8)$$

Where, $\overline{\text{GDP}}_i$ represents the Per capita GDP of city i from 2006 to 2020.

Measurement of Variables

Explained variable: green innovation. Patent is a central part of the innovation system. The percentage of green invention patents of total annual patent applications is selected as the proxy variable of green innovation [24].

Explanatory variable: ETS. The study selects ETS as the explanatory variable. ETS takes the value of 1 in the year of implementation in the pilot city and subsequent years, otherwise it is 0.

Mediating variables: The study mainly examines the transmission effect of foreign capital agglomeration from both quantitative and qualitative perspectives. Drawing on the research results of Ye et al. (2021) [25], two mechanism variables, foreign investment scale and foreign investment quality, are selected. (1) The scale of foreign investment (FDI_1): It is measured by the ratio of the actual utilization of foreign investment in the current year (ten thousand yuan) to the number of investment projects by foreign enterprises (each) (see Equation 10). (2) Quality of foreign investment (FDI_2): Measured as in Equation (11). FDI_{it} denotes the amount of foreign investment actually utilized by foreign investors in

city i in year t , FDI_{it} represents the actual use of foreign investment in the country in year t ; GDP_{it} denotes the gross domestic product of i city in year t , GDP_t denotes the national gross domestic product in year t .

Moderator variable: government environmental attention. The Chinese government's work reports typically serve as indicators of the allocation of public resources, with keywords related to the environment reflecting the local government's areas of focus. To gauge the level of attention given by local governments to environmental matters, this study conducts quantitative analysis by systematically organizing and tallying relevant keywords from the reports. The total number of environment-related keywords in the reports serves as a measure of the extent of concern expressed by local governments towards environmental issues.

Control Variables: The following control variables are selected in this study: green space area, consumer market potential, science and technology investment, financial development, economic development level. (1) The measurement of green space area is derived by calculating the ratio of the green space area (in hectares) to the built-up area of urban municipal districts. (2) The natural urban growth rate is employed as a measure of consumer market potential [26]. (3) The study uses the ratio of urban science and technology expenditures (ten thousand yuan) to urban general public budget expenditures (ten thousand yuan) to measure science and technology investment. (4) To measure financial development, this study employs the ratio of the Balance of RMB deposits institutions at the end of the year (in ten thousand yuan) to the gross municipal product [26]. (5) In this study, the level of economic development is measured using the growth rate of the gross municipal product.

Data Description

Given the availability and completeness of the sample data, the panel data for this study includes information on 284 cities in China, spanning the period from 2006 to 2020. (refer to Fig. 2 for a list of specific cities). City-level control variables and mechanism variables were collected from the China Urban Statistical Yearbook and the China Environmental Statistical Yearbook. Table 1 presents the statistical characteristics of each variable in the sample.

Results and Discussion

Parallel Trend Test

To ensure the validity of the DID approach, it is crucial to satisfy the parallel trend assumption. This assumption implies that, prior to the policy shock, there should be a consistent time effect or trend observed in the control group and the experimental group. By doing so, we can mitigate potential self-selection bias

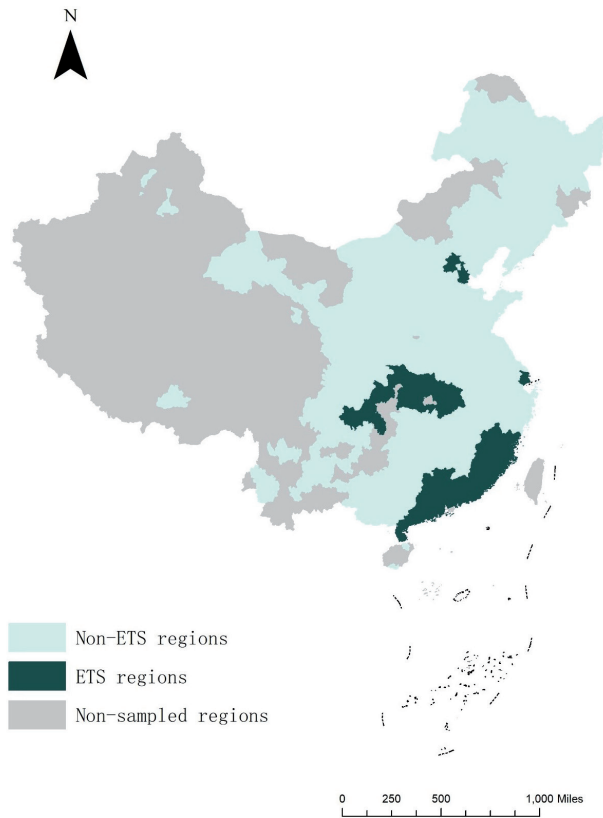


Fig. 2. Distribution of sample cities.

in the experimental group [28]. Failing to satisfy this assumption would compromise the accuracy of assessing the true impact of the policy. To test for parallel trends, this study adopts the model proposed by Jacobson [29], as presented below:

$$Innovation_{i,t} = \alpha + \sum_{j=-4}^3 \beta_j ETS_{i,t-j} + \gamma X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \quad (9)$$

The study selected 4 periods before to 3 periods after the implementation of ETS to test for parallel trends. In Equation (15), β_j is the key coefficient to focus on in the parallel trend test. $\beta_{-4} \sim \beta_{-1}$ are the coefficients for the 4 years prior to ETS implementation (i.e., *before₄ ~ before₁* in Fig. 3). $\beta_0 \sim \beta_4$ are the ETS post-implementation coefficients (i.e., *after₁ ~ after₃* in Fig. 3). If the $\beta_{-4} \sim \beta_{-1}$ coefficients are not significant and the $\beta_0 \sim \beta_4$ coefficients are significantly positive, it proves that the parallel trend hypothesis is passed. Fig. 3 reports the magnitude of the β_j coefficients and their 95% confidence intervals. As can be seen in Fig. 3, none of the regression coefficients for before1-before4 are significant and fluctuate up and down around 0 before the implementation of the ETS. And after the implementation of the ETS, the coefficients of *after₁ ~ after₃* are all greater than the law of 0, and the confidence interval of *after₃* does not contain 0 and the coefficient is significantly positive. This suggests that the model passes the parallel trend test and that there is a lag in the policy effects of the ETS.

Main Effects Test

In order to further guarantee the robustness of the regression results, the study adopts the regression by adding control variables step by step, and the estimation results of ETS for the impact of green innovation in pilot regions are shown in Table 2. It can be found that in the regression with the stepwise addition of control variables, the regression results show that the coefficients of ETS are all significantly positive at least at the 10% level. This suggests that the implementation of ETS can significantly contribute to green innovation in pilot cities compared to non-ETS pilot cities. Specifically analyzing the regression results in column (5), after adding all control variables to the regression, the regression results show that the coefficient of ETS is 0.0131, which is significantly positive at the 10% level. This suggests that an increase of 1 unit of ETS can significantly enhance green innovation by 0.0131

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Innovation	4,260	0.128	0.086	0	1
ets	4,260	0.068	0.253	0	1
willness3	4,260	45.76	48.20	0.335	1461.104
nir	4,260	5.770	5.311	-16.6	40.78
technology	4,260	0.014	0.015	0.000	0.206
finance3	4,260	1.368	0.697	0.371	20.10
gdprate	4,260	9.945	9.654	-530	109
regulation2	4,260	0.601	2.212	0	9.200
fdi1	4,260	0.239	0.488	0.000	8.173
fdi2	4,260	0.939	4.424	0.000	58.80

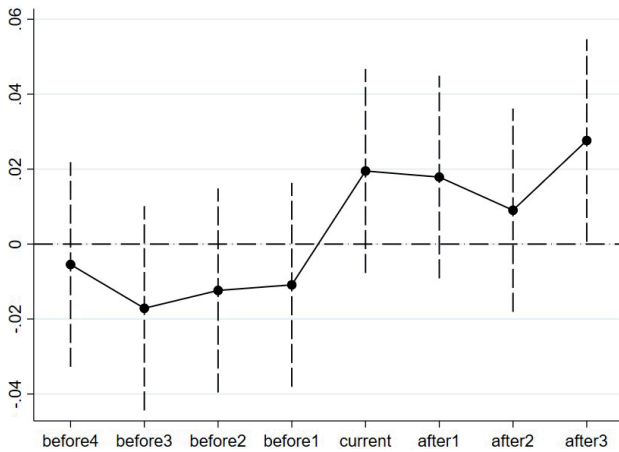


Fig. 3. Paralle trend test.

units. The results in Fig. 4, Fig. 5 and Table 3 show that the empirical results continue to hold after a series of robustness tests such as propensity score matching test and placebo test [30-32].

The results of the control variables are analyzed next. It can be found that after stepwise addition of control variables to the regression, the regression results show that only willness3 has a significantly positive regression result at the 1% level, with coefficient values all around 0.0001, while the results for the rest of the

control variables are not significant. This suggests that 1 unit of increased awareness of the city’s green industrial base and environmental protection can significantly enhance green innovation by 0.0001 units.

The empirical findings of this study provide strong evidence that ETS has a positive impact on green innovation. This result not only confirms the hypothesis H1 proposed earlier but also has significant practical implications. At the macro level, the implementation of ETS strengthens scientific, technological, and institutional innovation, accelerates the green and low-carbon technological revolution, and focuses on deepening reforms in the energy and related sectors. By leveraging market mechanisms, ETS creates effective incentives and constraints for green innovation. At the micro level, ETS compels polluting firms to engage in breakthrough innovations, explore new knowledge, and invest in high human capital to develop green technologies and products, thereby enhancing their competitiveness in green innovation and ensuring long term sustainable advantage.

Heterogeneity Test

Given the potential regional disparities in economic development and their implications for the implementation of the ETS, it is important to investigate

Table 2. Benchmark regression results.

Variable	(1)	(2)	(3)	(4)	(5)
ets	0.0138**	0.0126*	0.0129*	0.0131*	0.0131*
	(1.98)	(1.78)	(1.81)	(1.84)	(1.83)
willness3	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***
	(4.17)	(4.13)	(4.13)	(4.14)	(4.14)
nir		0.0004	0.0004	0.0004	0.0004
		(1.08)	(1.12)	(1.12)	(1.11)
technology			-0.0641	-0.0563	-0.0563
			(-0.43)	(-0.37)	(-0.37)
finance3				0.0019	0.0019
				(0.55)	(0.56)
gdprate,					0.0001
					(0.57)
cons	0.1086***	0.1061***	0.1061***	0.1039***	0.1028***
	(22.21)	(19.56)	(19.57)	(15.45)	(14.61)
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	4260	4260	4260	4260	4260
R ²	0.0143	0.0146	0.0147	0.0148	0.0148

Note: t statistics in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01

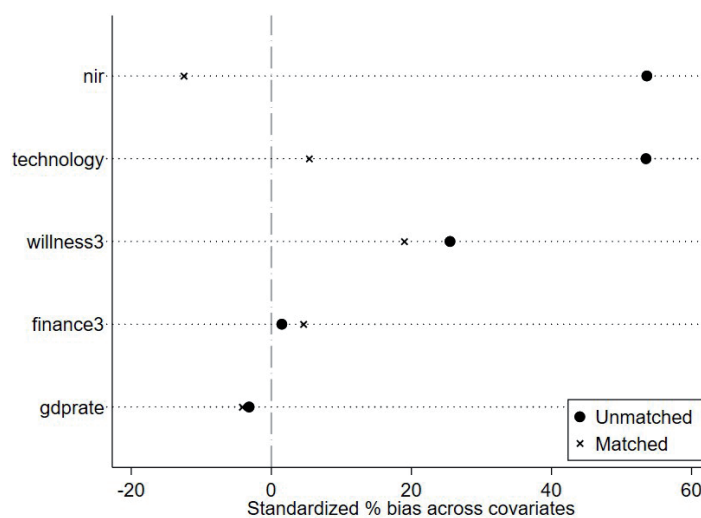


Fig. 4. Distribution of samples satisfying the common support hypothesis

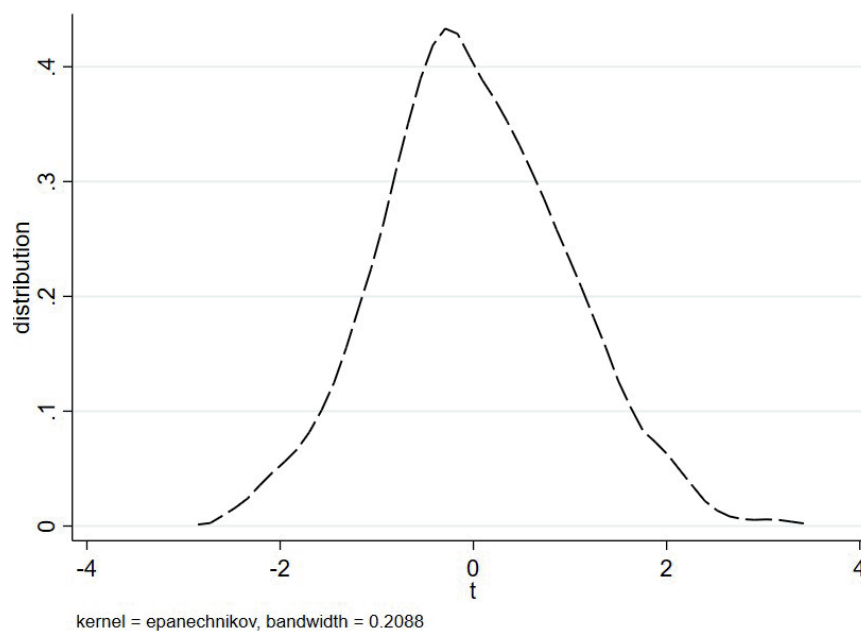


Fig. 5. Placebo test.

Table 3. Robustness test.

Variable	Two years ahead	Three years ahead	PSM-DID
ets	0.0053 (0.69)	0.0004 (0.05)	0.0130* (1.82)
_cons	0.1128*** (9.56)	0.1113*** (8.96)	0.1032*** (11.40)
City FE	Yes	Yes	Yes
Year FE	YES	Yes	Yes
N	4260	4260	4211
R ²	0.0135	0.0124	0.0148

Table 4. Geographic heterogeneity.

Variable	(1)	(2)	(3)
ets	0.0209**	-0.0062	-0.0942**
	(2.19)	(-0.35)	(-2.37)
_cons	0.1086***	0.1061***	0.1061***
	(22.21)	(19.56)	(19.57)
Control variables	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	1095	1500	1665
R ²	0.0200	0.0160	0.0772

Note: t statistics in parentheses, ** p<0.05, *** p<0.01

whether there are heterogeneous effects of ETS implementation on green innovation across different regions. To address this concern, the sample is divided into three subsamples based on the geographical regions of Eastern, Central, and Western China. The regression results for each subsample are presented in Table 4, with Columns 1-3 displaying the results for the Eastern, Central, and Western subsamples, respectively. This analysis aims to identify any variations in the impact of ETS implementation on green innovation across different regions. It can be found that the coefficient value of ETS is 0.0209 in the eastern subsample and is significant at the 5% level, which suggests that ETS can significantly promote green innovation in eastern cities. In the western subsample, the coefficient value of ETS is -0.0942 and significant at the 5% level, which indicates that ETS significantly inhibits green innovation in western cities. In the central region subsample, the coefficient of ETS is -0.0062 but not significant, which indicates that ETS has no significant effect on green innovation in central cities. This result corroborates hypothesis H2.

To examine the potential heterogeneity in the effects of ETS implementation based on resource endowments, the study divides the sample into two subsamples: resource-based cities and non-resource-based cities, in line with the National Sustainable Development Plan for Resource-based Cities (2013-2020) [33]. Resource-based cities, as identified in the plan, face unique challenges in integrating population development and green development, which may influence the implementation of the ETS and subsequently result in varied effects on green innovation. By regressing the sample separately for each subsample, the study aims to investigate whether there are heterogeneous differences in the impact of ETS implementation based on resource endowments. The division of the sample into resource-based and non-resource-based cities is depicted in Fig. 6. The regression results are shown in Table 5, with columns 1-2 showing the regression results for the

resource-based and non-resource-based city subsamples, respectively. This result corroborates hypothesis H3.

Historically, cities in western China and resource-based cities have faced significant ecological challenges as both exporters of resources and sources of ecological protection. These regions have often sacrificed valuable development opportunities due to over-reliance on a single mode of development, leading to an imbalance between the eastern and western regions of China and a stagnant industrial structure that hinders economic transformation. The heterogeneity analysis in this

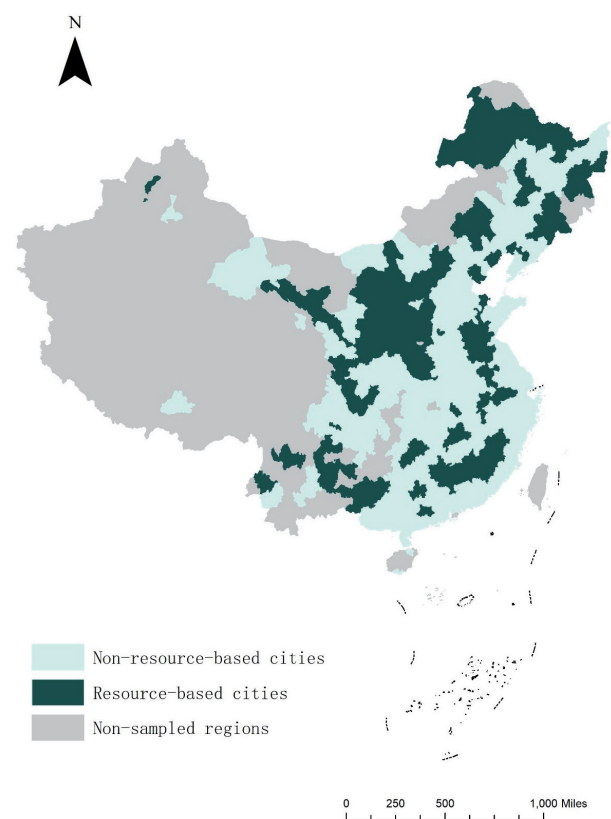


Fig. 6. Distribution of resource-based cities.

Table 5. Resource endowment heterogeneity.

Variable	(1)	(2)
ets	0.0456***	0.0023
	(2.65)	(0.30)
_cons	0.1125***	0.0994***
	(5.59)	(12.06)
Control Variables	YES	YES
City FE	YES	YES
Year FE	YES	YES
N	1501	2759
R ²	0.0298	0.0181

Note: t statistics in parentheses, *** p<0.01

study reveals that the promotion effect of ETS on green innovation is particularly significant in the eastern and western regions of China, as well as in resource-oriented cities. This finding holds great importance for promoting coordinated regional integration and balanced development in China.

Mechanism Test

To investigate the potential influence of ETS on green innovation through foreign investment agglomeration, the study employs two mechanism variables: the scale of foreign investment and the quality of foreign investment. By combining model (3) and model (4), regression analyses are conducted, and the results are presented in Table 6. Column (1) displays the regression results using the size of foreign investment as the mechanism variable. It can be found that the coefficient value of ETS

is -0.2063 and is significantly negative at 1% level. This indicates that ETS significantly and negatively affects the size of foreign investment. Combined with the viewpoint derived from the previous theoretical analysis that the scale of foreign investment shows a negative correlation with green innovation, the study concludes: The ETS will promote green innovation by squeezing out foreign investment through “winnowing”. Column (2) shows the results of the regression with the quality of foreign investment as the mechanism variable. It can be found that the coefficient value of ETS is 0.8400 and is significantly positive at 1% level. This indicates that ETS significantly and positively affects the quality of foreign investment. Combined with the idea derived from the previous theoretical analysis that the quality of foreign investment shows a positive correlation with green innovation, the study concludes that ETS will promote green innovation by enhancing the quality of foreign investment. This result corroborates hypothesis H4.

The subsequent analysis examines potential moderating effects of government environmental attention on the relationship between ETS and green innovation. Using model (5), a re-regression was conducted and the findings are presented in column (3) of Table 6. It can be found that the coefficient of the interaction term between ETS and government environmental attention is 0.0038 and is significant at the 10% level. This suggests that government environmental attention can positively moderate the relationship between ETS and green innovation. This result corroborates hypothesis H5.

While large-scale foreign direct investment (FDI) can bring about positive effects such as economic growth and employment opportunities, it also has negative consequences. It can crowd out the market share of local enterprises and lead to the loss of

Table 6. Mechanism test.

Variable	(1)	(2)	(3)
ets	-0.2063***	0.8400***	
	(-5.79)	(6.67)	
ets*regulation1			0.0038*
			(1.66)
_cons	0.1125***	0.0994***	0.1027***
	(5.59)	(12.06)	(14.59)
Control Variables	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	4260	4260	4260
R ²	0.1100	0.0220	0.0148

Note: t statistics in parentheses, * p<0.1, *** p<0.01

Table 7. Spatial spillover test

	(1)	(2)	(3)	(4)
	Main	Total	Direct	Indirect
ets	-0.0613***	-0.0437**	0.0148**	-0.0585***
	(-3.46)	(-2.42)	(2.09)	(-3.41)
Control	Yes	Yes	Yes	Yes
rho	-0.0809***			
	(-2.70)			
sigma2_e	0.0058***			
	(45.40)			
N	4260	4260	4260	4260

Note: t statistics in parentheses, ** p<0.05, *** p<0.01

domestic green R&D personnel. Additionally, the uncontrolled expansion of low-quality FDI in specific regions or low-carbon areas of China has resulted in predatory, monopolistic, and irrational competition, exacerbating environmental pollution issues in the country. To address these challenges, the establishment of ETS can enhance the government's commitment to environmental protection and improve ecological governance efficiency.

Spatial Spillover Effects

To explore the spatial spillover effects of ETS on green innovation, this study employs a spatial Durbin model based on Equations (6-8) and conducts a regression analysis using an economic geography matrix. Before delving into the spatial panel regressions, the study conducts a Moran's index test to assess the presence of spatial correlation in green innovation across cities. The test results reveal a significant spatial correlation, thereby justifying the examination of the relationship between ETS and green innovation through spatial panel modeling. The regression results of the spatial econometric model are presented in Table 7. Column (1) showcases the overall regression results, while columns (2) to (4) present the regression results after decomposing the spatial Durbin effect into total, direct, and indirect effects. It can be found that the spatial autoregressive coefficient of green innovation, rho, is significantly negative at the 1% level and the coefficient of the direct effect is significantly positive at the 5% level with a coefficient value of 0.0148. The coefficient of the indirect effect was significantly negative at the 1% level with a coefficient value of -0.0585. This suggests a negative spatial dependence in the quality of foreign investment. That is, while ETS enhances green innovation in the local city, it has a significant dampening effect on green innovation in neighboring cities.

The findings indicate that ETS can indeed promote green innovation within the local city; however, it also has a significant inhibitory effect on green innovation

in neighboring cities. This outcome can be attributed to the relocation of high-carbon enterprises to neighboring regions following the implementation of ETS. These enterprises are compelled to move due to rising operating costs and increased pressure to reduce emissions in the ETS pilot regions. Consequently, neighboring regions have become attractive destinations for high-carbon industries, leading to increased abatement costs and pressures in these regions. As a result, the incentives for green innovation in neighboring regions are diminished.

Conclusions and Recommendations

The Research Conclusion

The establishment of a carbon emissions trading mechanism is a crucial tool in advancing the green development strategy, as it not only sustains the momentum of green innovation but also serves as a reliable means to achieve sustainable economic growth. In light of this, this empirical study investigates the influence of ETS policies on green innovation using panel data from 284 cities in China spanning the period from 2006 to 2020. By employing a difference in differences method, mechanism testing model, moderating model, and spatial Durbin model, the study aims to uncover whether ETS can effectively foster green innovation and facilitate sustainable economic growth. The findings of the study are as follows:

(1) ETS policies have a significant positive impact on green innovation, with a particularly pronounced effect observed in cities located in the eastern and western regions of China, as well as in resource-oriented cities.

(2) The promotion of green innovation by ETS primarily occurs through the reduction of foreign investment scale and the enhancement of foreign investment quality. Thirdly, government attention to environmental issues plays a positive moderating role in the relationship between ETS and green innovation.

(3) ETS exhibits significant spatial spillover effects, promoting green innovation in local municipalities while simultaneously dampening green innovation in neighboring municipalities.

Policy Suggestions

(1) In the long run, it is crucial to summarize China's ETS pilot experience, improve the construction of the carbon emissions trading market, and fully leverage market mechanisms within the nationwide implementation of the ETS mechanism. This will further promote the adoption of advanced green and low-carbon technologies and practices, contributing to the global efforts in addressing climate change and promoting sustainable green development.

(2) In the eastern region, it is crucial to formulate effective policies and innovative regulatory mechanisms that fully leverage the promotional effect of ETS on green innovation. Additionally, the construction of the ETS market presents an opportunity to enhance energy efficiency, promote clean energy adoption, and facilitate industrial structure adjustments. In contrast, western cities and resource-based cities exhibit relatively homogeneous industrial structures and rely heavily on traditional coal and oil resources for their energy needs. Thus, these regions should seize the opportunity presented by ETS construction to improve local industrial production processes, enhance energy efficiency, promote the adoption of energy-saving technologies, and realize economic transformation and sustainable development by fully capitalizing on the promotional effect of ETS on green innovation.

(3) The government can optimize the foreign investment environment by integrating enforcement and inspection measures related to production safety, environmental protection, and product quality. By combining these measures with market mechanisms, low-quality foreign investment can be phased out in an orderly manner, while high-quality foreign investment can be attracted. Furthermore, the government can actively promote high-quality foreign investment in the low-carbon sector. This can be achieved by supporting foreign investment in establishing R&D centers in China, fostering collaborative technological research and development between foreign-invested enterprises and domestic firms, and encouraging foreign-invested enterprises to innovate and develop globally-leading green products in China.

(4) To address the weakening incentives for green innovation in neighboring regions, it is crucial to consider the broader implications of implementing ETS across the entire country. While maximizing the positive impact of ETS on green innovation, particular attention should be given to deepening its demonstrative effect on neighboring regions. This can be achieved by fostering collaboration and knowledge and technology exchanges among regions, thereby promoting a collaborative low-carbon development model. By enhancing synergy

and cooperation among neighboring regions, a more conducive environment for green innovation can be created, ultimately leading to sustainable and coordinated regional development.

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Conflict of Interest

The authors declare no conflict of interest.

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