REDUCING CARBON EMISSION INTENSITY THROUGH CARBON EMISSIONS TRADING POLICY: EVIDENCE FROM 283 CHINESE CITIES

SHI, H. P.* – YANG, Y. P.

School of Economics, Xihua University, Chengdu 610039, China

**Corresponding author*
e-mail: happystone2015@163.com

(Received 5th May 2025; accepted 16th Jun 2025)

Abstract. Based on panel data from 283 Chinese cities spanning 2005-2021, this study employs a multi-period difference-in-differences (DID) model and finds that the carbon emission trading policy significantly reduces urban carbon emission intensity. This conclusion remains robust after a series of tests, including the parallel trend test, placebo test, and PSM-DID analysis. Mechanism analysis shows that the policy lowers carbon emission intensity by promoting green technological innovation, upgrading industrial structures, and adjusting the energy mix. In terms of heterogeneity, the reduction in carbon emission intensity is more pronounced in cities with high-digitalization levels than in low-digitalization cities. The policy's carbon emission reduction effects are also stronger in key urban agglomerations such as the Beijing–Tianjin–Hebei region, the Yangtze River Delta, the middle reaches of the Yangtze River, and the Chengdu–Chongqing region. From a spatial perspective, the carbon emission trading policy not only lowers carbon emission intensity within pilot cities but also generates spillover effects that reduce carbon emissions in neighboring areas. Regarding economic outcomes, the policy achieves coordinated gains in carbon emission reduction and green growth. The findings of this study provide policy-relevant insights for achieving a win–win outcome between environmental protection and economic development in China.
Keywords: *green technological innovation, energy structure adjustment, spatial spillover effects, industrial structure upgrading, difference-in-differences method*

Introduction

Since the launch of China's reform and opening up, its economic growth has outpaced that of other countries, particularly during the initial high-speed phase. Yet such rapid expansion has exacted a toll in terms of resource depletion and environmental degradation. In tandem with swift industrialization and urbanization, carbon emissions have become an escalating challenge. As the world's largest energy consumer and CO_2 emitter, China now confronts unprecedented pressure to rein in its emissions. At the General Debate of the 75th Session of the United Nations General Assembly, the Chinese government pledged to peak carbon emissions before 2030 and achieve carbon neutrality before 2060. To honor these commitments, it has implemented a suite of carbon reduction policies. In 2011, the National Development and Reform Commission approved carbon emission trading pilot programs in seven regions—Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen. Shenzhen launched the first trading scheme in 2013, and Fujian, later added as the last pilot area, inaugurated its carbon market in 2016.

The carbon emission trading pilot program establishes a strict national cap on allowances and harnesses market dynamics to allocate them efficiently. However, this approach can be a double-edged sword: while it compels firms to curb emissions, the resulting compliance costs may impede economic growth. Unfortunately, few studies

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

have examined the joint benefits of emission reduction and economic expansion under environmental regulation. Scholars typically employ carbon emission intensity—CO_2 emissions per unit of GDP—as a key indicator for assessing the synergy between emission reduction and economic growth. This prompts a crucial question: Can the carbon emission trading policy lower carbon emission intensity and thus foster low-carbon economic development? To explore this, our study embeds carbon mitigation and economic performance within a single analytical framework, investigating the emission reduction impacts, driving mechanisms, spatial spillovers, and economic repercussions of the carbon emission trading policy. By doing so, we not only elucidate the policy's emission reduction pathways but, more importantly, offer essential guidance for helping China break free from the "carbon trap," fully decouple economic growth from carbon emissions, and fulfill its carbon peak and carbon neutrality commitments on schedule.

This paper makes three key contributions:

Mechanism clarification. It uncovers the causal pathways by which the carbon emission trading policy reduces carbon emissions, demonstrating that green technological innovation, industrial structure upgrading, and energy mix adjustments are the principal influencing channels.

Enhanced industrial-structure metrics. It enriches the traditional indicator system—normally limited to "advancement" and "rationalization"—by introducing an "ecological orientation" dimension. This ecological index deepens the scientific connotation of industrial upgrading under China's new development paradigm.

Broader economic assessment. It broadens the research scope on the economic consequences of the carbon emission trading policy. Beyond demonstrating a significant reduction in carbon emission intensity, this paper further explores the policy's wider economic impacts, thereby offering theoretical foundations and academic support for the government's comprehensive implementation of the carbon emission trading policy.

Literature review

In recent years, the carbon emission trading pilot policy has attracted close attention from scholars at home and abroad. From an economic perspective, as countries pursue rapid economic growth, excessive carbon emissions have damaged global ecosystems and generated negative economic externalities (Hardin, 1968). To internalize these externalities, early economists proposed market-based remedies, such as Pigou's taxation theory (Pigou, 1920) and Coase's property rights theory (Coase, 1960). Building on Coase's insights, the American economist Dales first introduced the concept of "pollution rights trading" in 1968 (Dales, 1968). Compared with traditional command and control regulations, carbon emission trading policy offers significant cost advantages for reducing pollutants (Montgomery, 1972) and has demonstrated effectiveness in cutting carbon emissions (Ibikunle et al., 2012).

Since carbon emission trading policy is derived from the pollution rights paradigm, scholars have examined its allowance allocation mechanisms in depth. If historical emissions are used to distribute allowances, high-emitting firms receive more permits, potentially undermining low-emitting firms' incentives and generating a "whipping the fast ox" effect that reduces overall abatement efficiency. Conversely, allocating allowances strictly by carbon emission intensity makes it difficult to cap total emissions and yields unimpressive reduction results (Demailly and Quirion, 2006). Accordingly, a

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

hybrid approach combining carbon emission trading policy with a carbon tax can achieve better abatement outcomes (Fell and Morgenstern, 2010) and promote greater equity (Lehmann, 2012).

Compared with developed economies, China’s carbon market emerged relatively late and has suffered from weak market mechanisms, low efficiency, and lagging legislation (Zhao et al., 2016). Under these circumstances, can the experiences of advanced nations effectively guide China’s carbon market development? Domestic scholars have debated these issues extensively, finding that market-based environmental regulations significantly reduce carbon emissions (Zhou and Liu, 2020), exhibit regional heterogeneity (Lu et al., 2022), and generate spatial spillovers (Li et al., 2022b). However, the impact of carbon emission trading policy on reducing carbon emission intensity remains contested. Wang et al. (2020) argued that such policies facilitate the decoupling of economic growth from carbon emissions, achieving dual benefits for economic development and environmental protection. In contrast, others contend that trading schemes curb emissions primarily by suppressing economic growth, thus failing to reduce carbon emission intensity (Zhang et al., 2019). Regarding mechanisms, most researchers agree that trading policies spur carbon emission reduction through green technology innovation (Zhang et al., 2022; Yu et al., 2023), although the effectiveness of these mechanisms is shaped by allowance allocation schemes (He, 2022). Furthermore, severe local protectionism undermines market liquidity for carbon allowances, impeding policy effectiveness (Tu and Chen, 2015).

A review of the existing literature highlights a relative dearth of studies on carbon emission intensity, particularly concerning the mechanisms, spatial spillovers, and economic consequences of the carbon emission trading policy. Therefore, this paper treats the carbon emission trading pilot policy as a “quasi-natural experiment” to examine whether it effectively reduces carbon emission intensity and explores its underlying mechanisms, spatial effects, and economic outcomes.

Mechanism analysis

Direct emission reduction effect of carbon emission trading policy

The emission reduction mechanism of the carbon emission trading policy primarily exploits market forces to internalize the negative external costs of carbon emissions, thereby achieving actual abatement (Stavins, 2008). According to neoclassical economic theory, such an environmental policy generates twofold incentives for regulated firms. On the one hand, firms holding surplus allowances can realize marginal gains through allowance trading, which motivates them to adopt carbon abatement measures whose costs lie below the prevailing carbon price and to allocate part of their trading revenues to green technology innovation (Jaffe et al., 2005), thus enhancing their carbon control capacity and lowering their carbon emission intensity. On the other hand, firms facing an allowance shortfall encounter compliance cost pressures; to mitigate the crowding out effect of these costs on overall production expenses, they are compelled to optimize production processes or adjust capacity structures, thereby reducing emissions (Porter and van der Linde, 1995). Simultaneously, the price signal conveyed by the carbon market drives the reallocation of production factors—such as capital and technology—from high-carbon to low-carbon sectors, hence improving the efficiency of market-based resource allocation (Knizig and Konradt, 2024). Based on this analysis, we posit the following hypothesis:

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

H_1: The carbon emission trading policy significantly reduces carbon emission intensity.

Indirect emission reduction effect of carbon emission trading policy

It is well understood that technological innovation is characterized by high investment costs, high risks, and long development cycles. Under the “hard constraints” of command-and-control environmental regulations, firms adopt various strategies to meet emission targets, such as investing in technological innovation, implementing end-of-pipe treatment, or curbing production. Failure to comply with these regulations often results in the closure or restructuring of firms (Tao et al., 2021). Porter (1995) argues that appropriately designed environmental regulations can incentivize innovation. Compared with traditional command-and-control regulations, market-based environmental regulations offer greater flexibility, encouraging firms to adopt green technological innovations that enhance total factor productivity and reduce carbon emissions. Consequently, the carbon emission trading policy helps drive firms toward green technological innovation, improves production efficiency, and reduces carbon emissions per unit of output (Guo et al., 2024). Moreover, the practice of trading emission allowances fosters inter-firm communication and creates a market environment conducive to collaborative green innovation. It accelerates the cross-boundary flow of innovative resources among firms, promotes joint development efforts, and further decreases carbon emission intensity. Based on these considerations, we propose the following hypothesis:

H_2: The carbon emission trading policy indirectly reduces carbon emission intensity by promoting green technological innovation.

Industrial structure upgrading is one of the key pathways to reduce carbon emission intensity. Following Gan and Chen (2021), such upgrading can be decomposed into three dimensions: advancement, rationalization, and ecologicalization.

First, the carbon emission trading policy facilitates industrial structure advancement. Constrained by environmental regulation, the secondary sector gradually shifts toward the tertiary sector through structural optimization, thereby driving the industrial structure toward a higher-order configuration (Zhang et al., 2023). Advancement of the industrial structure supports the growth of high-value-added, high-technology emerging industries, which inherently exhibit lower carbon emission intensity.

Second, the carbon emission trading policy accelerates industrial structure rationalization. On one hand, by “following the cost effect,” it raises production costs for firms, driving pollution- intensive enterprises either out of the market or toward so-called “pollution havens” (Shen et al., 2017). On the other hand, technology-intensive firms can capitalize on trading profits from carbon allowances to bolster innovation investment, thereby strengthening their green technology capabilities. Furthermore, by optimizing resource allocation, the policy adjusts the structure of both upstream and downstream industries, fostering coordinated development and furthering rationalization. Rationalizing the industrial structure enhances resource integration and allocative efficiency, promoting balanced industrial growth and reducing carbon emission intensity.

Finally, the carbon emission trading policy promotes industrial structure ecologicalization. Through the mechanisms of allowance allocation and carbon pricing, it incentivizes firms to engage in green technology innovation, thereby generating technology diffusion effects, raising the industry’s green technology standards, and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

driving the ecological transformation of the industrial structure. Additionally, the policy helps channel finance—via green bonds, green credit, and similar instruments—into low-carbon industries, fostering their high-quality development. Ecologicalization of the industrial structure effectively stimulates further green technology advances and optimizes the industrial chain layout, thereby lowering carbon emission intensity.

H_{3a}: The carbon emission trading policy reduces carbon emission intensity by promoting the advancement of the industrial structure.

H_{3b}: The carbon emission trading policy reduces carbon emission intensity by facilitating the rationalization of the industrial structures.

H_{3c}: The carbon emission trading policy reduces carbon emission intensity by advancing the ecologicalization of the industrial structures.

During the 13th Five-Year Plan period, China's adoption of dual controls on total energy consumption and energy intensity provided a robust institutional framework to enhance the synergies between pollution and carbon emission reduction and economic growth. In implementing these dual controls, the carbon emission trading policy has leveraged market mechanisms to generate a twofold energy-saving effect. First, according to Popp's (2019) theory of energy technology diffusion, the carbon price signal restructures the relative costs of different energy sources, prompting firms to increase their share of clean energy and reduce the intensity of fossil fuel consumption. Second, drawing on Porter's innovation compensation mechanism, the constraint imposed by carbon allowances internalizes compliance costs into firms' production expenses, thereby driving the optimization of energy management systems and the upgrade to more efficient equipment to lower energy consumption per unit of GDP (Dechezleprêtre et al., 2023).

H_{4a}: The carbon emission trading policy reduces carbon emission intensity by reducing total energy consumption.

H_{4b}: The carbon emission trading policy reduces carbon emission intensity by suppressing energy consumption intensity.

Research design

Model construction

To accurately assess the effectiveness of a public policy, it is common to compare economic agents' outcomes before and after the policy implementation. However, a simple pre-post comparison is often inadequate, because agents may also be influenced by other contemporaneous shocks. To address this issue, the difference-in-differences (DID) methodology is widely employed (Zhang et al., 2023). DID extends the traditional single-difference approach by incorporating a control group and computing differences along two dimensions, thereby effectively overcoming endogeneity concerns in policy evaluation and accurately estimating the policy's net effect. Consequently, this methodology is widely employed for the quantitative assessment of public policies (Angrist, 2008).

To investigate the intrinsic mechanisms by which the carbon emission trading policy may reduce carbon emission intensity, this study treats the launch of China's pilot carbon emission trading policy as a "quasi-natural experiment." Our treatment group comprises 46 pilot cities—which include the four municipalities of Beijing, Tianjin, Shanghai, and Chongqing, as well as 42 cities in Guangdong, Hubei, and Fujian—while the remaining 237 non-pilot cities (*excluding Tibet and the Hong Kong, Macao, and*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

Taiwan regions) serve as the control group. Because the pilot programs were implemented at different points in time across regions, we estimate a multi-period DID model to rigorously assess the abatement effect of the carbon emission trading policy.

$$Y_{it} = \alpha_0 + \alpha_1 DID_{it} + \alpha_2 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad \text{(Eq.1)}$$

where, i and t represent city and year, respectively. Y_{it} is the dependent variable, representing carbon emission intensity. DID_{it} is the core explanatory variable, which is the interaction term of the treatment dummy variable $treat_i$ (*indicating whether the city is in the policy pilot area*) and the post-policy dummy variable $post_{it}$ (*indicating the year of policy implementation*). X_{it} represents control variables, which could include factors such as population density, industrialization level, market scale, and resident income level. μ_i and λ_t represent city and year fixed effects, respectively. ε_{it} is the random error term.

The coefficient α_1 is the key parameter of interest. It measures the net effect of the carbon emission trading pilot policy on carbon emission intensity. If the carbon emission trading policy significantly reduces carbon emission intensity, α_1 should be negative.

Variable explanation

Dependent variable: carbon emission intensity (*ln_CI*). Whereas Western countries principally target the control of total carbon emissions, China has emphasized controlling carbon emission intensity (Zhou and Fan, 2016). Carbon emission intensity measures the amount of CO_2 emitted per unit of GDP, thereby capturing the interaction between carbon emission reduction and economic growth. Unlike absolute emission metrics, intensity indicators offer a more holistic assessment of the environmental impact of economic activities. In practice, carbon emission intensity is calculated as the natural logarithm of the ratio of total carbon emissions to regional GDP. A higher ratio indicates greater carbon emissions per unit of GDP, reflecting higher carbon emission intensity. Following the methodologies of Cong et al. (2014) and Xu et al. (2022), total urban carbon emissions are classified into: direct emissions from the transportation sector, the construction industry, and the secondary sector; indirect emissions from electricity generation and heat supply; and emissions attributable to transmission and distribution losses.

Core explanatory variable: carbon emission trading pilot policy (DID_{it}). The core explanatory variable is the interaction term DID_{it}, which represents the exposure of city i to the carbon emission trading pilot policy at time t. It is defined as:

$$DID_{it} = treat_i \times post_t$$

where, $treat_i = 1$ if city i is one of the four municipalities (*Beijing, Tianjin, Shanghai, Chongqing*) or one of the 42 cities in Guangdong, Hubei, or Fujian. Otherwise, $treat_i = 0$. Considering the variation in start dates of the carbon emission trading policy across these cities and to improve evaluation precision, we follow Sun and Zheng (2024), if the policy is implemented in the first half of year t, then $post_{it} = 1$; if it is implemented in the second half of year t, it is treated as taking effect in $year_{t+1}$, and $post_{t+1} = 1$.

Technological innovation, particularly green technology innovation, is a crucial pathway for reducing carbon emission intensity. Green technological innovation is typically measured by the number of patents related to environmentally friendly technologies. This study focuses on green invention patents, as these patents more directly reflect innovation in sustainable technologies compared to utility model and design patents. Specifically, the variables used are ln_patent_1, the number of green invention patent applications. ln_patent_2, the number of green invention patent grants. Both variables are logarithmically transformed for analysis.

This study evaluates industrial structure upgrading through three dimensions: advancement (*SA*), rationalization (*SR*), and ecologization (*SE*).

Based on Yuan and Zhu (2018), industrial structure advancement is measured by the weighted sum of the output proportion and labor productivity across industries. The formula is as follows:

$$SA_{i,t} = \sum_{m=1}^{3} y_{i,m,t} \times l_{i,m,t}, m = 1,2,3 \tag{Eq.2}$$

where, $y_{i,m,t}$ is the ratio of output from industry *m* to total GDP of city *i* in year *t*, and $l_{i,m,t}$ is labor productivity in industry *m* for city *i* in year *t*.

Based on Han et al. (2017), industrial structure rationalization is measured using the degree of structural deviation. The formula is:

$$SR_{i,t} = -\sum_{m=1}^{3} y_{i,m,t} \, | l_{i,m,t} / l_{i,t} - 1 | \tag{Eq.3}$$

where, $l_{i,t}$ is the total labor productivity in city *i* in year *t*, and the other variables are as defined above. Since $SR_{i,t}$ is a reverse indicator, its negative value is used for analysis.

Following the approach of Yang and Shao (2018), industrial structure ecologization is measured by the reciprocal of the ratio of total energy consumption to city GDP, where the ratio is adjusted for positive orientation. The total energy consumption includes various forms of energy such as electricity, gas, natural gas, and liquefied petroleum gas, all of which are converted into standard coal equivalents for consistency. This indicator reflects the level of coupling and optimization among industrial, natural, and social systems within a region. A higher value of ecologization signifies a better integrated and optimized system, where industrial processes are more aligned with environmental sustainability, resulting in lower energy consumption relative to economic output and indicating a more ecologically efficient industrial structure.

Energy structure adjustment is assessed by the total consumption of fossil energy (*ln_EC*) and energy consumption intensity (*ln_EI*). The total consumption of fossil energy sources (*electricity, gas, natural gas, and LPG*), converted into standard coal, with logarithmic transformation. The ratio of fossil energy consumption to city GDP, also logarithmically transformed.

In addition to the influence of carbon emission trading policy, carbon emission intensity is also closely related to various socio-economic factors, such as economic development, industrialization, market scale, and resident income. To mitigate potential omitted variable bias, the following control variables are included in the analysis:

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

Population density (*intensity*). Measured as the ratio of urban population to the area of the city. Higher population density typically leads to greater energy consumption and carbon emissions due to increased demand for services, transportation, and residential energy use.

Industrialization level (*industry*). Defined as the proportion of industrial added value relative to total GDP. This variable reflects the degree of industrialization, which is strongly associated with higher carbon emission intensity due to energy-intensive industrial processes.

Market scale (*market*). Measured by the ratio of total retail sales of consumer goods to GDP. A larger market size tends to drive economic growth but may also increase carbon emissions as consumption and production activities intensify.

Resident income (*income*). Captured by the logarithmic transformation of the average wage of urban employees. This variable is included based on the Environmental Kuznets Hypothesis, which suggests an inverted U-shaped relationship between per capita income and environmental pollution, implying that pollution may initially increase with income but decrease at higher income levels as more resources are available for environmental protection.

Data sources

Considering data availability, this study employs panel data from 283 cities in China over the period 2005-2021.

Carbon emission data are derived from the energy balance sheets and electricity balance sheets in each city's statistical yearbook, as well as from the statistical bulletins of individual cities. Emission factors are based on the *Guidelines for Compiling Provincial Greenhouse Gas Inventories* (*Trial*) and the IPCC Emission Factor Database.

Green patent data are obtained from the patent database of the China National Intellectual Property Administration and filtered according to the Green List published by the World Intellectual Property Organization (WIPO).

Data for mechanism variables and control variables are sourced from the *China City Statistical Yearbook*. Missing values are supplemented using linear interpolation, and all continuous variables are winsorized at the 1% level. Descriptive statistics of variables are presented in *Table 1*.

Table 1. *Descriptive statistics of variables*

Variable	Symbol	Obs	Mean	Std. dev	Min	Max
Carbon emission intensity	ln_CI	4811	1.331	0.648	0.214	3.490
Industrial structure advancement	SA	4811	0.575	0.273	0.085	2.045
Industrial structure rationalization	SR	4811	-5.854	17.720	-165.2	-0.050
Industrial structure ecologization	SE	4811	0.157	0.090	0.027	0.449
Fossil Energy consumption	ln_EC	4811	13.690	1.296	10.390	16.880
Fossil energy intensity	ln_EI	4811	0.093	0.081	0.010	0.568
Green patent applications	ln_patent_1	4811	3.768	1.828	0.693	10.088
Green patent grants	ln_patent_2	4811	2.788	1.654	0.693	9.211
Population density	intensity	4811	5.726	0.899	2.866	7.244
Industrialization level	industry	4811	0.393	0.132	0.095	0.839
Market scale	market	4811	0.364	0.356	0.102	0.128
Resident income	income	4811	10.61	0.577	9.334	11.66

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

Empirical results analysis

Baseline regression results

Table 2 reports the estimated effects of the carbon emission trading policy on carbon emission intensity. Column (1) reports the results of the baseline regression without control variables, including only city and year fixed effects. The estimated coefficient for the carbon emission trading policy is -0.084, which is statistically significant at the 1% level. Columns (2) to (6) show the results of a stepwise regression, in which population density, industrialization level, market scale, and resident income are introduced sequentially as control variables. The results consistently indicate a significantly negative coefficient for the carbon emission trading policy, confirming that the policy has effectively reduced carbon emission intensity. This finding supports Hypothesis H_1.

To improve the effectiveness of the carbon emission trading market and reduce carbon emission intensity at both the city and industry levels, local governments across China are actively advancing policy optimization through multiple dimensions. At the top-level design stage, the State Taxation Administration has standardized the value-added tax classification for carbon emission trading, thereby strengthening the institutional foundation. In local practice, provinces such as Zhejiang and Guangdong have enhanced market liquidity by developing carbon-inclusive mechanisms. Meanwhile, Hubei has leveraged blockchain technology to empower carbon emission monitoring, significantly improving data quality and regulatory precision. These coordinated efforts are collectively driving the carbon market toward greater efficiency and transparency.

Table 2. *Estimation results of the carbon emission trading policy on carbon emission intensity*

Variable	ln_CI				
	(1)	(2)	(3)	(4)	(5)
DID	-0.084^{***} (0.009)	-0.082^{***} (0.009)	-0.077^{***} (0.023)	-0.061^{***} (0.024)	-0.057^{***} (0.022)
Intensity		-0.043^{**} (0.020)	-0.052 (0.036)	-0.049 (0.037)	-0.036 (0.036)
Industry			-0.704^{***} (0.125)	-0.637^{***} (0.120)	-0.554^{***} (0.118)
Market				0.542^{***} (0.098)	0.496^{***} (0.093)
Income					-0.305^{***} (0.057)
_Cons	1.337^{***} (0.002)	1.584^{***} (0.115)	1.911^{***} (0.219)	1.670^{***} (0.230)	4.812^{***} (0.617)
City FE	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes
N	4811	4811	4811	4811	4811
Adjusted_R^2	0.954	0.954	0.959	0.960	0.962

*, **, and *** indicate significance at the 10%, 5%, and 1% statistical levels, respectively
Values in parentheses are cluster-robust standard errors
The same notation applies to subsequent tables

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

Parallel trend test

The baseline regression results indicate that the carbon emission trading policy significantly reduces carbon emission intensity. However, an important assumption underlying the DID method is that the treatment and control groups exhibit similar trends in the dependent variable prior to the policy intervention. While the traditional approach of plotting time trend graphs can offer some insights, the event study method provides a more precise way to test the parallel trend assumption (Jacobson et al., 1993), and has become the standard approach in empirical research. Therefore, this study adopts the event study method to analyze the trends in carbon emission intensity before and after the implementation of the carbon emission trading policy, comparing both the treatment and control groups.

The model specification is as follows:

$$Y_{i,t} = \alpha_0 + \sum_{s=1}^{6} \alpha_{before\_s} Before\_s + \alpha_c Current + \sum_{m=1}^{6} \alpha_{after\_m} After\_m + \rho X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \qquad \text{(Eq.4)}$$

where, *Before_s*, *Current*, and *After_m* represent the interaction terms for the years *s* before, during, and *m* years after the policy implementation, respectively, with city-specific fixed effects. Using a sample window of six years before and after the policy implementation, this study conducts a parallel trend test, with the year before policy implementation as the baseline period. If the coefficient for *Before_s* is insignificant, while the coefficient *After_m* is significant, the parallel trend assumption is considered to hold.

As shown in *Figure 1,* prior to the implementation of the carbon emission trading policy, there were no significant differences in the emission reduction effects between the treatment and control groups, as indicated by the insignificance of the *Before_s* coefficient. However, after the policy was implemented, significant differences emerged between the two groups, with the *After_m* coefficient being significantly negative. This result confirms that the parallel trends assumption is satisfied for the study sample.

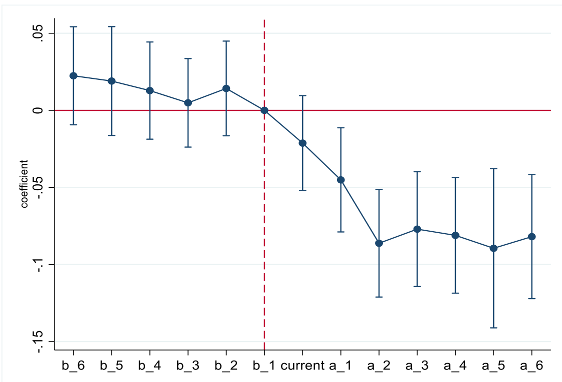


Figure 1. *Parallel trend test*

Placebo test

In the previous section, a two-way fixed effects model was employed, controlling for factors such as population density, economic development, and market conditions. However, unobservable factors could still introduce bias into the estimation results. To

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

enhance the robustness of the baseline regression findings, a placebo test was conducted. Following the methodology of Ferrara et al. (2012), this study randomized the impact of the carbon emission trading policy across different regions (*via computer-generated randomization*). The randomization process was repeated 1000 times, yielding 1000 corresponding regression coefficients and p-values. The p-value distribution is shown in *Figure 2*.

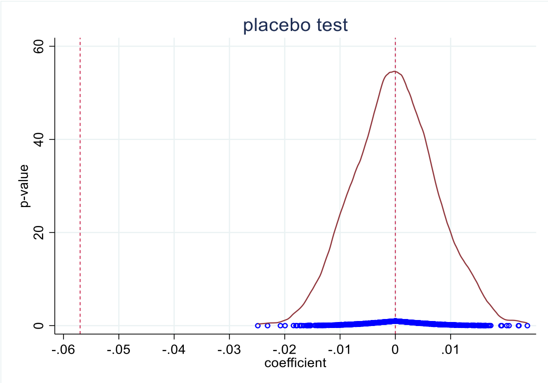


Figure 2. *Placebo test*

The results indicate that the estimated coefficients from the placebo test are primarily distributed around zero and follow a normal distribution. The baseline regression's DID coefficient (column 5, -0.057) falls at the lower tail of the placebo test coefficient distribution, with most p-values above zero. This suggests that the majority of the placebo test results are insignificant and exhibit a clear distinction from the baseline regression coefficient. Therefore, the placebo test supports the baseline regression findings, confirming that the inhibitory effect of the carbon emission trading policy on carbon emission intensity is not due to unobservable factors. This strengthens the reliability of the baseline regression results.

Robustness tests

Although the carbon emission trading policy was issued by the National Development and Reform Commission (NDRC), the selection of pilot cities was not random but based on internal and external factors, which could potentially introduce self-selection bias. To address this endogeneity concern, the study employed the propensity score matching-difference-in-differences (PSM-DID) method. The procedure involved three steps:

First, logit regression. All control variables from the baseline regression model were used as covariates in a logit regression to estimate the propensity score for each city.

Second, nearest-neighbor matching. A 1:1 nearest-neighbor matching was performed based on the propensity scores, followed by a balance test to assess the quality of the matching.

Third, regression analysis. The final step involved re-estimating the regression analysis using the matched sample.

The balance test results are reported in *Table 3*. The average treatment effect on the treated (ATT) T-statistic is 5.16 (*greater than 2.56*), indicating significance at the 1% level. Additionally, the standardized bias values of all covariates after matching are less

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

than 10%, and the p-values are insignificant, suggesting a good matching effect. The regression results using the matched sample are presented in column (1) of *Table 4*. After addressing the self-selection bias, the baseline conclusion remains robust.

Table 3. *Balance test results*

Covariate	**Matched or not**	**Average value**		**Standardized deviation**	**T-test**	
	Unmatched U / Matched M	**Process group**	**Control group**	**(%)**	**t**	**P > |t|**
Intensity	U	6.150	5.644	62.8	14.72	0.000
	M	6.121	6.109	1.5	0.36	0.719
Industry	U	0.408	0.390	14.7	3.53	0.000
	M	0.404	0.403	1.5	0.31	0.758
Market	U	0.410	0.355	55.1	13.98	0.000
	M	0.402	0.404	-2.5	-0.51	0.609
Income	U	10.639	10.607	5.4	1.42	0.155
	M	10.642	10.653	-1.7	-0.33	0.738

First, recognizing that most cities implemented the carbon emission trading policy in 2014, this year was adopted as the policy start date in a single-time-point difference-in-differences (DID) model for robustness testing. The results, presented in column (2) of *Table 4,* show that the policy's estimated coefficient remains significantly negative at the 1% level, indicating a substantial reduction in carbon emission intensity.

Second, to more accurately reflect the actual policy start dates, the initiation time was redefined following the method of Lu et al. (2017) as (12-month + 1)/12, where "month" represents the time of policy initiation. A multi-time-point difference-in-differences (DID) model was then employed for robustness testing. The results, shown in column (3) of *Table 4,* confirm that the policy's estimated coefficient remains significantly negative at the 1% level. Therefore, whether using single-time-point or multi-time-point DID models, the carbon emission trading policy consistently demonstrates a significant inhibitory effect on carbon emission intensity.

To further verify the robustness of the model, the dependent variable was substituted, and the model was re-estimated. When total carbon emissions replaced carbon emission intensity as the dependent variable, the results in column (4) of *Table 4* still show a significantly negative coefficient for the core explanatory variable. This suggests that whether the dependent variable is carbon emission intensity or total carbon emissions, the results and significance remain consistent.

Given the transition in environmental governance in China from "pollution reduction" to "carbon reduction," and recognizing that both SO_2 and CO_2 emissions stem from non-renewable energy consumption, it is expected that carbon trading policy may also promote synergistic effects in reducing both pollutants. Using SO_2 emissions as a dependent variable instead of carbon emission intensity, the results in column (5) of *Table 4* show a significant reduction in SO_2 emissions. This finding supports the synergistic control of SO_2 and CO_2 emissions under environmental regulations, further confirming that the carbon emission trading policy has a significant effect on both.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

During the study period, other environmental policies, such as the Air Quality Improvement Action Plan and the Air Pollution Prevention and Control Law, may have influenced carbon emission intensity in pilot cities, potentially confounding the effects of the carbon emission trading policy. Specifically, the Emissions Trading Pilot Policy (2007) and the "Ten Measures for Air" (2013) policies could also impact carbon emission intensity in pilot cities. To account for these potential confounding effects, this study follows Li et al. (2022a) by incorporating interaction terms for these policies into the baseline regression model. The results, shown in columns (6) and (7) of *Table 4,* reveal that the estimated coefficients for the carbon emission trading policy remain significantly negative even after controlling for these other policies, confirming the robustness of the baseline findings.

As an important supplement to market-based environmental regulation, voluntary environmental regulation may interfere with the policy effects of the carbon emission trading policy. For instance, although Sichuan Province is not a carbon emission trading pilot region, it initiated voluntary China Certified Emission Reductions (CCER) trading in December 2016. To mitigate the potential interference of such voluntary regulations, Sichuan Province's city samples were excluded, and the model was re-estimated. The results, shown in column (8) of *Table 4,* confirm that the estimated coefficients for the carbon emission trading policy remain significantly negative, further supporting the robustness of the findings.

Among the pilot cities, Beijing, Tianjin, Shanghai, and Chongqing are municipalities directly under central government, with stronger policy support, more economic resources, a larger talent pool, and better infrastructure compared to other cities. These cities may also implement stricter energy saving policies, which could confound the effects of the carbon emission trading policy. To address this, these municipalities were excluded from the sample, and the model was re-estimated. The results, presented in column (9) of *Table 4,* show that the core explanatory variable (DID) remains significantly negative at the 1% level, further validating the reliability of the baseline regression results.

Table 4. *Robustness test results*

Variable	PSM-DID	Changing the policy implementation timeline		Replacing the dependent variable		Excluding concurrent policy interference		Excluding special samples	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DID	-0.081*** (0.012)	-0.042*** (0.009)	-0.155*** (0.020)	-0.016*** (0.005)	-0.141*** (0.041)	-0.057*** (0.009)	-0.060*** (0.009)	-0.055*** (0.009)	-0.045*** (0.009)
_Cons	2.574*** (0.953)	4.843*** (0.477)	4.783*** (0.471)	7.630*** (0.173)	4.264*** (1.289)	4.812*** (0.476)	4.696*** (0.473)	4.854*** (0.489)	4.899*** (0.498)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1476	4811	4811	4811	4811	4811	4811	4505	4743
Adjusted_R^2	0.966	0.962	0.963	0.975	0.858	0.962	0.963	0.963	0.963

Heterogeneity analysis

Differences in digitalization levels and urban agglomeration patterns may lead to significant variations in the effectiveness of the carbon trading policy. To explore this,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

the study conducts a heterogeneity analysis from two key perspectives: digitalization level and urban agglomeration degree.

Urban digitalization can improve access to information, enhance green technological innovation, and reduce energy consumption in production and operations. Thus, the levels of digitalization may influence the effectiveness of the carbon trading policy. This study uses the internet penetration rate to measure the digitalization level of cities. Cities with an internet penetration rate above the median are classified as high-digitalization cities, while those below the median are categorized as low-digitalization cities.

The regression results for digitalization-level heterogeneity are presented in columns (1) and (2) of *Table 5*. The findings show that the carbon emission trading policy significantly reduces carbon emission intensity in high-digitalization cities, but the effect is not significant in low-digitalization cities. This discrepancy can be explained by several factors: firstly, enhanced enforcement of environmental policies. High-digitalization cities are equipped with advanced digital tools like the Internet of Things (IoT), cloud computing, and big data, which improve the efficiency of environmental policy enforcement. Secondly, promotion of low-carbon technologies. Digital technology in high-digitalization cities helps enterprises leverage tools for the development of green and low-carbon technologies. Thirdly, cities with advanced digital infrastructure can collect and analyze energy consumption data more effectively, enabling better emission reduction measures. Finally, development of green finance and carbon markets. Digital technology can enhance the transparency and efficiency of carbon market transactions, reduce transaction costs, and encourage greater participation from enterprises in high-digitalization cities.

Geographic location, ecological environment, resource endowments, and economic development create varying levels of industrial, talent, and resource clustering across cities, which may influence the effectiveness of carbon emission trading policy. China has designated five major urban agglomerations: the Beijing-Tianjin-Hebei (BTH), the Yangtze River Delta (YRD), the Pearl River Delta (PRD), the Middle Yangtze River, and the Chengdu-Chongqing urban agglomerations. This study conducts group regressions to assess the heterogeneous effects of carbon emission trading policy across these agglomerations, with results shown in *Table 5,* columns (3) to (7).

Table 5. *Heterogeneity analysis*

Variable	Low-digitalization	High-digitalization	BTH	YRD	PRD	Middle Yangtze River	Chengdu-Chongqing
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DID	-0.033 (0.024)	-0.110*** (0.013)	-0.065* (0.038)	-0.152*** (0.032)	0.051** (0.023)	-0.030* (0.018)	-0.252*** (0.055)
_Cons	0.951* (0.544)	4.134*** (0.483)	0.725 (1.411)	-0.217 (0.945)	5.341*** (0.698)	2.046** (0.858)	-10.166*** (1.891)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2401	2406	238	442	153	476	255
Adjusted_R^2	0.978	0.966	0.970	0.973	0.975	0.974	0.974

The results indicate that the carbon emission trading policy significantly reduces carbon emission intensity in the BTH, YRD, Middle Yangtze River, and Chengdu-

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

Chongqing urban agglomerations. However, the estimated coefficient for the PRD is significantly positive, suggesting that the policy may have increased carbon emission intensity in this region. Several factors may explain this anomaly: first, lagging industrial structural restructuring effects. The PRD, a critical manufacturing hub, has a high concentration of energy-intensive, high-emission industries. These industries are resistant to transitioning from extensive growth models, leading to delays in industrial restructuring. As a result, carbon emission intensity may rise in the short term before it decreases. Secondly, the pollution haven effect. The difference in environmental regulatory stringency between carbon emission trading pilot cities and non-pilot cities in the PRD has encouraged high-pollution, energy-intensive enterprises to relocate to non-pilot cities, alleviating regulatory constraints in the PRD but increasing emissions in non-pilot regions. This phenomenon is often referred to as the “pollution haven” effect. Thirdly, the industrial agglomeration effect. Due to its favorable geographic location, supportive policies, and strong industrial foundations, the PRD has experienced rapid economic growth and attracted substantial foreign direct investment. The resulting industrial agglomeration effect may temporarily increase energy demand and carbon emissions, which could lead to a rise in carbon emission intensity in the short term.

Mechanism analysis

The previous analysis has demonstrated that the carbon emission trading policy significantly reduces carbon emission intensity in pilot cities. However, a critical question for policymakers is: What are the underlying mechanisms through which the policy achieves its emission reduction effects? To explore this, the study investigates three potential mechanisms: green technological innovation, industrial structure upgrading, and energy structure adjustment.

To analyze these mechanisms, the following econometric model is constructed:

$$M_{it} = \alpha_0 + \alpha_1 DID_{it} + \rho X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \qquad \text{(Eq.5)}$$

where, M_{it} are the mechanism variables, which include green technological innovation, industrial structure upgrading, and energy structure adjustment. Other variables are the same as in the baseline model and are not repeated here.

To further explore the Porter effect of environmental regulation and assess whether the carbon emission trading policy can incentivize firms to engage in green technological innovation, this study uses the number of green invention patent applications and grants as proxies for green innovation. The results are presented in columns (1) and (2) of *Table 6*. These results show that the carbon emission trading policy significantly enhances firms’ green innovation capacity, as reflected in both patent applications and grants, thereby contributing to the reduction of carbon emission intensity. This finding confirms Hypothesis H_2.

First, the carbon emission trading policy allows greater flexibility for firms engaging in green innovation. Even if innovation efforts fail, firms are not forced to shut down or restructure. This relatively lenient policy environment provides more room for experimentation, facilitating technological breakthroughs and the accumulation of innovation capacity.

Second, as public demand for high-quality ecological goods continues to rise, environmental awareness among citizens is growing. Under the dual pressures of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

environmental regulation and social media oversight, firms are increasingly motivated to pursue green technological development to enhance their public reputation and reduce the carbon emission intensity of their operations.

Finally, as China's carbon market continues to mature, green financial instruments have gradually emerged, offering financial support for firms engaging in green innovation. These developments have promoted green technology research and development (R&D), attracted innovation talent, and improved firms' green total factor productivity.

The carbon emission trading policy regulates and optimizes resource allocation through market mechanisms, guiding high-pollution industries toward green and low-carbon transformation. This study measures industrial upgrading through three dimensions: industrial structure advancement, rationalization, and ecologicalization, in order to assess the impact of the carbon emission trading policy on industrial structure upgrading. The results in column (3) of *Table 6* show that the estimated coefficient of the policy on industrial structure advancement is significantly positive at the 1% level, indicating that the carbon emission trading policy significantly promotes the upgrading of industrial structure toward higher value-added sectors. This finding confirms Hypothesis H_{3a}.

On one hand, the carbon emission trading policy, through the carbon quota mechanism, internalizes the negative externalities associated with pollution, thereby increasing the production costs for polluting firms. This incentivizes traditional, high-pollution, and energy-intensive industries to transition towards more technology-intensive, knowledge-driven, and value-added sectors, thereby facilitating their upward movement along the value chain. On the other hand, the carbon emission trading policy is often accompanied by a range of complementary measures that support the development of green industries, further incentivizing firms to shift towards strategic emerging industries and enhancing the overall value-added across the industrial sector.

The positive and significant coefficient in Column (4) indicates that the carbon emission trading policy accelerates the rationalization of industrial structure. This finding supports Hypothesis H_{3b}. On one hand, the carbon emission trading policy promotes the diversification of industrial structures, encourages a more balanced and coordinated industrial development, reduces excessive reliance on pollution-intensive industries, and mitigates carbon emissions through a more rationalized industrial layout. On the other hand, the policy fosters low-carbon synergies throughout the upstream and downstream segments of industrial chains, promoting the development of green industrial chains and reducing carbon intensity across the entire value chain.

The positive and significant coefficient in Column (5) at the 1% level suggests that the carbon emission trading policy drives ecological transformation. This finding supports Hypothesis H_{3c}. Specifically, by imposing costs on pollution, the carbon emission trading policy incentivizes firms to adopt clean technologies and environmentally friendly processes, thereby facilitating an ecological production cycle. Additionally, mechanisms such as forest carbon sinks and ecological compensation encourage firms to invest in ecosystem restoration projects, enhancing carbon sequestration and fostering synergies between environmental and economic objectives.

Carbon emissions primarily stem from industrial exhaust gases generated during production. Market-oriented environmental regulations, such as the carbon emission trading policy, incentivize firms to optimize their energy structures by increasing the proportion of clean energy consumption, thereby reducing carbon emission intensity at

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

the source. Column (6) of *Table 6* demonstrates that the carbon emission trading policy significantly decreases fossil energy consumption, supporting Hypothesis H_{4a}.

While optimizing the energy structure is crucial for reducing carbon emissions, focusing solely on total fossil energy consumption may not fully capture the effects of carbon emission trading policy. A decline in fossil energy use might reflect the shutdown of pollution-intensive enterprises or constrained economic activity rather than substantive adjustments in energy structure. Therefore, fossil energy consumption intensity is employed as an alternative indicator to assess the impact more accurately.

The results in Column (7) reveal that the carbon emission trading policy significantly reduces fossil energy consumption intensity, supporting Hypothesis H_{4b}. On one hand, the policy encourages firms to adopt advanced technologies, optimize production processes, and enhance energy management practices, thereby minimizing energy waste and reducing consumption intensity. On the other hand, by fostering innovation, the carbon emission trading policy lowers the costs of clean energy while raising the costs of fossil fuels. This cost dynamic compels firms to prioritize clean and renewable energy sources, further driving down energy consumption intensity and associated carbon emissions.

Table 6. *Mechanism analysis results*

Variable	GreenTech		IndStruc			EnergyStruc	
	ln_patent$_1$	**ln_patent$_2$**	**SA**	**SR**	**SE**	**ln_EC**	**ln_EI**
	(1)	**(2)**	**(3)**	**(4)**	**(6)**	**(6)**	**(7)**
DID	0.144^{***} (0.038)	0.278^{***} (0.045)	0.043^{***} (0.014)	3.885^{***} (1.029)	0.023^{***} (0.003)	-0.093^{***} (0.029)	-0.018^{***} (0.003)
_Cons	1.982^{*} (1.023)	4.666^{**} (2.281)	1.787^{***} (0.338)	63.146^{**} (30.735)	0.329^{***} (0.082)	2.897^{***} (1.114)	-0.459^{***} (0.101)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	4811	4811	4811	4811	4811	4811	4811
Adjusted_R^2	0.910	0.808	0.753	0.221	0.841	0.905	0.699

Further research

Spatial effect analysis

Moran's index is a key indicator for assessing spatial autocorrelation in geographic data. A significantly positive Moran's index indicates a positive coordination relationship between a city and its neighboring cities. In other words, cities with high-carbon emission intensity may contribute to an increase in the carbon emission intensity of neighboring cities, while cities with low-carbon emission intensity may reduce the carbon emission intensity of nearby cities. The global Moran's index is reported in *Table 7*.

The results clearly show that, from 2005 to 2021, the Moran's index for carbon emission intensity across 283 cities in China consistently remains significantly positive. This indicates a strong positive spatial clustering of carbon emission intensity during the sample period. Such spatial clustering may reflect a combination of factors, including

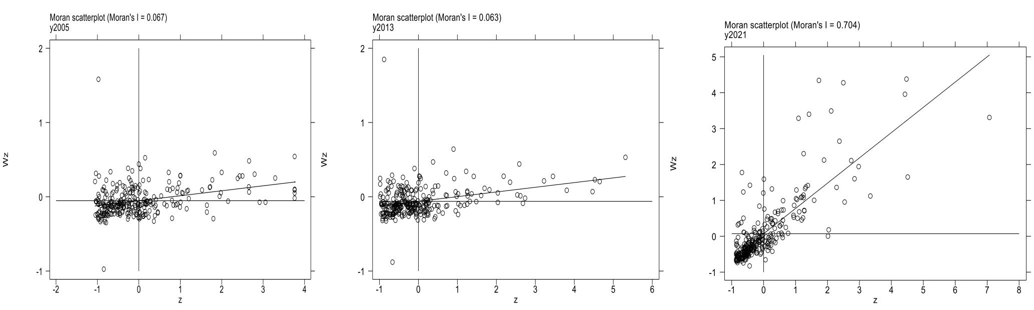
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

industrial distribution between cities, technological diffusion, and policy coordination. These findings highlight the importance of considering spatial linkages and coordination effects when formulating and implementing environmental policy. Regional cooperation can enhance the overall effectiveness of these policies by addressing the interconnectedness of neighboring cities.

Table 7. *Global Moran's index*

Year	I	E(I)	Sd(I)	Z	P-value
2005	0.067	-0.004	0.007	10.035	0.000
2006	0.065	-0.004	0.007	9.711	0.000
2007	0.064	-0.004	0.007	9.695	0.000
2008	0.063	-0.004	0.007	9.486	0.000
2009	0.066	-0.004	0.007	9.912	0.000
2010	0.069	-0.004	0.007	10.389	0.000
2011	0.073	-0.004	0.007	10.962	0.000
2012	0.066	-0.004	0.007	9.927	0.000
2013	0.063	-0.004	0.007	9.560	0.000
2014	0.074	-0.004	0.007	11.221	0.000
2015	0.076	-0.004	0.007	11.490	0.000
2016	0.084	-0.004	0.007	12.780	0.000
2017	0.088	-0.004	0.007	13.290	0.000
2018	0.095	-0.004	0.007	14.107	0.000
2019	0.122	-0.004	0.007	18.050	0.000
2020	0.122	-0.004	0.007	18.194	0.000
2021	0.140	-0.004	0.007	20.726	0.000

The local Moran's index is employed to analyze the spatial autocorrelation between individual observations and their neighboring regions. *Figure 3* presents the local Moran's scatter plots for 283 cities in China for the years 2005, 2013, and 2021. It is clear that most cities are concentrated in the first and third quadrants, indicating high-high and low-low clustering effects. Specifically, high-carbon-intensity cities are adjacent to other high-carbon -intensity cities (high-high), while low-carbon-intensity cities are clustered with other low-carbon- intensity cities (low-low). This spatial distribution further confirms the significant spatial clustering of carbon emission intensity across geographic space.



2005 2013 2021

Figure 3. *Scatter plot of localized Moran's index*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

Several factors contribute to these clustering effects. First, the geographical concentration of similar industries leads to industrial agglomeration, which fosters the convergence of energy consumption and carbon emission intensity in neighboring cities. Second, economic interactions and regional cooperation play a crucial role in shaping the spatial clustering of carbon emissions. These interactions help align the carbon emission profiles of neighboring cities, influencing the overall spatial pattern.

Table 8 presents the estimated spatial effects of carbon emission trading policy on carbon emission intensity. The results in column (1) indicate that the carbon emission trading policy significantly reduces carbon emission intensity, aligning with the findings of the baseline regression. Columns (2) and (3) further reveal that both the direct and indirect effects of the carbon emission trading policy on carbon emission intensity are significantly negative. This suggests that the policy not only decreases carbon emission intensity in pilot cities but also exerts a suppressing effect on neighboring non-pilot cities.

Table 8. *Estimation results of the spatial effects of carbon emission trading policy*

Variable	FE	LR_direct	LR_indirect	LR_total
	(1)	(2)	(3)	(4)
DID	-0.047** (0.013)	-0.046*** (0.013)	-0.086*** (0.027)	-0.132*** (0.033)
Intensity	0.0003 (0.015)	-0.001 (0.014)	0.075 (0.096)	0.075 (0.093)
Industry	-0.353*** (0.028)	-0.352*** (0.026)	0.220* (0.117)	-0.131 (0.121)
Market	0.580*** (0.034)	0.580*** (0.034)	0.149 (0.125)	0.729*** (0.131)
Income	-0.177*** (0.017)	-0.178*** (0.017)	0.187** (0.094)	0.009 (0.094)
rho	2.387*** (0.029)			
Sigma2_e	0.011*** (0.0002)			
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	4811	4811	4811	4811
Adjusted_R^2	0.119	0.119	0.119	0.119

These findings highlight that the carbon emission trading policy generates significant inhibitory effects on carbon emission intensity in both pilot regions and their surrounding non-pilot regions, fostering a role-model effect. Neighboring cities are incentivized to emulate the success of pilot areas. Two key mechanisms may explain this phenomenon: first, market efficiency mechanisms. carbon emission trading policy enhances resource allocation efficiency, resulting in significant reductions in pollution and carbon emissions within pilot cities. Second, technology diffusion and knowledge spillovers. The carbon trading market facilitates the dissemination of advanced technologies and promotes knowledge spillovers to neighboring non-pilot cities, enabling them to adopt similar emission reduction strategies.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

In conclusion, carbon emission trading policy establishes a ripple effect, driving reductions in carbon emission intensity across neighboring non-pilot cities. This supports broader regional pollution control and carbon reduction goals, underscoring the significant spatial spillover effects of the policy.

Economic consequences analysis

Environmental regulation refers to the policy and frameworks established by governments to mitigate activities that pollute the environment, with the goal of balancing environmental protection and economic growth. Under such regulations, firms typically adopt one of three strategies: first, investing in pollution control technologies. Second, innovating green technologies. Third, ceasing operations entirely. While the first two approaches lead to increased production costs due to compliance, the third may suppress economic activity, thereby conflicting with the policy objective of achieving environmental protection without sacrificing economic growth.

Although the previous analysis confirmed that the carbon emission trading policy significantly reduces carbon emission intensity, it remains necessary to further investigate its economic consequences. This analysis seeks to determine whether reductions in carbon emission intensity occur at the expense of economic growth, or if this policy can achieve a win-win outcome for both environmental protection and economic growth.

Table 9 reports the estimation results measuring economic growth by the actual per capita GDP of pilot cities, using a stepwise regression approach. Column (5) shows that the carbon emission trading policy does not exert a suppressive effect on economic growth while promoting carbon emission intensity reduction in pilot cities, but rather demonstrates a significant positive impact.

Table 9. *Economic consequences analysis*

Variable	**Economic growth**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
DID	0.080^{***} (0.010)	0.077^{***} (0.010)	0.074^{***} (0.009)	0.057^{***} (0.010)	0.054^{***} (0.009)
Intensity		0.068^{***} (0.017)	0.074^{***} (0.018)	0.072^{***} (0.018)	0.062^{***} (0.016)
Industry			0.503^{***} (0.042)	0.434^{***} (0.040)	0.374^{***} (0.039)
Market				-0.553^{***} (0.056)	-0.519^{***} (0.054)
Income					0.222^{***} (0.024)
_Cons	1.521^{***} (0.002)	1.131^{***} (0.097)	0.898^{***} (0.107)	1.143^{***} (0.107)	-1.150^{***} (0.265)
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	4811	4811	4811	4811	4811
Adjusted_R^2	0.952	0.952	0.955	0.958	0.959

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

This outcome can be explained as follows: in the short term, the internalization of negative externalities through the carbon emission trading policy increases production costs, which compels firms to improve management efficiency, optimize organizational structures, and enhance production processes, thereby boosting productivity. In the long term, the policy incentivizes firms to engage in green technological innovation, improving total factor productivity and driving high-quality economic development.

Therefore, the carbon emission trading policy not only significantly reduces carbon emission intensity in pilot cities, but also promotes their economic growth. This evidence demonstrates that through scientifically designed policies that fully leverage market incentives, the carbon emission trading policy contributes to achieving a win–win outcome of environmental protection and economic growth.

Conclusions and recommendations

Conclusions

Using panel data from 283 cities in China spanning 2005 to 2021, this study employs a multi-period difference-in-differences (DID) model to examine the carbon mitigation effects of the carbon emission trading policy. It also explores the mechanisms, spatial effects, and economic consequences of the policy's impact on carbon emission intensity. The results indicate that the carbon emission trading policy significantly reduces carbon emission intensity, a finding that holds across various robustness checks, including parallel trend tests, placebo tests, and PSM-DID tests.

The key findings are as follows:

Mechanisms of impact. The policy reduces carbon emission intensity in pilot cities through green technological innovation, industrial structure upgrading, and energy structure adjustments.

Heterogeneous effects. The policy's carbon mitigation effects are significant in cities with high levels of digitalization but not in those with low levels. Moreover, the policy's effects are more pronounced in urban agglomerations such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta, the Middle Yangtze River, and the Chengdu-Chongqing urban clusters.

Spatial spillover effects. Beyond pilot cities, the policy exerts a spillover effect, reducing carbon emission intensity in neighboring non-pilot cities through radiative effects.

Economic consequences. The policy not only reduces carbon emission intensity but also promotes economic growth, effectively achieving the dual goals of environmental protection and economic development.

Recommendations

Based on these findings, the following policy recommendations are proposed:

Expand the scope of carbon emission trading policy and build a unified national market

Broaden the coverage of industries and regions participating in the carbon trading policy, with a view toward national implementation. Develop standardized carbon quota allocation frameworks to ensure equitable participation across regions and industries, avoiding local protectionism and market fragmentation. Enhance monitoring, reporting, and verification systems to ensure data accuracy, transparency, and reliability. Establish

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

standardized trading rules to create a unified national carbon market and prevent fragmentation across regional markets.

Design tailored carbon Trading mechanisms while balancing economic goals

Adapt carbon quota standards to local conditions. For cities with high carbon emission intensity, slightly relax allocation standards to avoid overly stringent policies that could hinder economic development, while tightening quotas in low-carbon-intensity cities. Implement a dynamic quota adjustment mechanism. Initial allocations should consider historical emissions and economic development goals, with gradual reduction of quotas to encourage energy structure restructuring and industrial upgrading. Later reallocations should factor in technological progress, industrial structure, and abatement capacity, allowing high-performance cities to benefit economically and incentivizing low-performance cities to improve efficiency through quota purchases.

Encourage green technological innovation, energy restructuring, and industrial optimization

Increase government funding for green innovation through subsidies, tax incentives, and R&D tax deductions to encourage corporate investment in green technologies. Foster collaborative innovation among enterprises, universities, and industrial parks to enhance R&D efficiency and accelerate the commercialization of green technologies. Promote investments in the green energy sector and optimize energy policies to enhance clean energy utilization and reduce reliance on fossil fuels. Through market mechanisms and policy guidance, facilitate the phased withdrawal of high-pollution, high-energy-consuming industries, promote clean energy adoption, and optimize the energy structure. Support the development of emerging green industries, steering the economic structure toward high-value-added, low-carbon industries.

Leverage spatial spillover effects to amplify regional benefits

Strengthen inter-regional coordination and establish collaborative development mechanisms to integrate policies, resources, technologies, and funds across cities, facilitating the diffusion of policy experiences and development models from pilot cities to surrounding non-pilot cities. Promote the extension of leading industries from pilot cities to neighboring areas, creating core-centric industrial chains that drive upstream and downstream synergy. Develop cross-regional carbon trading markets to facilitate the transfer of carbon quotas across regions. This would allow high-emission cities to purchase quotas from low-emission cities, enhancing resource and policy coordination while amplifying the policy’s spatial spillover effects.

Funding. The research was supported by the Open Fund of Sichuan Province Cyclic Economy Research Center (No. XHJJ-2406), the Sichuan Provincial Philosophy and Social Science Key Research Base “Cultural and Tourism Integration Development Research Center Project” (No. WRF202411), the Chengdu Philosophy and Social Sciences Research Base “Chengdu Green and Low Carbon Development Research Base Project” (No: LD2024Z11), the Sichuan Provincial Philosophy and Social Science Key Research Base “Tuojiang River Basin High-quality Development Research Center Project” (No. TJGZL2025-16).

Conflict of interests. We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and company that could be construed as influencing this manuscript.

REFERENCES

[1] Angrist, J. D., Pischke, J. S. (2008): Mostly Harmless Econometrics: An Empiricist's Companion. – Princeton University Press, Princeton.
[2] Coase, R. H. (1960): The problem of social cost. – Journal of Law & Economics 3: 1-44.
[3] Cong. J. H., Liu, X. M., Zhao, X. R. (2014): Boundary definition and measurement method for urban carbon emission accounting. – China Population, Resources and Environment 24(4): 19-26.
[4] Dales, J. H. (1968): Pollution, Property and Prices: An Essay in Policy-making and Economics. – Edward Elgar Pub.
[5] Dechezleprêtre, A., Nachtigall, D., Venmans, F. (2023): The joint impact of the European Union emissions trading system on carbon emissions and economic performance. – Journal of Environmental Economics and Management 118: 102758.
[6] Demailly, D., Quirion, P. (2006): CO_2 Abatement, competitiveness and leakage in the European cement industry under the EU ETS: grandfathering versus output-based allocation. – Climate Policy 6(1): 93-113.
[7] Fell, H., Morgenstern, R. D. (2010): Alternative approaches to cost containment in a cap-and-trade system. – Environmental and Resource Economics 47(2): 275-297.
[8] Ferrara, E. L., Chong, A., Duryea, S. (2012): Soap operas and fertility: evidence from Brazil. – American Economic Journal: Applied Economics 4(4): 1-31.
[9] Gan, Q. H., Chen, S. M. (2021): The impact of market integration on regional economic growth from the perspective of industrial structure upgrading. – Industrial Economics Research 5: 40-53.
[10] Guo, J. J., Fang, Y., Guo, Y. (2024): Environmental regulation, tolerance for short-term failure, and corporate green innovation: evidence from the practice of the green credit policy. – Economic Research Journal 59(3): 112-129.
[11] Han, Y. H., Huang, L. X., Wang, X. B. (2017): Has industrial policy promoted local industrial structure upgrading? – Economic Research Journal 8: 33-48.
[12] Hardin, G. (1968): The tragedy of the commons. – Science 162: 1243-1248.
[13] He, Y. N. (2022): The impact of the carbon trading market on corporate innovation strategies and its mechanism. – China Population, Resources and Environment 32(7): 37-48.
[14] Ibikunle, G., Gregoriou, A., Hoepner, A., Rhodes, M. (2012): Liquidity and Market Efficiency: European Evidence from the World's Largest Carbon Market. – Research output: Working paper, The University of Edinburgh.
[15] Jacobson, L. S., Lalonde, R. J., Sullivan, D. G. (1993): Earnings losses of displaced workers. – American Economic Review 83(4): 685-709.
[16] Jaffe, A. B., Newell, R. G., Stavins, R. N. (2005): A tale of two market failures: technology and environmental policy. – Ecological Economics. https://doi.org/10.1016/j.ecolecon.2004.12.027.
[17] Knzig, D. R., Konradt, M. (2024): Climate policy and the economy: evidence from Europe's carbon pricing initiatives. – IMF Economic Review 72(3): 1081-1124.
[18] Lehmann, P. (2012): Justifying a policy mix for pollution control: a review of economic literature. – Journal of Economic Surveys 26(1): 71-97.
[19] Li, T., Xu, F., Qi, Y. Y. (2022a): From "drinking the same river water" to "protecting the same river water together"—changes in farmers' employment and income under the Xin'an River ecological compensation. – Management World 38(11): 102-124.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

[20] Li, Z. G., Che, S., Wang, J. (2022b): An investigation on the implementation effectiveness of carbon emission trading pilot policies. – Statistics and Decision 38(18) 166-170.
[21] Lu, M., Xu, H., Chen, F. X. (2022): The pollution reduction and carbon emission reduction effects of the carbon emission trading mechanism under the "dual carbon" background. – China Population, Resources and Environment 32(11): 121-133.
[22] Lu, Y., Tao, Z. G., Zhu, L. M. (2017): Identifying FDI spillovers. – Journal of International Economics 107: 75-90.
[23] Montgomery, W. D. (1972): Markets in licenses and efficient pollution control programs. – Journal of Economic Theory 5: 395-418.
[24] Pigou, A. C. (1920): Economics of Welfare. – Macmillan, London.
[25] Popp, D. (2019): Environmental Policy and Innovation: A Decade of Research. – CESifo Working Paper Series, Munich.
[26] Porter, M. E., Van der Linde, C. (1995): Toward a new conception of the environment-competitiveness relationship. – Journal of Economic Perspectives 9(4): 97-118.
[27] Shen, K. R., Jin, G., Fang, X. (2017): Has environmental regulation led to pollution proximity transfer? – Economic Research 52(5): 44-59.
[28] Stavins, R. (2007): A U.S. – cap-and-trade system to address global climate change. Working Paper 32(2): 293-371.
[29] Sun, B. W., Zheng, S. L. (2024): The synergistic effects of environmental regulation on pollution reduction and carbon mitigation: a quasi-natural experiment based on the implementation of cleaner production standards. – China Economic Quarterly 24(2): 624-642.
[30] Tao, F., Zhao, J. Y., Zhou, H. (2021): Has environmental regulation achieved "incremental quality improvement" in green technological innovation?—Evidence from the environmental responsibility system. – China Industrial Economics 2: 136-154.
[31] Tu, Z. G., Chen, R. J. (2015): Can the emission trading mechanism achieve the porter effect in China? – Economic Research 50(7) 160-173.
[32] Wang, L. H., Wang, H., Dong, Z. Q. (2020): Compatibility of economic growth and environmental quality: a test of policy bias effects from the perspective of environmental technological progress. – Management World 36(3): 39-60.
[33] Xu, L. X., Wang, Y. F. (2022): Carbon emission accounting in Chinese cities: measurement and method construction based on international statistical standards. – Statistical Research 39(7): 12-30.
[34] Yang, L. J., Shao, J. (2018): Re-estimation of regional industrial structure optimization in China. – Quantitative and Technical Economics Studies 35(10): 59-77.
[35] Yu, D. F., Jiang, Y. H., Zhang, Z. W. (2023): Innovation spillover effect of China's carbon emission trading pilot policies: a perspective based on the production network. – Journal of Quantitative Economics and Technical Economics Research 40(3): 28-49.
[36] Yuan, H., Zhu, C. L. (2018): Has the national high-tech zone promoted the industrial structure transformation and upgrading in China? – China Industrial Economics 8: 60-77.
[37] Zhang, G. X., Fan, M. M., Ma, R. K. (2022): Collaborative emission reduction effect of carbon trading policies. – China Population, Resources and Environment 32(3): 1-10.
[38] Zhang, H., Duan, M., Deng, Z. (2019): Have China's pilot emissions trading schemes promoted carbon emission reductions?—The evidence from industrial sub-sectors at the provincial level. – Journal of Cleaner Production 234: 912-924.
[39] Zhang, J., Shen, J., Xu, M. (2023): Does carbon emission trading promote industrial structure transformation and upgrading?—Empirical evidence from China's carbon emission trading pilot policies. – Economic Issues 8: 84-91.
[40] Zhao, X. G., Jiang, D. N., Chen, H. (2016): How to improve the market efficiency of carbon trading: a perspective of China. – Renewable and Sustainable Energy Reviews 59: 1229-1245.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447

[41] Zhou, D., Liu, Y. C. (2020): The impact and mechanisms of China's carbon trading pilot policies on urban carbon emission performance. – China Environmental Science 40(1): 453-464.
[42] Zhou, X. H., Fan, Q. Q. (2016): Mechanisms for achieving carbon intensity reduction targets and optimization design of industry emission reduction paths. – World Economy 39(7): 168-192.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_84238447