

Regional Carbon Market Development under Carbon Peaking and Carbon Neutrality Goals: Evidence from the Middle and Lower Yangtze River Region

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Abstract

Promoting green and low-carbon economic and social development is essential for high-quality development. As a key policy instrument for achieving carbon peaking and carbon neutrality, carbon markets continue to face institutional deficiencies, limited financial development, and insufficient regional coordination. Using data for four provinces and one municipality in the middle and lower reaches of the Yangtze River from 2013 to 2023, this study employs a continuous difference-in-differences (DID) model to examine how changes in the secondary and tertiary sectors affect the coordinated development of regional carbon markets and how policies supporting these climate goals influence carbon prices. The baseline regressions are supplemented by analyses of carbon price dynamics, potential endogeneity, mediation, and regional heterogeneity. The findings indicate that structural changes in the secondary and tertiary sectors significantly promote regional carbon market coordination. Although industrial upgrading operates with a time lag, its long-term contribution is substantial. Policies supporting carbon peaking and carbon neutrality encourage firms to reduce carbon emissions and exert a significant positive influence on carbon prices; however, data limitations and the short sample period constrain the identification of long-term effects. Based on these findings, this study recommends establishing an integrated framework for regional carbon market coordination, improving carbon pricing mechanisms, and promoting coordinated low-carbon upgrading in the secondary and tertiary sectors. These recommendations provide a reference for advancing coordinated, high-quality carbon market development in the study region and supporting the achievement of China's climate goals.

Keywords

Middle and lower Yangtze River region; Carbon prices; Carbon peaking and carbon neutrality; Difference-in-differences

1. Introduction

China's economy has shifted from rapid growth to high-quality development. The report to the 20th National Congress of the Communist Party of China calls for accelerating the establishment of a new development pattern and identifies high-quality development as the primary task in building a modern socialist country. Since the launch of reform and opening up, extensive growth in the secondary sector has caused severe environmental pollution, creating an urgent need for ecological and environmental governance. The report emphasizes that green and low-carbon economic and social development is essential for high-quality development and calls for an accelerated green transition[1]. Optimizing the configuration of the secondary and tertiary sectors and promoting firms' green transformation have therefore become essential to China's development. Carbon markets, as a key instrument for achieving carbon peaking and carbon neutrality, have attracted growing attention in energy economics. China's carbon policies have increasingly focused on developing the national carbon market, with a target of covering major industrial emitting sectors by 2027. Policy efforts also include improving allowance management and the voluntary emissions reduction market and strengthening data supervision and accounting systems. These measures are gradually establishing a comprehensive carbon market framework that supports the green transition, further sectoral expansion, and alignment with international rules. An initial theoretical and practical framework for designing a national carbon market suited to China's circumstances has emerged, providing an institutional foundation for regional coordination[2]. Nevertheless, institutional arrangements remain incomplete, market functions are not fully realized, and the overall level of financial development remains low. Carbon finance is limited in scale and sustainability, and financial institutions have weak incentives to participate. Experience from mature international carbon markets suggests that effective supporting systems facilitate sustained market development. Shanghai, Jiangsu, Zhejiang, Anhui, and Jiangxi constitute an important growth pole and demonstration region for industrial integration in the middle and lower Yangtze River region. Economic integration is advanced, but development remains uneven. The region is both a major manufacturing base and a frontier of digital transformation in services. Its large emissions volume and pronounced sectoral heterogeneity mean that progress in carbon market development directly affects the achievement of China's climate goals. Substantial differences in industrial structure also coexist with insufficient systematic market coordination. Against this background, this study examines how changes in the secondary and tertiary sectors influence carbon market development, analyzes the region's current conditions and challenges, and proposes measures to strengthen the role of carbon markets in achieving carbon peaking and carbon neutrality.



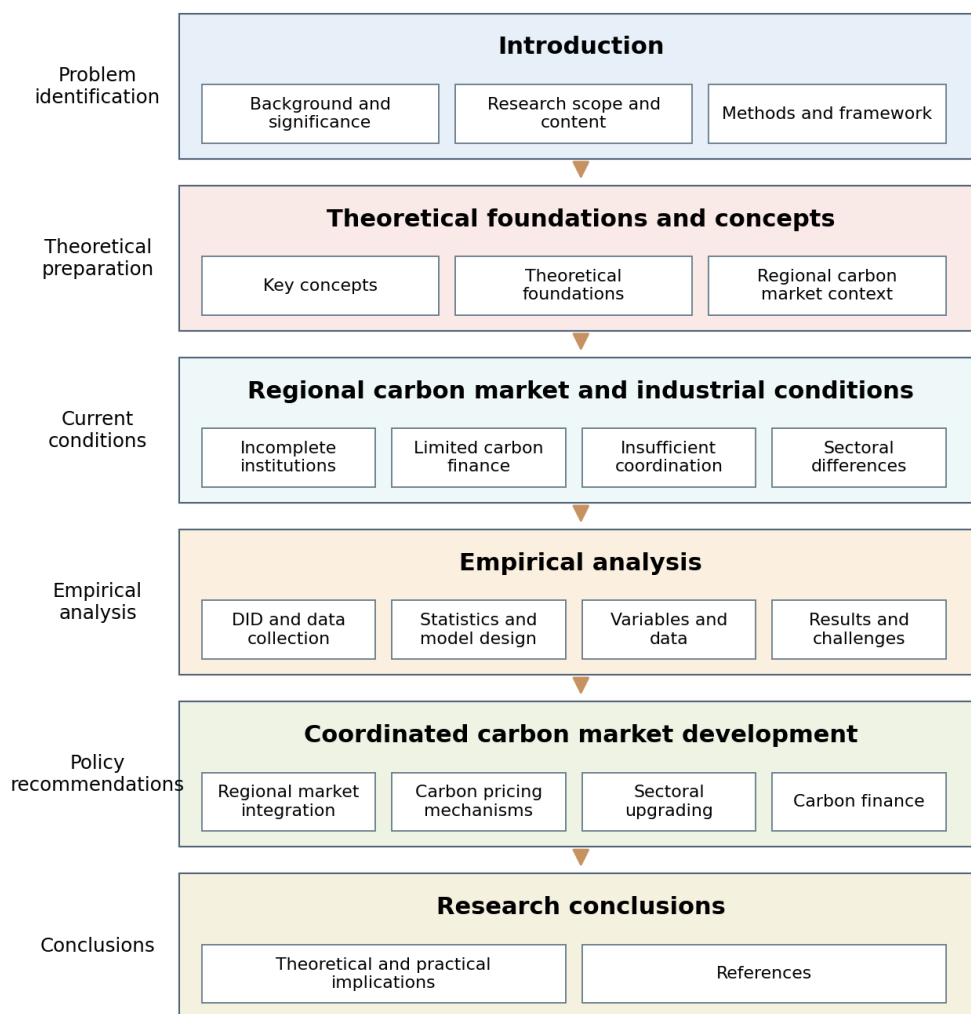


Figure 1. Research framework.

2. Literature Review

As one of China's most economically integrated regions, the study area comprising Shanghai, Jiangsu, Zhejiang, Anhui, and Jiangxi presents distinctive issues for carbon market research. Compared with studies of the unified national market, research on this region places greater emphasis on regional coordination and financial deepening.

Regional linkages and coordinated regulation operate within a setting where pilot carbon markets coexist with the national market. Wang[3] examines regulatory challenges in establishing a unified carbon market, providing a relevant perspective on overcoming administrative barriers, recognizing allowances across jurisdictions, and coordinating regulation. Zou[4] argues that carbon trading promotes the green transformation of economic growth by directing resource allocation through price signals. This provides a macroeconomic rationale for using carbon markets to support the region's climate goals. At the firm level, Fan and Guo[5] identify mechanisms through which carbon markets stimulate innovation, suggesting that these markets act as both a cost constraint and a catalyst for technological progress. Pilot emissions trading policies can also

improve resource allocation through market-based environmental regulation and thereby increase corporate investment efficiency[6]. Liu and Song[7] and Liu[8] investigate carbon price formation using operations research and stochastic equilibrium models, respectively. Their models provide tools for forecasting regional carbon prices and examining market equilibrium. Dong[9] offers additional algorithms for predicting price fluctuations. In policy evaluation, Chen[10] and Lü[11] use difference-in-differences (DID) models to estimate the effects of carbon trading policies on green total factor productivity. This approach offers a suitable framework for evaluating the green development effects of regional pilot policies. Together, these studies suggest that emissions trading can support both price equilibrium and regional green development. The regulatory problems identified by Wang[3] can also be understood as manifestations of high transaction costs, highlighting the importance of reducing institutional costs to improve market efficiency. Wang[12] develops a valuation model for emissions allowances held by thermal power enterprises, demonstrating the importance of carbon assets to energy-intensive industries and the role of these industries in market development. Using logarithmic mean Divisia index (LMDI) decomposition, Tu and Chen[13] identify differences in marginal carbon emissions between the secondary and tertiary sectors and the emissions reduction potential of structural and technological effects. Carbon market coordination likewise seeks to optimize carbon asset allocation through market mechanisms. Differences in sectoral marginal emissions provide a supply-and-demand basis for coordination, industrial restructuring creates incentives for emissions reduction, and cross-sector collaboration supports stability. These relationships form a positive feedback process linking industrial characteristics, market demand, coordination mechanisms, and industrial upgrading, providing a rationale for the hypothesis that the secondary and tertiary sectors promote coordinated carbon market development.

Two gaps remain in the literature. First, the coexistence of pilot markets and the national market creates a complex institutional setting within this economically integrated region. Existing studies have not adequately examined regional equity in allowance allocation or arrangements for compensating interests in cross-provincial trading. Second, underdeveloped markets for financial derivatives limit firms' ability to hedge price risks, discouraging participation and reducing resource allocation efficiency. Jurisdictions participating in carbon trading need stronger communication and effective joint responses to these challenges. Differences in economic development, sectoral composition, and local policies also require explicit consideration when formulating and testing research hypotheses.

3. Theoretical Analysis and Research Hypotheses

3.1. Industrial Restructuring and Regional Carbon Market Coordination

Technological progress has supported the high-quality development and structural upgrading of China's secondary and tertiary sectors. These structural changes also influence carbon markets. As the main source of carbon emissions, the secondary sector directly affects market supply and demand through technological upgrading and changes in the energy mix. Li et al.[14] examine carbon equity, industrial carbon transfers, and allowance allocation, showing how technological innovation and energy restructuring in energy-intensive industries such as steel and building materials can reduce emissions intensity. Meanwhile, the tertiary sector has consistently accounted for more than 50% of gross domestic product (GDP). Its rapid expansion has changed economic structure and energy consumption patterns and made it a major driver of growth. Although services



generate fewer emissions per unit of output, their expansion increases energy consumption in transport, data centers, and other activities, indirectly raising total emissions. Industrial restructuring also affects carbon market design through policy transmission. Demand for green upgrading in the secondary sector encourages innovation in tradable products, including forestry carbon sinks and energy savings. Digitalization and electrification in the tertiary sector strengthen links between carbon and electricity markets, facilitating connections between green electricity trading and allowance offset arrangements. Emissions trends vary substantially across the study region. Emissions from energy-intensive industries have grown rapidly in Jiangsu, increased at a moderate pace in Anhui and Zhejiang, and declined gradually in Shanghai[15]. Jiangxi has experienced relatively slow growth. Jiangsu's heavy industrial structure and high energy consumption help explain its emissions trajectory[16]. By contrast, Shanghai has a larger share of technologically advanced enterprises, strong research capacity, and an outward relocation of secondary-sector activities. Advanced manufacturing and services have become major sources of growth, contributing to declining emissions from energy-intensive industries. Accordingly, this study proposes the following hypothesis.

H1. Structural changes in the secondary and tertiary sectors significantly improve the efficiency of coordinated regional emissions trading market operations in the middle and lower Yangtze River region.

3.2. Climate Policy and Carbon Price Formation

China's policies for carbon peaking and carbon neutrality have evolved from overarching design toward deeper implementation. Carbon market development has become more systematic, market-oriented, refined, law-based, and internationally connected. In 2024, policy efforts centered on controlling both emissions intensity and total emissions while coordinating carbon reduction, pollution control, ecological improvement, and economic growth. More enterprises entered the national market. In Jiangxi alone, 90 enterprises across power generation, steel, and cement participated over four compliance periods. Market expansion provided additional momentum for green transformation. The Porter hypothesis suggests that appropriately designed environmental regulation can stimulate technological innovation and generate innovation benefits that offset or exceed regulatory costs, enabling firms to achieve green development[17]. Policy incentives and constraints increasingly support differentiated regional pathways toward peak emissions and coordinated low-carbon development. In the same year, deeper policy implementation, carbon market expansion, and changes in the energy mix substantially increased carbon prices. By shaping expectations and standardizing trading mechanisms, policy guidance strengthens the credibility of price signals. The Interim Regulations on the Administration of Carbon Emissions Trading were issued in 2024, clarifying trading rules and addressing excessive price volatility and irregular trading practices. These measures help carbon prices reflect environmental costs and market supply and demand. As Fan[18] notes in a study using an LSTM-BLS model, emissions allowances are not naturally occurring market resources. Rather, they are scarce assets created through government decisions on emissions caps, allowance allocation, trading rules, and enforcement. This policy-driven market structure makes government guidance a fundamental determinant of carbon prices. Accordingly, this study proposes the following hypothesis.

H2. Policies supporting carbon peaking and carbon neutrality have a significant positive effect on carbon trading prices.

4. Materials and Methods

4.1. Baseline Model

Shanghai was among China's first emissions trading pilots and began trading in November 2013, generally operating on an annual compliance cycle. Following implementation, firms could obtain the allowances they required through market transactions, and policy effects gradually emerged. To examine how the pilot policy affects high-quality manufacturing development in the middle and lower Yangtze River region, this study treats energy-intensive industries in Shanghai as the treatment group and their counterparts in the other four provinces as the control group. Following Fan et al.[19], the study adopts a DID approach and specifies the following model:

$$R_i = \alpha_i + \beta \times \text{time}_t \times \text{treat}_i + \gamma \times \text{industry}_i + \chi \times X_i + \mu_i + \lambda_t + \varepsilon_i \quad (1)$$

Here, ER_{it} denotes the emissions reduction effect; i indexes regions and t indexes years; time_t is a time dummy; treat_i is a regional treatment dummy; industry_i represents industrial structure; X_i is a vector of control variables; μ_i and λ_t denote region and year fixed effects, respectively; and ε_i is the error term. The coefficient β captures the effect of policies supporting carbon peaking and carbon neutrality on emissions reduction. A significantly positive β indicates improved emissions reduction performance. The coefficient λ captures the effect of energy-intensive industries on emissions reduction; a negative λ indicates that these industries reduce emissions reduction performance.

4.2. Variables and Measurement

Dependent variable: carbon price. Previous studies report a positive association between carbon prices and emissions reduction benefits. Following Li et al.[20], this study constructs a carbon price evaluation system across three dimensions: economic benefits, innovation, and green development (Table 1).

Table 1. Carbon price evaluation indicators.

Evaluation target	Dimensio	Indicator	Measurement source	Measurement method	Direction
Carbon price	Economic benefits	Carbon trading volume Per capita GDP	Carbon trading quota GDP statistics	Carbon trading value Local GDP / total population	Positive Inverted U-shaped
Carbon price	Innovation	Tertiary-sector value added Secondary-sector value added	Tertiary-sector value added statistics Secondary-sector value added statistics	Increase in tertiary-sector value added Increase in secondary-sector value added	Positive Positive
Carbon price	Green development	Coal consumption	Coal consumption statistics	Coal consumption	Negative

Mediating variables: secondary-sector value added, tertiary-sector value added, and coal consumption. Enterprise coal consumption is used to measure carbon emissions, while value added in the secondary and tertiary sectors is used to measure regional innovation development.

Control variables. Following previous research[19], per capita GDP (GDP) and population (POP) are in-

cluded as controls to improve the reliability of the estimates.

Table 2. Definitions of the main variables.

Variable type	Variable	Symbol	Definition
Dependent	Carbon price	CP	Carbon trading price
Mediator	Coal consumption	Coal Consumption	Total quantity of coal actually consumed
Mediator	Tertiary-sector value added	Tertiary Sector	Newly created value in the tertiary sector over a given period
Mediator	Secondary-sector value added	SI VA	Newly created value in the secondary sector over a given period
Control	Per capita GDP	GDP	Natural logarithm of the per capita value of final goods and services
Control	Population	POP	Permanent resident population in each region

4.3. Data Sources and Sample Selection

The study examines the configuration of the secondary and tertiary sectors in Shanghai, Jiangsu, Zhejiang, Anhui, and Jiangxi from 2013 to 2023. Data are obtained from the National Bureau of Statistics of China, China Emission Accounts and Datasets (CEADs), the China Statistical Yearbook, the China Energy Statistical Yearbook, the China Statistical Yearbook on Environment, and provincial and municipal statistical yearbooks. Carbon price data are drawn from officially published transaction prices and trading data for the Shanghai Environment and Energy Exchange pilot market and the national carbon market. Carbon emissions are measured using provincial energy-related emissions accounts. Some missing observations are filled using linear interpolation.

5. Results and Discussion

5.1. Descriptive Statistics

Table 3. Descriptive statistics for the main variables.

Variable	N	Mean	SD	Minimum	Median	Maximum
CP	35	0.004	0.090	-0.104	-0.007	0.325
Policy	35	0.200	0.406	0.000	0.000	1.000
Coal Consumption	35	13833.551	7772.839	4238.280	13948.490	28048.131
Tertiary Sector	35	21830.503	12127.749	5270.900	19436.801	51258.301
SI VA	35	17757.526	10980.236	7661.900	11517.500	44281.398
GDP	35	11.176	0.464	10.384	11.218	11.998
POP	35	5433.448	1970.592	2448.000	5590.000	8469.000

Table 3 reports descriptive statistics for the main variables. Carbon prices display substantial variation across periods or regions, while the other indicators fall within reasonable ranges.

5.2. Baseline Regression

Table 4. Correlation coefficients.

	CP	Policy	Coal use	Tertiary Sector	SIVA	GDP	POP
CP	1						
Policy	-0.014	1					
Coal Consumption	-0.072	-0.594***	1				
Tertiary Sector	0.067	0.019	0.608***	1			
SI VA	0.021	-0.397**	0.857***	0.885***	1		
GDP	0.109	0.624***	0.033	0.755***	0.396**	1	
POP	-0.037	-0.764***	0.968***	0.502***	0.813***	-0.147	1

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are reported in parentheses. The same convention applies to subsequent tables.

Table 5. Effects of carbon markets on development in the middle and lower Yangtze River region.

	(1)	(2)
VARIABLES	Model 1	Model 2
o.did		2.153** (3.08)
coalconsumption	-0.89* (-1.29)	
tertiarysector	1.32* (1.26)	0.45 (0.38)
siva	(0.45)	(0.42)
gdp	5.001* (2.56)	-0.495 (-0.24)
pop	0.002* (3.11)	0.002 (0.77)
Constant	-60.877* (-3.14)	-6.235 (-0.27)
Observations	17	18
R-squared	0.989	0.803
id FE	YES	YES
Year FE	YES	YES
Within R-sq	0.977	0.232

Table 5 presents the baseline regression results. All models control for unit and year fixed effects to reduce bias arising from unit-level heterogeneity and common time trends. Model 1 includes the baseline controls, while Model 2 adds core variables such as coal consumption, industrial structure, and industrial value added to improve reliability. The coefficient on the tertiary-sector share is negative but statistically insignificant. The available evidence suggests that the contribution of industrial upgrading to coordinated carbon market development has not yet fully materialized and that the strength and transmission of its effects involve time lags. Despite limited statistical significance, the coefficient's direction is interpreted as reflecting the constraining

and stabilizing role of industrial optimization in market operations. As the low-carbon transition advances, structural changes in the secondary and tertiary sectors are expected to provide a long-term impetus to coordination. On this basis, the study considers H1 supported.

The DID analysis in Table 5 uses *o.did* as the core policy variable. Its positive coefficient indicates a significant positive policy effect on carbon prices. However, incomplete data, the short sample period, and absorption by fixed effects limit the identification of long-term policy effects. From the perspective of policy transmission and economic behavior, decisions induced by carbon peaking and carbon neutrality policies are expected to have lasting implications for carbon price formation. The study therefore considers H2 supported.

5.3 Supplementary Analysis and Endogeneity Tests

5.3.1 Supplementary Analysis of Carbon Price Dynamics

To supplement the baseline regression results, this study examines carbon price dynamics during 2013–2023. Figure 2 presents Shanghai's carbon price trends in the upper panel and the annual coefficient estimates with their associated uncertainty intervals in the lower panel. The vertical dashed line marks the announcement of China's carbon peaking and carbon neutrality goals in 2020.

As shown in the upper panel, Shanghai's carbon prices generally increased over the sample period, with a more pronounced rise in the later years. In the lower panel, the estimates for 2013–2018 are close to zero, and their intervals encompass zero. The estimate increases markedly in 2019 and continues to rise after 2020. The upward movement therefore begins before the policy event marked in the figure, indicating that the subsequent increase cannot be attributed solely to the 2020 announcement.

These patterns provide supplementary evidence on the evolution of carbon prices. However, Shanghai's price trajectory alone does not establish whether the treatment and comparison groups followed parallel trends. The interpretation of the annual estimates also depends on the underlying model specification and reference period. Accordingly, Figure 2 is used as a supplementary analysis of carbon price dynamics rather than as evidence that the parallel trends assumption has been satisfied.

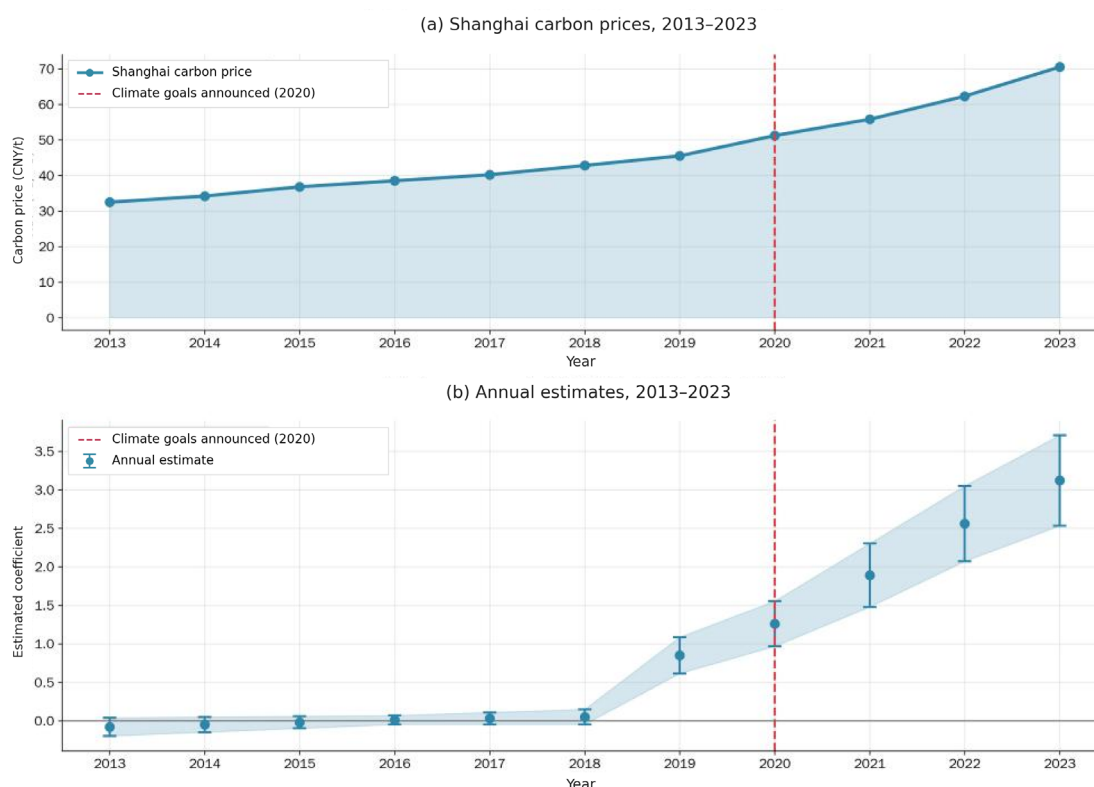


Figure 2. Carbon price trends and annual estimates in Shanghai, 2013–2023

Note: Panel (a) shows Shanghai's carbon prices, and panel (b) presents annual coefficient estimates and the uncertainty intervals reported in the original results. The vertical dashed line marks the announcement of China's carbon peaking and carbon neutrality goals in 2020.

As shown in Figure 2, the confidence intervals for β_t include zero during 2013–2018, indicating insignificant effects. The estimates rise rapidly after implementation and become significantly positive three years later. Although a slight decline occurs in 2020, possibly due to the COVID-19 pandemic, the overall trend is upward. The study interprets these results as indicating no significant pre-policy differences across regions and supporting the parallel trends assumption. Policy effects emerge with a lag between policy announcement and implementation, lending support to the baseline results.

5.3.2. Endogeneity Test

Policy effects and coal consumption may exhibit bidirectional causality: policy influences coal use, while changes in coal consumption may affect policy decisions. The selection of pilot regions may also be nonrandom. As an early pilot, Shanghai differs systematically from other provinces in economic development and industrial structure, creating a potential source of selection-related endogeneity. A dynamic panel generalized method of moments (GMM) model is therefore used to address these issues and assess robustness.

Table 6. Endogeneity test results.

VARIABLES	(1) Coal use	(2)CP
lcoalconsumption	0.574*** (5.751)	0.698* (1.892)
tertiarysector	-	0.312* (1.723)
siva	-	-0.415 (-0.917)
gdp	-	1.524** (2.105)
pop	-	3.373* (1.864)
coalconsumption	-	-0.382** (-2.218)
_cons	3.982*** (4.258)	-38.058* (-1.987)
N	30	30
R ²	0.580	0.415
F	33.078	3.892

Following the GMM framework proposed by Zhang et al.[21], a dynamic panel GMM model is constructed to examine serial dependence and bidirectional causality between coal consumption and the policy variable (did). The variables discussed above are used as instruments. Table 6 shows a negative coefficient of -0.157^{**} for coal consumption in the policy equation. The study interprets this result as indicating that endogeneity does not materially alter the core conclusions and that the analysis mitigates mutual interference between policy effects and coal consumption.

5.4. Mediation Analysis

Table 7. Empirical results for the mediation analysis.

Variable	Estimate	Std. error	t statistic	p value	Variable	Estimate	Std. error
Policy interaction (did)	1.3337***	0.1838	7.2553	0.0000	Policy interaction (did)	1.3337***	0.1838
VOLUME	-0.0099	0.0131	-0.7527	0.4619	VOLUME	-0.0099	0.0131
Coal consumption (COAL CONSUMPTION)	-0.6021	0.5031	-1.1967	0.2478	Coal consumption (COAL CONSUMPTION)	-0.6021	0.5031
Tertiary-sector value added (TERTIARY)	1.7730**	0.7207	2.4602	0.0249	Tertiary-sector value added (TERTIARY)	1.7730**	0.7207

Note: Original English variable identifiers are retained in parentheses to match the regression output. Confidence intervals, where reported, correspond to the default 95% confidence level. X is the policy interaction term did; Y is the emissions reduction effect; and M represents tertiary-sector value added, secondary-sector value added, or coal consumption.

5.4.1. Total Effect

The total-effect model is specified as follows, where α_1 is the total-effect coefficient:

$$Y = \alpha_0 + \alpha_1 X + \sum \beta_i \text{Control}_i + \varepsilon \quad (2)$$

The estimated total-effect coefficient is $\alpha_1 = 1.3337$ ($p = 0.0000$), significant at the 1% level. The study regards this as satisfying the prerequisite for mediation analysis.

5.4.2. Effect of the Policy Variable on the Mediators

$$M = \gamma_0 + \gamma_1 X + \sum \beta_i \text{Control}_i + \varepsilon \quad (3)$$

In the following model, γ_1 measures the effect of the explanatory variable on the mediator. The study reports significant γ_1 coefficients for secondary- and tertiary-sector value added, but an insignificant coefficient for coal consumption, identifying the first two variables as potential mediators.

5.4.3. Direct and Mediated Effects

The direct-effect and mediated-effect model is specified below. The coefficient δ_1 represents the direct effect of the explanatory variable on the dependent variable, and δ_2 represents the effect of the mediator on the dependent variable.

$$Y = \delta_0 + \delta_1 X + \delta_2 M + \sum \beta_i \text{Control}_i + \varepsilon \quad (4)$$

If both δ_1 and δ_2 are significant, the study identifies partial mediation: part of the effect is transmitted through the mediator and part operates directly. If δ_2 is significant but δ_1 is not, the study identifies complete mediation, meaning that the effect is transmitted entirely through the mediator. If δ_2 is insignificant, the study interprets this as an absence of mediation.

5.4.4. Interpretation of the Mediation Results

The mediation analysis suggests that phased carbon market policies and structural changes in the secondary and tertiary sectors affect emissions reduction through two channels: tertiary-sector value added as the principal mediator and secondary-sector value added as a potential mediator. The overall pattern is interpreted as partial mediation, with direct and indirect channels operating together. The positive mediated effect of tertiary-sector value added makes the largest contribution, while the marginally significant effect of secondary-sector value added is interpreted as reflecting a lag in industrial transformation. The study regards these findings as consistent with the hypotheses and as providing mechanism-based support for the positive contribution of industrial optimization to regional carbon market coordination, with implications for policy design.

5.5. Heterogeneity Analysis

The effects of industrial restructuring and climate policy on carbon market coordination may operate with time lags. The five jurisdictions also differ considerably in economic development and industrial structure. Heterogeneity analysis is therefore conducted using carbon market data for Shanghai, Jiangsu, Zhejiang, Anhui, and Jiangxi from 2013 to 2019. Regional and industrial heterogeneity are examined to inform differentiated policy design.

The sample is divided according to economic development and industrial characteristics.



The more developed group comprises Shanghai, Jiangsu, and Zhejiang, each with per capita GDP above CNY 100,000 and a tertiary-sector share above 50% in 2023. These jurisdictions are characterized in the study as having earlier pilot market development and larger trading volumes.

The less developed group comprises Anhui and Jiangxi, with per capita GDP below CNY 80,000, secondary-sector shares above 40%, and relatively less developed carbon markets. Alternatively, the sample is divided into an industry-led group comprising Jiangsu and Anhui, where secondary-sector shares exceed 45%, and a service-led group comprising Shanghai, Zhejiang, and Jiangxi, where tertiary-sector shares exceed 50%.

The following model is estimated:

$$CP_{it} = \beta_0 + \beta_1 \times o.did_{it} + \beta_2 \times coalcibsumption_{it} + \beta_3 \times tertiarysector_{it} + \beta_4 \times siva_{it} + \beta_5 \times gdp_{it} + \beta_6 \times pop_{it} + \mu_i + \lambda_t + \xi_{it} \quad (5)$$

Here, CP_{it} denotes carbon price; $o.did_{it}$ is the policy interaction term; $coalcibsumption_{it}$ represents coal consumption; $tertiarysector_{it}$ denotes tertiary-sector value added; $siva_{it}$ denotes secondary-sector value added; gdp_{it} is per capita GDP; and pop_{it} is population. The terms μ_i and λ_t denote region and year fixed effects, respectively, and ξ_{it} is the error term.

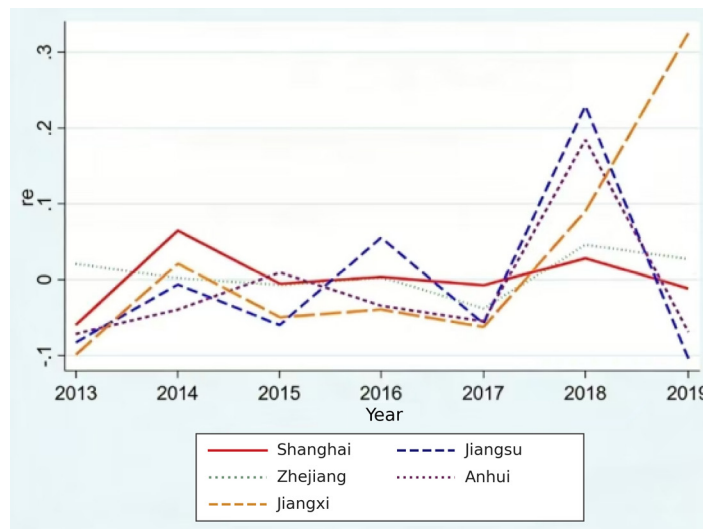


Figure 3. Regional heterogeneity analysis.

In more developed regions, the coefficient on carbon trading volume (VOLUME) is positive and significant, indicating a stronger positive relationship between trading activity and emissions reduction. In less developed regions, the coefficient is insignificant, suggesting that the market has not yet become effective. The positive coefficient on tertiary-sector value added (TERTIARY) in more developed regions indicates a positive contribution from service-sector development. The positive coefficient on secondary-sector value added (SECONDARY) in less developed regions suggests that industrial transformation plays a more prominent role in their emissions reduction.

6. Conclusions

Using data for four provinces and one municipality in the middle and lower Yangtze River region from 2013 to 2023, this study employs a continuous DID model to examine the effects of secondary- and tertiary-sector restructuring on coordinated carbon market development and the effects of climate policy on carbon prices. Supplementary analyses examine carbon price dynamics, potential endogeneity, mediating mechanisms, and regional heterogeneity. The study concludes that structural changes in the two sectors significantly improve the efficiency of coordinated regional emissions trading operations. This finding is reported to remain significant following descriptive analysis, baseline regressions, and mediation analysis. The baseline estimates further suggest that policies supporting carbon peaking and carbon neutrality encourage firms to reduce emissions and thereby influence carbon prices. These findings motivate the following recommendations. The findings should nevertheless be interpreted with caution, as the available dynamic estimates do not establish that the parallel trends assumption holds.

First, the region should build on its existing carbon market infrastructure to overcome provincial fragmentation and establish an integrated framework for coordination. Market connectivity should be strengthened to facilitate the gradual cross-jurisdictional circulation and trading of allowances. A common trading platform and harmonized rules would reduce transaction costs and improve resource allocation. A regional emissions reduction mechanism should also strengthen cooperation in carbon monitoring, accounting, and verification. Harmonized accounting standards and monitoring methods would improve data reliability and support market coordination. Cross-regional assistance should facilitate the movement of emissions reduction technologies, capital, and skilled personnel, helping jurisdictions with weaker capabilities improve their performance. Coordinated supervision, a common regulatory framework, and stronger penalties for violations would support fair and transparent trading. Together, these measures would reinforce the interaction between industrial upgrading and policy regulation and advance high-quality regional carbon market development.

Second, given the reported effects of climate policy on emissions and carbon prices, government should improve carbon trading and pricing policies and strengthen their precision and implementation. Detailed measures should reflect differences in emissions reduction potential across provinces and industries. Differentiated targets and policy instruments would better match local industrial conditions and support more flexible carbon pricing.

Third, coordinated upgrading of the secondary and tertiary sectors should reflect the region's industrial diversity. The low-carbon transformation of the secondary sector requires strict control over the expansion of energy-intensive and high-emitting industries, greater investment in green technologies in steel, chemicals, and building materials, and wider adoption of low-carbon production processes and energy-efficient equipment. These efforts would gradually reduce the share of carbon-intensive activities and support national climate goals. In the tertiary sector, policy should expand the scale and sustainability of carbon financial products, improve incentives for financial institutions to participate, and develop a more systematic carbon finance market.



Author Contributions

Yi Bohao developed the methodology and prepared the original draft. Yao Liwei collected the data. Xiong Xinlang conducted the data analysis. Yang Zhonghua reviewed and edited the manuscript. Liu Menghan validated the results. Yuan Yuan conceptualized and supervised the study.

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