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Original Research

The Impact of Carbon Emission Intensity on High-Quality Economic Development: An Empirical Study from 284 Prefecture-Level Cities in China

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Abstract

Currently, China is at a critical juncture for achieving high-quality economic development, and the goals of carbon peaking and carbon neutrality pose new challenges to this endeavor. Therefore, based on panel data from 284 prefecture-level cities in China spanning from 2011 to 2021, this study employs various econometric methods and considers green technological innovation as a mediating variable to empirically examine the impact of carbon emissions on high-quality economic development and its underlying mechanisms. The results indicate that there exists a non-linear, inverted "U-shaped" relationship between carbon emission intensity and high-quality economic development. As carbon emission intensity increases, its role transitions from promoting high-quality economic development to inhibiting it. Furthermore, both carbon emission intensity and high-quality economic development exhibit significant spatial positive correlations and spatial spillover effects. The local area's carbon emission intensity also affects the high-quality economic development of neighboring regions. Green technological innovation serves as a mediator, implying that carbon emission intensity can influence high-quality economic development through its impact on fostering green technological innovation. This study holds significant theoretical and practical implications in aiding the implementation of China's carbon reduction policies and fostering high-quality economic development across various cities.

Keywords: Carbon emission intensity, High-quality economic development, Green technological innovation, Spatial Durbin Model

Introduction

In recent years, climate issues caused by carbon dioxide emissions have received widespread attention from countries around the world [1-3]. Since 2013, global carbon emissions have continued to rise. In 2020, the average concentration of carbon dioxide in the atmosphere was approximately 415ppm, significantly higher compared to pre-industrial levels [4]. The rapid industrialization process has led to increased energy consumption, particularly from the use of fossil fuels such as coal and oil, resulting in a rapid surge in carbon emissions and increased environmental pollution [5, 6]. Simultaneously, rapid urbanization has not only improved living standards but also led to a sharp increase in carbon emissions [7-9]. To address the issue of increasing carbon

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dioxide emissions, 137 countries have proposed to achieve carbon neutrality by 2050, accounting for 73% of global carbon emissions. Since 2005, China has been the world's largest emitter of carbon, with its carbon dioxide emissions reaching 10.55 billion tons in 2022, accounting for 30.69% of the global total. In order to effectively curb the increase in carbon emissions, the Chinese government announced in 2020 its aim to achieve a carbon peak before 2030 and to reach carbon neutrality before 2060 [10].

The issue of carbon emissions and economic development has increasingly garnered widespread attention among scholars. To achieve carbon reduction targets, countries have implemented carbon emission restrictions. Developed countries, having completed industrialization and modernization through high-density carbon emissions, possess significant advantages in energy-saving and emission-reduction technologies. In contrast, the rapid economic development of developing countries requires large-scale infrastructure construction and the undertaking of high-carbon industries from developed countries, placing them in a relatively unequal position in terms of carbon reduction [11]. Moreover, carbon emission restrictions may increase the risk of disruptions in the food supply chain, exacerbating the food crisis and poverty in underdeveloped regions [12]. Furthermore, the implementation of various carbon pricing strategies can exacerbate social inequalities [13], thereby further leading to unbalanced economic development. In 2017, the 19th National Congress of the Communist Party of China first introduced the concept of "high-quality development," indicating a shift from high-speed economic growth to high-quality development, which holds significant global importance for China's economy [14]. Currently, China is in a critical period of high-quality economic development. The sacrifice of economic growth to achieve carbon reduction targets, along with the dilemma of local economic development faced by local governments under the strict carbon reduction target assessments set by the central government, poses new challenges to the implementation of China's dual-carbon policy on high-quality economic development [15]. Therefore, studying the impact of carbon emissions on high-quality economic development is of great significance.

This study, considering China's carbon emission characteristics, measures carbon emission intensity using per capita carbon emissions. It evaluates the level of high-quality economic development based on five dimensions: industrial structure, inclusive total factor productivity (TFP), technological innovation, residents' livelihoods, and the ecological environment. Additionally, it measures the digital economy and high-quality development levels of 284 prefecture-level cities in China from 2011 to 2021. Employing various econometric methods and considering green technological innovation as a mediating variable, this study empirically examines the impact of carbon emissions on high-quality economic development and its underlying mechanisms. This study holds vital theoretical and practical significance in aiding the implementation of carbon reduction policies in China and fostering high-quality economic development in various cities.

The remaining sections of this paper are divided as follows: Section 2 comprises a literature review, Section 3 includes theoretical analysis and research hypotheses, Section 4 details the research design, Section 5 presents baseline regression and robustness tests, Section 6 analyzes spatial effects and mediating effects, and Section 7 concludes with conclusions and policy recommendations.

Literature Review

Current domestic and international scholars have conducted extensive research on carbon emissions and high-quality economic development, focusing mainly on three aspects. Firstly, there are studies on the impact of carbon emissions on economic development. The classic Porter Hypothesis suggests that appropriate environmental regulations can promote technological innovation in enterprises. Although it may increase costs in the short term, it can enhance production efficiency and competitiveness in the long term, thus offsetting the costs brought about by environmental protection and enhancing the profitability of enterprises in the market, which in turn promotes economic growth [16]. Building on the Porter Hypothesis and assuming economic neutrality, Huang et al. simulated the boundaries of the Porter Hypothesis and found that achieving carbon neutrality targets would reduce China's annual economic growth rate during 2020-2060, and the impact of carbon neutrality on the economy could be much greater than that of carbon peaking. Due to the significant spatial dependence and dynamic effects of carbon emissions, economic growth is usually accompanied by high carbon emissions [17]. Additionally, some scholars have conducted research from a long-term equilibrium perspective, finding common development trends and long-term equilibrium relationships between trade openness, economic growth, and carbon emissions: as trade openness increases, the impact of carbon emissions on economic growth gradually weakens [18]. Simultaneously, there exists a long-term equilibrium relationship between industrial structure upgrading, economic growth, and carbon emissions; carbon reduction can promote the upgrading of industrial structures and thereby promote economic growth [19]. The government can influence carbon emissions through resource allocation and adjustments to the industrial structure [20].

Secondly, regarding the measurement of high-quality economic development, before the concept of high-quality development was proposed, scholars focused on the quality rather than the quantity of economic growth. Total Factor Productivity (TFP) was commonly used to measure the quality of economic growth [21, 22]. However, using TFP to measure economic growth has certain limitations, as it is difficult to fully reflect the economic effects of production factors and the status of resource allocation

[23]. In 2017, the 19th National Congress of the Communist Party of China first introduced the concept of "high-quality development," after which scholars conducted rich research on the measurement of high-quality economic development from multiple dimensions. Zhao et al. constructed an index of high-quality economic development from five dimensions: industrial structure, inclusive TFP, technological innovation, residents' living standards, and ecological environment, to measure the level of high-quality development in prefecture-level cities [24]; Wei and Li measured the level of high-quality economic development in 30 provinces of China from ten dimensions including economic structure and innovation drive, finding an obvious spatial distribution pattern of "high in the east, moderate in the middle, and low in the west." [25].

Thirdly, regarding the measurement of carbon emissions, Jiang proposed different methods for calculating carbon emissions at various levels based on energy consumption and statistical data from different countries, regions, and industries, finding that economic development has the most significant impact on the increase in carbon emissions [26]. Cong et al. summarized nine urban carbon accounting methods from different perspectives, including "Scope 1 emissions, Scope 2 emissions, and Scope 3 emissions," clarifying the relationships between various definitions [27]. Zhang et al. used the IPCC emission factor method to estimate carbon emissions data for 30 provinces in China, examining the factors affecting China's carbon emission intensity and its spillover effects [28]. Chen et al. estimated the carbon emissions of counties (districts) in China using the Particle Swarm Optimization-Back Propagation (PSO-BP) algorithm [29].

In summary, there is a close relationship between carbon emission intensity and high-quality economic development. However, existing literature predominantly focuses on research related to calculation methods, with limited studies investigating the impact mechanisms of carbon emissions on high-quality economic development. Moreover, literature exploring the relationship between these factors, specifically within prefecture-level cities, remains scarce. Therefore, this study takes the period from 2011 to 2021 and examines 284 prefecture-level cities in China as its research scope. It aims to investigate the impact of carbon emission intensity on high-quality economic development as well as the mechanisms influencing the relationship among carbon emission intensity, green technological innovation, and high-quality economic development.

Accordingly, the marginal contributions of this paper are as follows: (1) In terms of model selection, this paper utilizes the Spatial Durbin Model to study the spatial spillover effects of carbon emission intensity and high-quality economic development, supplementing the research on the relationship between carbon emissions and high-quality economic development. (2) In terms of the influencing mechanism, this paper introduces green technological innovation as a mediating variable, studying the impact path of carbon emissions on high-quality economic development, thereby deepening the existing literature.

Theoretical Hypothesis

The Nonlinear Impact of Carbon Emission Intensity on High-Quality Development

As Chinese socialism with distinctive characteristics enters a new era, the Chinese economy has transitioned from a phase of high-speed growth to one of high-quality development. The Economic Work Conference of China has highlighted that achieving peak carbon emissions and carbon neutrality is an intrinsic requirement for propelling high-quality development. There exists a "U-shaped" relationship between economic pressure and carbon emissions. While rapid economic growth leads to issues like overcapacity and environmental pollution as negative externalities, the singular pursuit of economic growth speed may erode the quality of economic growth [20]. Carbon emissions contribute to the full development of the economy, fostering equilibrium, yet they exhibit a significant negative impact on the economy's green development [30]. Carbon emission intensity has a non-linear "U-shaped" impact on high-quality economic development. Pressure for carbon reduction can stimulate environmental protection investments, thus propelling high-quality economic development [31]. Environmental inputs characterized by carbon emissions exhibit a "U-shaped" impact on high-quality economic development. Simultaneously, during the process of consumption upgrading, the marginal substitution rate of economic output demand for environmental demand declines [32]. Therefore, this paper proposes the following hypothesis:

H1: There exists a non-linear relationship between carbon emission intensity and high-quality economic development.

Spatial Spillover Effects of Carbon Emission Intensity on High-Quality Development

Many of the provinces with the highest carbon emissions in China are situated in economically developed coastal regions. There's a certain spatially positive autocorrelation in the distribution of carbon emissions among provinces. Additionally, there's a positive correlation between economic growth and carbon emissions, indicating a strong dependence of carbon emissions on economic growth [33]. There exists a coupled and coordinated relationship of mutual influence and constraint between carbon emission intensity and the level of high-quality economic development. Notably, the central Yangtze River city cluster exhibits significant spatial effects in the coupled coordination between carbon emission intensity and high-quality economic development [34]. The trend of the impact of carbon

emission intensity on high-quality economic development shifts from promoting to inhibiting, and there are spatial spillover effects between the carbon emission intensity in adjacent areas and the level of high-quality economic development [31]. Therefore, this paper proposes the following hypothesis:
H2: Carbon emission intensity will influence the level of high-quality economic development in adjacent areas through spatial spillover effects.

The Mediating Effect of Green Technological Innovation

Green technological innovation refers to technological advancements oriented towards ecological civilization. It possesses a dual nature, combining both traditional and innovative elements, representing an extension and enhancement of technological innovation. Jung et al. find that excessive carbon emissions leading to carbon taxation can incentivize enterprises to engage in green innovation to achieve emission reduction goals [35]. In order to achieve carbon peaking and carbon neutrality objectives, the Chinese government implemented a policy of carbon emission trading, significantly stimulating technological innovation among enterprises and increasing research and development investments in high-carbon industries [36]. Simultaneously, green development, as a fundamental requirement for high-quality development, has a positive long-term impact [37]. Green technological innovation can enhance the efficiency of natural resource utilization and reduce environmental pollution and ecological damage, thereby propelling high-quality economic development [38]. Consequently, this paper proposes the following hypothesis:
H3: Green technological innovation serves as a mediating factor between carbon emissions and high-quality development.

Research Design

Model Construction

Baseline Model

To examine the influence of carbon emission intensity on the level of high-quality economic development in cities, this paper constructs the following model:

$$Hqd_{i,t} = \beta_0 + \beta_1 Carbon_{i,t} + \beta_2 Control_{i,t} + \mu_i + \delta_i + \varepsilon_{i,t} \quad (1)$$

Wherein i and t, respectively, represent cities and years. The dependent variable Hqd signifies the level of high-quality economic development in cities. The primary explanatory variable, Carbon, denotes carbon emission intensity, while Control represents a series of city-level control variables. μ_i represents individual fixed effects of cities that do not vary over time, δ_i signifies time-fixed effects that do not vary across individual units, and $\varepsilon_{i,t}$ denotes the error term capturing random disturbances.

Spatial Panel Econometric Models

Spatial panel models encompass Spatial Autoregressive (SAR), Spatial Error (SEM), and Spatial Durbin Models (SDM). The Spatial Durbin Model is an extended form that combines both SAR and SEM models. The spatial effects of the dependent variable are not solely attributed to the independent variables themselves but also include the spillover effects of neighboring regions' explanatory variables. To further discuss the spatial spillover effects of carbon emission intensity on high-quality economic development, this paper constructs the following spatial econometric model:

$$\begin{aligned} Hqd_{i,t} = \beta_0 + \rho WHqd_{i,t} + \beta_1 Carbon_{i,t} + \varphi_1 WCarbon_{i,t} \\ + \beta_2 Control_{i,t} + \varphi_2 WControl_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \end{aligned} \quad (2)$$

Wherein represents the spatial regression coefficient (reflecting spatial spillover effects) and φ_1 and φ_2 stand for the coefficients of spatial lag variables, indicating the impact of neighboring regions' explanatory variables on the dependent variable in the focal area. W signifies the spatial weight matrix, and in this paper, a geographic distance standardized matrix is utilized for regression.

Variable Selection

Dependent Variable

In this study, the dependent variable is carbon emission intensity. Drawing from the research conducted by Cong et al. [27], the latest methodologies for Scope 1, Scope 2, and Scope 3 accounting are employed to calculate the total carbon emissions for each prefecture-level city. The calculation involves determining the total amount of carbon emissions for each prefecture-level city per year and computing carbon emissions per capita based on the ratio between the total carbon emission intensity and the resident population.

Explanatory Variable

In this study, the core explanatory variable is the level of high-quality economic development. Drawing from the measurement method proposed by Zhao et al. [24], an index system is constructed based on five dimensions: industrial structure, inclusive Total Factor Productivity (TFP), technological innovation, residents' living standards, and ecological environment. Principal Component Analysis (PCA) is utilized to measure the comprehensive, high-quality economic development index for each prefecture-level city. The specific construction method is illustrated in Table 1.

Intermediate Variables

Green Technological Innovation. This can be measured through various methods, including the quantity of green patent applications, the number of green patents granted, etc. In this study, the percentage of green patent

Table 1. Measurement Indicators for High-Quality Economic Development

Primary Indicator	Secondary Indicator	Tertiary Indicator	Indicator Attribute
High-Quality Economic Development Index	Industrial Structure	Upgrading of Industrial Structure	+
		Rationalization of Industrial Structure	-
		Proportion of Productive Service Industry	+
	Inclusive Total Factor Productivity (TFP)	Inclusive Total Factor Productivity (TFP) Index	+
	Technological Innovation	Innovation Index	+
	Ecological Environment	Sulfur Dioxide Removal Rate	+
		Comprehensive Utilization Rate of Industrial Solid Waste	+
		PM2.5	-
	Resident Living Standards	Per Capita GDP	+
		Per Capita Education Expenditure	+
		Number of Hospital Beds per Capita	+

applications compared to the total number of patents filed in the region annually is adopted as the measurement indicator for green technological innovation.

Control Variables

Building upon existing research [24, 31, 39, 40], this study selects control variables that may impact high-quality economic development. Specifically: (1) Industrial development level: Measured by the proportion of the value added in the secondary industry to the regional Gross Domestic Product (GDP). (2) Level of Financial Development: Indicated by the ratio of institutional loans and deposits to the regional GDP. (3) Degree of Government Intervention: Represented by the proportion of fiscal expenditures to the regional GDP, signifying the extent of government intervention. (4) Urbanization Rate: Represented by the ratio of the urban population to the regional population. (5) Population: Represented by the logarithm of the total registered population. (6) Human Capital: Indicated by the logarithm of educational expenditures.

Data Source and Descriptive Statistics

This study employs a balanced panel dataset comprising 284 prefecture-level cities in China from 2011 to 2021, totaling 3124 observations. The original data for each variable is derived from various statistical yearbooks, such as the "China Urban Statistical Yearbook," "China Environmental Statistical Yearbook," "China Energy Statistical Yearbook," and data from local statistical bureaus. The definition and calculation of variables are shown in Table 2, and descriptive statistics for each variable are presented in Table 3.

Results and Discussion

Baseline Regression Results

Table 4 presents the baseline regression results depicting the impact of carbon emission intensity on high-quality economic development. In Model (1), the coefficient of the core explanatory variable, carbon emission intensity, is significantly positive at the 1% level, confirming a positive influence of carbon emission intensity on the level of high-quality development in cities. However, in Model (2), the coefficient of the quadratic term of carbon emission intensity is significantly negative at the 5% level. This signifies that carbon emissions initially promote and subsequently restrain the level of high-quality economic development in cities, thus validating Hypothesis 1. As China's per capita production capacity continues to increase and industrialization and urbanization processes accelerate, substantial energy consumption and carbon

Table 2. Definitions and Explanations of the Variables.

Variable Types	Variable Name	Variable Symbol	Definitions of Variables
Explained Variables	High quality development	Hqd	High quality development index
Explanatory Variables	Carbon	Carbon	Total carbon emissions
Intermediate Variables	Green technological innovation	Innovation	Green patent application volume/the total number of patents applied for in the region
Control Variables	Industrial development level	Industry	Value added of the secondary industry/GDP
	Financial development level	Financial	Institutional deposit and loan balance/GDP
	Government intervention level	Government	Fiscal expenditure/GDP
	Urbanization rate	Urbanization	Urban population/total population of the region
	Population	Population	The natural log of registered population
	Human capital	Capital	The natural log of education expenditure

Table 3. Descriptive Statistical Results of Sample Variables.

Variables	Mean	Std. dev.	Min	Max
Hqd	0.335	0.113	0.063	0.815
Carbon	12.149	12.893	1.111	171.810
Innovation	0.133	0.058	0	0.872
Industry	45.428	11.000	10.680	89.340
Finance	2.523	1.223	0.588	21.301
Government	0.203	0.102	0.043	0.916
Urbanization	0.568	0.148	0.214	1.000
Population	5.892	0.698	2.970	8.136
Capital	13.173	0.789	9.906	16.256

Table 4. Baseline Regression Results

Variables	(1)	(2)
Carbon	0.00138***	0.00212***
	(0.000270)	(0.000441)
$Carbon^2$		-0.00000644**
		(0.00000293)
Industry	0.000671***	0.000673***
	(0.000127)	(0.000127)
Finance	0.00374**	0.00371**
	(0.00161)	(0.00161)
Government	0.0523***	0.0502***
	(0.0167)	(0.0168)
Urbanization	-0.0254	-0.0263
	(0.0189)	(0.0190)
Population	0.0449***	0.0494***
	(0.0117)	(0.0120)
Capital	0.00518	0.00553
	(0.00372)	(0.00373)
Constant	-0.0504	-0.0876
	(0.0768)	(0.0796)
Individual fixed effects	YES	YES
Time fixed effects	YES	YES
N	3124	3124
R^2	0.963	0.963
adj. R^2	0.959	0.959

Table 5. System GMM Regression Results

Variables	coefficient	Standard error	Z-Score
L.Hqd	0.379***	0.058	6.51
Carbon	0.008***	0.002	3.38
$Carbon^2$	-0.00004***	0.00001	-2.69
Control	YES	YES	YES
AR(1)	0.000		
AR(2)	0.120		
Hansen	0.123		

dioxide emissions are propelled. Consequently, the initial increase in carbon emission intensity may foster high-quality economic development. However, in the long run, issues stemming from carbon emissions, such as environmental pollution and human health hazards, pose threats to high-quality economic development.

Regarding the control variables, the industrial structure demonstrates a significant positive impact on high-quality economic development, indicating an increase in the level of urban high-quality development with the rise in the proportion of secondary industry. The coefficient value of financial development is significant at the 5% level, suggesting that a higher level of financial development facilitates the promotion of high-quality economic development in cities. Government intervention and population also exhibit positive impacts on urban high-quality economic development. Both urbanization rate and human capital are not statistically significant at the 10% level, suggesting their less apparent role in promoting the level of high-quality economic development in cities.

Robustness Test

In the aforementioned empirical tests, there might exist a reverse causal relationship between carbon emission intensity and high-quality economic development. On one hand, an increase in carbon emissions can affect high-quality economic development; on the other hand, high-quality economic development can also influence carbon emission intensity to a certain extent. This study conducted robustness tests on the model using the Generalized Method of Moments (GMM) proposed by Blundell and Bond [41]. Table 5 reports the regression results of the GMM estimation. The value of AR (1) is $0.000 < 0.05$, and the value of AR (2) is $0.120 > 0.05$, consistent with the assumption of no serial correlation in the GMM estimation. Additionally, the P-value of the Hansen test is 0.123, greater than 0.1, indicating that we cannot reject the null hypothesis that all instruments are valid, proving the effectiveness of the estimation. The coefficients of carbon emission intensity and its quadratic term in the dynamic panel data model are consistent with the baseline regression results and significant at the 1% level, indicating the robustness of the results obtained in this study.

Considering that there might be a lagged effect of carbon emission intensity on high-quality economic development, this study lagged the core explanatory variable by one period and re-estimated the baseline model. The regression estimation results are shown in Table 6.

Further Analysis

Spatial Spillover Analysis

Spatial Autocorrelation Test

Before conducting an analysis of spatial spillover effects, it is necessary to examine the spatial autocorrelation of carbon emission intensity and the

Table 6. Lagged Core Explanatory Variables Estimation Results

Variables	(1)	(2)
L.Carbon	0.00092***	0.00170***
	(0.000254)	(0.000419)
L.Carbon^2		-0.00000668***
		(0.00000234)
Control	YES	YES
Constant	0.061	0.015
	(0.076)	(0.078)
Individual fixed effects	YES	YES
Time fixed effects	YES	YES
N	2840	2840
R^2	0.964	0.964
adj. R^2	0.960	0.960

Table 7. Moran's I Test for Carbon Emission Intensity and High-Quality Economic Development from 2011 to 2021

Year	Carbon	Z-Score	Hqd	Z-Score
2011	0.031***	7.643	0.087***	17.665
2012	0.028***	7.017	0.086***	17.414
2013	0.027***	6.953	0.090***	18.342
2014	0.030***	7.486	0.089***	18.080
2015	0.034***	8.164	0.089***	18.065
2016	0.034***	8.222	0.093***	18.842
2017	0.037***	8.597	0.085***	17.270
2018	0.034***	7.927	0.090***	18.277
2019	0.033***	8.078	0.086***	17.442
2020	0.047***	10.425	0.090***	18.323
2021	0.042***	9.464	0.089***	18.090

Table 8. Test Results of Spatial Panel Models

Testing Method	Test Statistic	Statistical Value	P-value
LM test	Moran's I	27.505***	0.000
	LM	682.243***	0.000
	Roubst LM	328.468***	0.000
	LM-lag	472.663***	0.000
	Roubst-LM-lag	118.888***	0.000
LR test	LR_lag	50.74***	0.000
	LR_error	60.80***	0.000
Wald test	Wald_lag	49.89***	0.000
	Wald_error	59.32***	0.000
Hausman test	Hausman	317.38***	0.000

index of high-quality economic development. This study employed a geographical distance standardized matrix to calculate and analyze the global Moran's I index for each year. The results are presented in Table 7. From 2011 to 2021, both the carbon emission intensity and the index of high-quality economic development exhibited Moran's I indices at a significant level of 1% under the geographic matrix weight. This indicates the presence of spatial spillover effects among carbon emission intensity and the level of high-quality economic development across cities in China from 2011 to 2021.

Spatial Panel Model Selection

The results of the spatial autocorrelation test indicate a significant spatial spillover effect between carbon emission intensity and high-quality economic development. The next step involves selecting an appropriate spatial panel model for regression. The LM test, Wald test, LR test, and Hausman test results are presented in Table 8. It is evident from Table 8 that all the test results strongly reject the null hypothesis, suggesting that the Spatial Durbin Model under fixed effects should be adopted.

The Spatial Durbin Model under fixed effects encompasses spatial fixed, time fixed, and two-way fixed effects. To further determine which fixed effects model should be employed, this study conducted regressions for each of the three fixed effects models. The results indicate that the Spatial Durbin Model with spatial fixed effects is the optimal choice.

Spatial Durbin Model Regression Analysis

This study conducted estimations using a geographic distance standardized matrix and employed the Spatial Durbin Model under spatial fixed effects. Additionally, to compare the robustness of the estimations, the results of the spatial lag and spatial error models are also provided. As shown in Table 9, across the three spatial models, the coefficients and significance levels of both the carbon emission intensity and its quadratic term are generally consistent, validating the robustness of the results. Additionally, the coefficient of the spatial interaction term for carbon emission intensity is significantly positive, indicating a positive impact on the level of high-quality economic development in adjacent areas when there is an increase in carbon emission intensity in a particular city. However, as the carbon emission intensity continues to rise, this impact transitions from positive to negative.

The regression coefficients of the spatial panel model cannot entirely reflect the influence of carbon emission intensity on the level of high-quality economic development. Therefore, this study employs a method of solving variable partial derivatives to decompose spatial effects into direct and indirect effects. According to Table 10, the direct and indirect effect coefficients of carbon emission intensity are both significantly positive, indicating that in the short term, an increase in carbon emission intensity promotes high-quality economic

Table 9. Regression Results of Different Spatial Models under Spatial Fixed Effects

Variables	SDM	SAR	SEM
Carbon	0.002***	0.002***	0.002***
	(0.0004)	(0.0004)	(0.0004)
$Carbon^2$	-0.0000054**	-0.0000068***	-0.0000055**
	(0.0000026)	(0.0000026)	(0.0000026)
W_Carbon	0.013***		
	(0.0040)		
W_ $Carbon^2$	-0.0000973**		
	(0.0000418)		
ρ/λ	0.614***	0.851***	0.951***
	(0.0837)	(0.0297)	(0.0105)
Control	YES	YES	YES
R^2	0.650	0.639	0.281
Log-likelihood	7554.751	7533.156	7514.826

Table 10. Direct, Indirect, and Total Effects of Spatial Durbin Model (SDM)

Variables	Direct effect	Indirect effect	Total effect
Carbon	0.002***	0.040***	0.0422***
	(0.0004)	(0.0138)	(0.0138)
$Carbon^2$	-0.0000064**	-0.000273**	-0.000279**
	(0.0000027)	(0.00013)	(0.00013)

Table 11. Mediation Effect Test Results

Variables	(1)	(2)
Carbon	0.000551	0.00125**
	(0.000546)	(0.000617)
Control	NO	YES
Constant	0.126***	-0.092
	(0.007)	(0.128)
Individual fixed effects	YES	YES
Time fixed effects	YES	YES
N	3121	3121
R^2	0.485	0.489
adj. R^2	0.432	0.434

development in the local area and neighboring regions. However, as carbon emission intensity continues to increase, it negatively impacts the high-quality economic development in both the local and adjacent areas, validating Hypothesis 2. This may be attributed to the significant spatial dependency of carbon emission intensity across various regions in China. Regions with high carbon emission intensity are often surrounded by other regions with similarly high carbon emission intensity. The escalation of carbon emission intensity positively impacts the high-quality development level of neighboring regions. However, over the long term, the detrimental effects associated with the continuous increase in carbon emission intensity inhibit the level of high-quality economic development in urban areas.

Intermediary Effect Analysis

To test the mediating effect of green technological innovation in the process of carbon emission intensity affecting high-quality economic development, this study applies an established intermediary effects model for regression analysis. A considerable amount of literature has verified the impact of green technological innovation on high-quality economic development [41]. Therefore, this paper reports only the impact of carbon emission intensity on green technological innovation. The results in Table 11 show that when the dependent variable is green technological innovation, in the first column, the regression coefficient of carbon emission intensity on high-quality economic development is positive but not significant. In the second column, after incorporating control variables into the regression equation, the coefficient of carbon emission intensity becomes significant at the 5% level, indicating that the increase in carbon emission intensity promotes green technological innovation. This advancement drives the development of a green economy, consequently enhancing the level of high-quality economic development in urban areas, thereby validating Hypothesis 3.

Conclusion and Recommendations

This study utilizes panel data from 284 prefecture-level cities in China from 2011 to 2021, employing fixed effects models, spatial Durbin models, and mediation effect models to empirically examine the influence of carbon emission intensity on high-quality economic development and its underlying mechanisms. The study draws the following conclusions: (1) Carbon emission intensity exhibits an inverted “U-shaped” relationship with high-quality economic development. In the short term, an increase in carbon emission intensity can promote high-quality economic development. However, over the long term, heightened carbon emission intensity tends to restrain high-quality economic development. (2) Spatial spillover effects exist between regions in close geographic proximity. Higher carbon emission and energy consumption levels in neighboring areas can stimulate economic development in both the local and adjacent regions, thereby fostering high-quality economic development. Nevertheless, once carbon emission intensity surpasses a certain threshold, it tends to impede high-quality economic development due to issues such as environmental management costs. (3) Green technological innovation serves as a mediating factor in the process where carbon emission intensity affects high-quality economic development. The escalation in carbon emission intensity drives green technological innovation, advances the development of a green economy, and consequently elevates the level of high-quality economic development in urban areas.

Based on our research findings, we propose the following policy recommendations: (1) Strengthen cooperation among regions to jointly promote carbon reduction goals and enhance high-quality economic development. As carbon emission intensity not only affects local economic development but also influences neighboring regions, it is essential to leverage the spatial spillover effects of carbon emissions and high-quality economic development. This can be achieved by monitoring policy changes in adjacent areas and fostering technological and resource-sharing mechanisms to stimulate high-quality economic development in other regions. (2) Sustainably enhance the level of green technological innovation and fully leverage its driving force for high-quality economic development. Increasing policy support for green innovation development, offering corresponding tax incentives, and providing financial support can help reduce the costs associated with green technology development and application.

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Conflict of Interest

The authors declare no conflict of interest.

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