Vol. 19 (2026): Proceedings of 2026 International Conference on Financial Technology, Mathematical Statistics, and Business Analytics (ICFMB 2026)
E-ISSN: 3105-0522 P-ISSN: 3105-0514
DOI: https://doi.org/10.70267/icfmb.2026198399

Green Agricultural Development and Urban Carbon Emission Reduction: Evidence from China

Sixuan Xin*

Department of Agricultural Economics, College of Economics and Management, Nanjing Agricultural University, Nanjing 210095, China

**Corresponding author: Sixuan Xin.*

Abstract

Against the backdrop of global climate warming and China's "dual carbon" goals, exploring the impact of green agricultural development on urban carbon emissions is of great significance for synergistically promoting agricultural green transformation and climate governance. Taking the establishment of National Agricultural Green Development Pilot Zones as a quasi-natural experiment, this study employs panel data from 288 cities in China from 2015 to 2023 and applies the multi-period difference-in-differences (DID) method to evaluate the impact of green agricultural development on urban carbon emissions. The results show that green agricultural development significantly reduces urban carbon emissions, and this finding remains robust after a series of robustness and endogeneity tests. Mechanism tests indicate that green agricultural development achieves carbon emission reduction by reducing agricultural fertilizer application, promoting the development of digital inclusive finance, and enhancing rural innovation and entrepreneurship. Heterogeneity analysis reveals that the effect is influenced by geographical location, topographic conditions, economic development level, and agricultural production functional zones. This paper provides important policy implications for green agricultural development policies, agricultural transformation, and urban carbon emission reduction in developing countries.

Keywords

green agriculture, urban carbon emissions, multi-period difference-in-differences method

1. Introduction

Global climate warming has become one of the most severe environmental challenges facing human society. The Paris Agreement has prompted countries to incorporate carbon emission reduction actions into their Nationally Determined Contributions. As one of the world's largest carbon emitters, China explicitly proposed in 2020 the strategic goal of "achieving carbon peaking by 2030 and carbon neutrality by 2060." In this context, how to effectively reduce carbon emissions has become a major practical issue that China urgently needs to address.

Existing studies have found that factors such as economic development [1,2,3,4], technological innovation [5,6], and environmental regulation [7,8] can effectively promote carbon emission reduction. However, current research on the influencing factors of carbon emission reduction has largely focused on the industrial sector or the urban socio-economic level, with relatively few studies examining the impact of agricultural development on urban carbon emissions. In addition, existing research indicates that agricultural development has significant effects on the ecological environment [9,10] and social well-being [11,12,13]. Nevertheless, the existing literature has not yet linked green agricultural development with urban carbon emissions. In developing countries, there remains a lack of systematic theoretical explanations and causal evidence regarding whether and how green agricultural development affects urban carbon emissions.

To address this core issue, this paper focuses on the impact of green agricultural development on urban carbon emissions. Taking the establishment of national agricultural green development pilot zones across cities as a quasi-natural experiment, it utilizes panel data from 288 Chinese cities from 2015 to 2023 and employs the multi-period difference-in-differences method for empirical testing. The results show that green agricultural development significantly reduces urban carbon emissions, and this conclusion remains valid after a series of robustness and endogeneity tests. Mechanism analysis indicates that green agricultural development reduces urban carbon emissions by decreasing agricultural fertilizer application, promoting the development of digital inclusive finance, and improving rural innovation and entrepreneurship levels. Heterogeneity analysis further reveals that the effect is more pronounced in eastern regions, cities with flat terrain, cities with high levels of economic development, and major grain-producing areas.

The marginal contributions of this paper are mainly reflected in the following three aspects. First, by leveraging the exogenous policy shock generated by the phased establishment of national agricultural green development pilot zones, this study identifies the effect of green agricultural development on urban carbon emission reduction. The use of the multi-period difference-in-differences method effectively addresses endogeneity issues and enhances the credibility of causal identification. Second, it systematically uncovers three transmission channels—reduction in agricultural fertilizer use, development of digital inclusive finance, and improvement in rural innovation and entrepreneurship—thereby deepening the theoretical understanding of the carbon emission reduction effect of green agricultural development. Third, by grouping cities according to geographical location, topographic conditions, economic development level, and agricultural production functional zones, the study reveals the heterogeneity of the carbon emission reduction effect of green agricultural development, providing empirical support for optimizing pilot zone construction according to local conditions and achieving synergistic agricultural green transformation and carbon emission reduction.

2. Literature Review and Research Hypotheses

2.1 Green Agriculture and Its Impacts

Green agricultural development was initially proposed as a modern agricultural development model aimed at achieving sustainable development in economic, social, and ecological dimensions, while promoting the greening of the entire process of agricultural production, ecology, and rural life [14,15]. In theoretical terms, it serves as both a means and an end of agricultural development [16].

Green agricultural development exerts multidimensional positive impacts on agricultural production, the ecological environment, and social well-being. First, green agriculture can enhance total factor productivity and promote agricultural economic growth, thereby advancing agricultural modernization [17]. Second, green agriculture plays a significant role in carbon emission reduction and pollution control. By reducing the application of chemical fertilizers and pesticides, it effectively mitigates soil and water pollution [9]. It also promotes soil carbon sequestration and suppresses carbon release through the regulation and maintenance of agricultural ecosystems [10]. Finally, green agriculture is regarded as an important pathway to promote common prosperity for farmers and rural areas. It not only directly increases farmers' income but also creates more non-agricultural employment opportunities and channels for property income by extending agricultural industrial chains and expanding the multifunctionality of agriculture, thereby effectively narrowing the income gap between urban and rural areas as well as within rural regions [11,12,13].

2.2 Carbon Emission Reduction and Its Influencing Factors

Carbon emissions primarily refer to the release of carbon dioxide into the atmosphere, originating from a wide range of sources, including fossil fuel combustion, agricultural and industrial processes, biological respiration, and other natural and anthropogenic activities [18]. Greenhouse gases such as carbon dioxide drive global warming and climate change and constitute the core driving force of the climate crisis [19,20].

Regarding the influencing factors of carbon emissions, existing studies have systematically examined them from multiple dimensions, including economic development, technological innovation, and environmental regulation. From the perspective of economic development, population growth is generally considered an important factor exacerbating carbon emissions, while the impact of economic affluence on carbon emissions exhibits an inverted U-shaped relationship [1,2]. In addition, factors such as capital investment, energy structure, and technological conditions in specific industries (e.g., transportation and logistics) also significantly affect carbon emission levels, highlighting the importance of developing differentiated emission reduction strategies for specific sectors [3]. Finally, the structure of trade networks within global supply chains has a significant impact on national carbon emissions; optimizing trade relations and reducing domestic consumption can help lower the overall carbon footprint [4].

From the perspective of technological innovation, it accelerates industrial low-carbon transformation by promoting virtual agglomeration and adjusting industrial structure [5], with a particularly pronounced effect in high-income countries [6]. From the perspective of environmental regulation, two differing views exist regarding its impact on carbon emissions: linear effects [7] and non-linear effects [8].

2.3 Theoretical Analysis and Research Hypotheses

2.3.1 The Direct Impact of Green Agricultural Development on Regional Carbon Emission Reduction

As an important policy pilot for promoting comprehensive green transformation in agriculture, the National Agricultural Green Development Pilot Zones inherently contain the internal logic of reducing carbon emissions in their policy design. The policy explicitly aims to achieve “intensive resource utilization, reduced input of production materials, resource utilization of waste, and ecological industrial models,” thereby driving the transformation of agricultural production toward low-carbon practices.

From the perspective of green agricultural philosophy, the policy emphasizes cultivating green socialized service organizations and new types of agricultural operators, using demonstration effects to generate scale effects in carbon emission reduction. From the perspective of green agricultural production methods, the promotion of fertilizer reduction, soil testing and formulated fertilization, and green pest control technologies directly reduces carbon emissions from agricultural production. From the perspective of green agricultural production technologies, pilot zones accelerate the upgrading of agricultural machinery and equipment and promote the development of green agricultural technologies, which will effectively reduce the use of chemical inputs in agricultural activities and consequently lower the carbon emissions generated by them.

In summary, the following hypothesis is proposed:

Hypothesis H1: Green agricultural development can significantly reduce regional carbon emissions.

2.3.2 Indirect Mechanisms of Green Agricultural Development on Regional Carbon Emissions

(1) Mechanism of Reducing Agricultural Fertilizer Application

The National Agricultural Green Development Pilot Zones policy promotes the reduction of agricultural fertilizer application from multiple dimensions. First, fertilizer reduction is incorporated into the performance evaluation system of the pilot zones, creating a binding constraint on excessive fertilizer use. Second, pilot zones promote the resource utilization of livestock and poultry manure through integrated crop-livestock farming, increasing the supply of organic fertilizer and directly reducing chemical fertilizer application through substitution effects [21]. Third, pilot zones rely on soil testing and formulated fertilization technologies to precisely match fertilizer types and quantities, thereby improving nutrient use efficiency and reducing fertilizer application at the source.

In agricultural activities, fertilizer application is an important source of greenhouse gas emissions [22]. The reduction in agricultural fertilizer use directly lowers carbon emissions from fertilizer production and transportation, while also reducing greenhouse gas emissions from farmland soils, thereby exerting a positive reduction effect on overall regional carbon emissions. Based on this, the following hypothesis is proposed:

Hypothesis H2: Green agricultural development can reduce agricultural fertilizer application, thereby decreasing regional carbon emissions.

(2) Mechanism of Digital Inclusive Finance Development

Digital inclusive finance has developed rapidly under the impetus of the pilot zone policy and effectively reduces regional carbon emissions through the promotion of green technologies and the guiding role of financial resources. The pilot zone policy has created favorable conditions for the development of digital inclusive finance. On the one hand, the construction of pilot zones requires substantial financial support for the promotion of green agricultural technologies and equipment upgrading, providing digital inclusive finance with a broader rural market [23]. On the other hand, the policy explicitly requires the innovation of green agricultural credit services and the application of digital technologies such as big data and cloud computing in agriculture, laying a technological foundation for the penetration and popularization of digital inclusive finance.

From the perspective of emission reduction mechanisms, digital inclusive finance leverages big data technology to effectively alleviate information asymmetry, precisely allocate financial resources to green and low-carbon industries, and guide capital flows toward efficient and low-consumption production sectors [24,25]. At the same time, it lowers financing thresholds to support enterprises in conducting green technology research and development, thereby promoting the adoption and application of energy-saving and carbon-reduction technologies [26]. Based on this, the following hypothesis is proposed:

Hypothesis H3: Green agricultural development can enhance the development level of regional digital inclusive finance, thereby reducing regional carbon emissions.

(3) Mechanism of Promoting Rural Innovation and Entrepreneurship

Innovation and entrepreneurship are of great significance to social development. The pilot zone policy improves the level of rural innovation and entrepreneurship from two dimensions: subject cultivation and factor agglomeration. In terms of subject cultivation, it encourages cooperatives, family farms, and leading enterprises to engage in green production and apply emission reduction technologies, creating green and low-carbon benchmark enterprises and stimulating rural innovation and entrepreneurship vitality. In terms of factor agglomeration, it encourages pilot zones to formulate special preferential policies to pool funds, technology, and talent, providing sustained support for rural innovation and entrepreneurship.

Rural innovation and entrepreneurship, in turn, reduce regional carbon emissions through two pathways: innovation-driven and entrepreneurship-driven mechanisms. From the innovation-driven pathway, technological innovation can improve energy utilization efficiency and accelerate industrial structure upgrading [27]. It also promotes the transformation of agriculture toward high-efficiency and clean production through patent technology development and the application of green inputs [28], thereby achieving carbon emission reduction. From the entrepreneurship-driven pathway, entrepreneurial activities promote the flow of production factors toward high-efficiency sectors through the creation of new enterprises and industrial agglomeration, optimizing resource allocation efficiency and effectively reducing carbon emissions [27]. Based on this, the following hypothesis is proposed:

Hypothesis H4: Green agricultural development can enhance the level of rural innovation and entrepreneurship, thereby reducing regional carbon emissions.

3. Research Design

3.1 Variable Selection

3.1.1 Dependent Variable

The primary dependent variable in this study is urban carbon emissions (lnCE), which includes energy consumption and emissions from agriculture, industry, transportation, construction, and other sectors in each city. The data are extracted from the Emissions Database for Global Atmospheric Research (EDGAR). All variables are logarithmically transformed and multiplied by 100 for scaling.

3.1.2 Core Explanatory Variable

The core explanatory variable is the level of green agriculture (did). The establishment of China's National Agricultural Green Development Pilot Zones provides a suitable quasi-natural experiment. Therefore, this variable is measured by whether a city is included in the list of National Agricultural Green Development Pilot Zones. If a city is selected as a pilot zone, the variable takes the value of 1 in that year and all subsequent years; otherwise, it takes the value of 0. In addition, following previous studies on pilot zone designation [21,29], a city is considered a National Agricultural Green Development Pilot Zone if the city itself or any county/district under its jurisdiction is included in the pilot zone list.

3.1.3 Control Variables

To reduce estimation bias caused by omitted variables and accurately identify the effect of green agricultural development, this study controls for a series of urban basic characteristics and other factors that may influence urban carbon emissions, drawing on existing literature [30,31,32]. The specific control variables are as follows:

(1) Logarithm of regional gross domestic product (lnGRP);

(2) Population density (lnDEN), measured as the logarithm of the ratio of urban registered population to the administrative land area;

(3) Fiscal investment intensity (lnFIN), measured as the logarithm of the ratio of fixed asset investment to general government fiscal expenditure;

(4) Industrial structure (lnIS), measured as the logarithm of the ratio of the added value of the tertiary industry to regional GDP;

(5) Human capital level (lnEDU), measured as the logarithm of the ratio of students enrolled in regular higher education institutions to the total population at the end of the year;

(6) Social consumption level (lnCONS), measured as the logarithm of the ratio of total retail sales of consumer goods to regional GDP;

(7) Urbanization rate (lnURB), measured as the logarithm of the ratio of urban permanent residents to the total population.

3.1.4 Mechanism Variables

The mechanism variables are defined as follows:

(1) Agricultural fertilizer application (lnFI) refers to the total amount of chemical fertilizer actually applied in agricultural production within the city, calculated in pure nutrient terms (nitrogen, phosphorus pentoxide, and potassium oxide) and then logarithmically transformed.

(2) Digital Inclusive Finance Index (DIFI) is taken from the Peking University Digital Inclusive Finance Index published by the Digital Finance Research Center of Peking University [33].

(3) China Rural Innovation and Entrepreneurship Index (CREI) uses the overall index from the "China Rural Innovation and Entrepreneurship Index" released by the China Academy for Rural Development at Zhejiang University [28].

3.2 Model Construction

3.2.1 Baseline Model

The National Agricultural Green Development Pilot Zones policy represents an exogenous policy shock and can be regarded as a quasi-natural experiment. This study employs the multi-period difference-in-differences (DID) method to evaluate the impact of green agricultural development on urban carbon emissions. A two-way fixed effects model is specified as follows:

$$\mathrm{lnCE}_{it}=c_1+c_2\mathrm{did}_{it}+c_3Z_{it}+v_i+\mu_t+\varepsilon_{it} \quad (1)$$

In Equation (1), lnCE_{it} is the dependent variable, representing the logarithm of carbon emissions in city i in year t; did_{it} is the core explanatory variable (the green agriculture level), a dummy variable indicating whether city i is a pilot zone in year t; Z_{it} represents a series of control variables that vary over time and may affect urban carbon emissions; v_i denotes city fixed effects; μ_t denotes year fixed effects; ε_{it} is the random disturbance term; and c_1 is the intercept term. The coefficient c_2 is the key parameter of interest.

3.2.2 Parallel Trends Test

To test the parallel trends assumption for the carbon emission reduction effect of the National Agricultural Green Development Pilot Zones policy, the following model is specified:

$$\mathrm{lnCE_{it}}=\alpha_0+\sum_{k=-5}^{k=5}\alpha_k\times \mathrm{D}_{i,t_0+k}+\alpha_1\mathrm{Z_{it}}+\nu_i+\mu_t+\varepsilon_{it} \quad (2)$$

In Equation (2), D_{i,t_0+k} is a dummy variable representing the k-th year since the establishment of the National Pilot Zone for Green Agricultural Development. Specifically, t_0 denotes the first year city i was designated as a pilot zone, and k represents the number of years following that designation. α_0 is the intercept term. The parallel trend test focuses on the values of α_k, which reflect the differences in the gap in urban carbon emissions between pilot and non-pilot cities in the k-th year after the policy implementation.

3.2.3 Mechanism Test Model

To examine the mechanisms through which green agricultural development affects urban carbon emissions, this study adopts a two-step approach following Jiang (2024) [34]. The mechanism test models are specified as follows:

$$\mathrm{M_{it}}=\beta_1+\beta_2\mathrm{did_{it}}+\beta_3\mathrm{Z_{it}}+\nu_i+\mu_t+\varepsilon_{it} \quad (3)$$

where $\mathrm{M_{it}}$ represents the mechanism variables, specifically agricultural fertilizer application (lnFI), the Digital Inclusive Finance Index (DIFI), and the China Rural Innovation and Entrepreneurship Index (CREI). In Equation (3), the primary focus is on the sign and magnitude of the coefficient β_2. A positive value indicates that green agricultural development has a promotive effect on the mechanism variable, whereas a negative value suggests an inhibitory effect. According to theoretical expectations, green agricultural development reduces urban carbon emissions by decreasing agricultural fertilizer application (thus lowering greenhouse gas emission intensity in agricultural production), enhancing digital inclusive finance to guide capital flows and support green technology R&D, and improving rural innovation and entrepreneurship to foster green production entities and low-carbon business models.

3.3 Data Sources and Preprocessing

The research sample includes 288 cities in China, of which 132 cities were included in the National Agricultural Green Development Pilot Zones list. The study period spans from 2015 to 2023, yielding a total of 2,592 observations. Raw data for city-level variables are mainly sourced from the China City Statistical Yearbook and the China Rural Statistical Yearbook. Urban carbon emission data are obtained from the Emissions Database for Global Atmospheric Research (EDGAR). The Digital Inclusive Finance Index comes from the Digital Finance Research Center of Peking University, and the China Rural Innovation and Entrepreneurship Index is from the China Academy for Rural Development at Zhejiang University. A small number of missing values are imputed using linear interpolation. In addition, the dependent variable and control variables are winsorized at the 1% level on both tails to mitigate the influence of extreme values on estimation results.

3.4 Descriptive Statistical Analysis

The descriptive statistics of the variables are presented in Table 1. The dependent variable, urban carbon emissions (lnCE), has a minimum value of 1,455.568, a maximum value of 1,900.818, and a mean of 1,699.464, indicating noticeable differences in carbon emissions across cities. However, the overall distribution shows no extreme skewness, suggesting good representativeness of the data. The core explanatory variable, green agriculture level (did), has a mean of 0.174, indicating that approximately 17.4% of the observations are in the post-implementation period of the pilot zone policy. All variables passed the multicollinearity test, with Variance Inflation Factor (VIF) values less than 5, indicating no serious multicollinearity issues among the variables.

Table 1: Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
lnCE	2592	1699.464	93.788	1455.568	1900.818
did	2592	0.174	0.380	0.000	1.000
lnGRP	2592	16.799	0.947	14.737	19.411
lnDEN	2592	1.849	0.619	0.196	3.241
lnFIN	2592	0.380	0.059	0.244	0.550
lnIS	2592	0.021	0.025	0.001	0.117
lnEDU	2592	0.329	0.078	0.142	0.535
lnCONS	2592	0.465	0.086	0.274	0.670
lnURB	2592	5.737	0.938	2.328	7.564

4. Empirical Analysis

The baseline regression results indicate that green agricultural development significantly reduces urban carbon emissions. Subsequently, this study verifies the robustness of the baseline results through four robustness tests (placebo test, exclusion of special values, adjustment of the study period, and variable replacement) and three endogeneity tests (PSM-DID, lagged explanatory variable, and alternative estimation model).

4.1 Baseline Regression

The baseline regression results of the impact of green agricultural development on urban carbon emissions are presented in Table 2. Column (1) controls only for city fixed effects and year fixed effects, without including control variables. Column (2) adds all control variables based on Column (1). Column (3) further incorporates clustered standard errors. In Column (3), the coefficient of the core explanatory variable did is -2.233, which is significant at the 5% level. This indicates that green agricultural development can significantly reduce urban carbon emissions, confirming Hypothesis H1.

Table 2: Baseline Regression Results

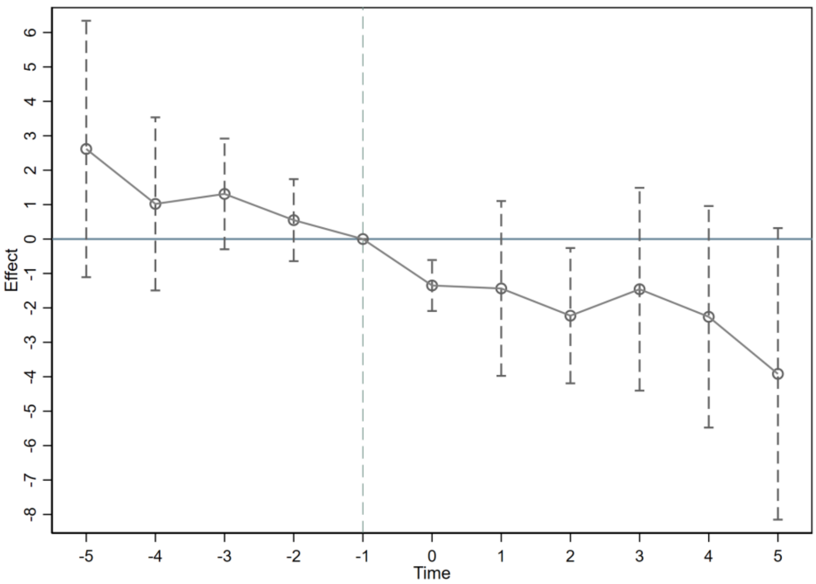
	(1)	(2)	(3)
Variables	lnCE	lnCE	lnCE
did	-2.190***	-2.233***	-2.233**
	(-2.914)	(-2.981)	(-1.990)
lnGRP		4.512***	4.512
		(2.699)	(1.618)
lnFIN		0.034	0.034
		(0.042)	(0.020)
lnIS		-33.021***	-33.021
		(-3.752)	(-1.488)
lnEDU		-82.670*	-82.670
		(-1.753)	(-1.636)
lnCONS		1.240	1.240
		(0.254)	(0.134)
lnURB		-8.229	-8.229
		(-0.811)	(-0.605)
lnDEN		-0.441	-0.441
		(-0.080)	(-0.058)
Cons	1699.846***	1644.235***	1644.235***
	(7551.191)	(41.988)	(27.882)
Control	No	Yes	Yes
City_FE	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes
N	2592	2592	2592
R^2	0.991	0.991	0.991

*Note: ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively; t-statistics are indicated in parentheses; the below table is the same.*

4.2 Parallel Trends Test

The parallel trends assumption is a key prerequisite for the multi-period difference-in-differences method, requiring that pilot and non-pilot cities exhibit parallel trends in urban carbon emissions prior to policy implementation. Taking the period before policy implementation as the base period, this study examines the dynamic differences in carbon emissions between the treatment and control groups within five periods before and after policy implementation. The results are shown in Figure 1. The coefficients for all pre-treatment periods are statistically insignificant, indicating that the differences between the treatment and control groups were stable before the policy. The estimated coefficients for the year of policy implementation and the second year after implementation are significantly negative, satisfying the parallel trends assumption.

Figure 1: Results of the Parallel Trends Test



Note: Hollow circles represent estimated coefficients; dashed lines indicate 90% confidence intervals. Control variables are the same as those in the baseline regression.

4.3 Robustness Tests

4.3.1 Placebo Test

Following Tang et al. [35], and considering that unobserved city-year-level factors may still affect the estimation results, this study conducts a placebo test by randomly assigning fictitious treatment cities and shock years. The fictitious core explanatory variable $did1_{it}$ is used to replace did_{it} in Equation (1) for regression. Figure 2 plots the distribution of estimated coefficients from 500 random sampling iterations. The results show that the estimated coefficients of the fictitious variable are concentrated around zero, with most p-values greater than 0.1. The vertical dashed line representing the true estimated coefficient lies to the right of most fictitious estimates, indicating that the baseline results are unlikely to be driven by unobserved city-year-level factors.

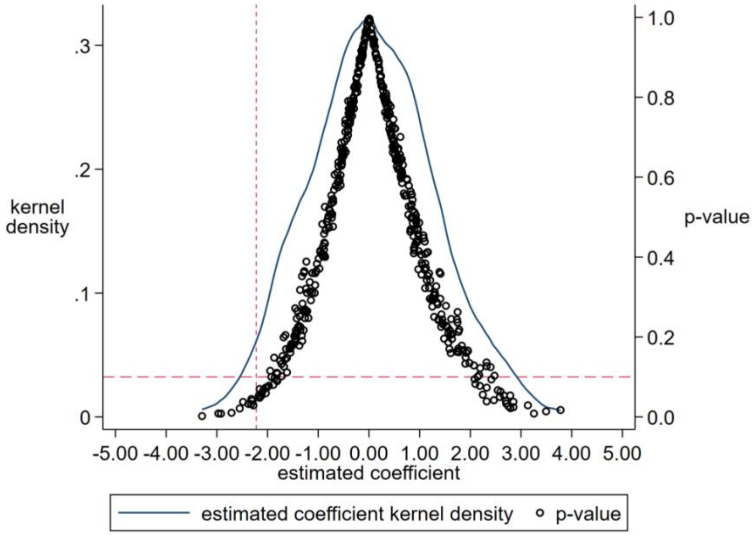
4.3.2 Other Robustness Tests

To further enhance the robustness of the baseline regression and rule out the influence of other confounding factors, this study conducts a series of additional robustness tests. The results are reported in Table 3.

(1) Exclusion of special values. Considering that municipalities directly under the central government and provincial capital cities differ significantly from prefecture-level cities in administrative hierarchy, policy resource access, and economic development level, which may interfere with the estimation of green

agricultural development effects, these cities are excluded from the sample. The result remains significantly negative at the 5% level, as shown in Column (1) of Table 3.

Figure 2: Placebo Test



(2) Adjustment of the study period. To exclude the influence of different time windows, the study period is shortened. First, the period is adjusted to 2017–2023; the result is significantly negative at the 1% level (Column (2)). Second, the period is adjusted to 2015–2021; the result is significantly negative at the 10% level (Column (3)).

(3) Variable replacement. To rule out the influence of variable measurement methods, both the dependent variable and core explanatory variable are replaced. First, the dependent variable is replaced with urban carbon emission intensity (lnCEI), defined as the logarithm of the ratio of total carbon emissions to regional GDP. The result is significantly negative at the 1% level (Column (4)). Second, the assignment of the core explanatory variable is adjusted by considering a one-year lag in policy effect; the result is significantly negative at the 10% level (Column (5)). Third, the fourth batch of pilot zones established in 2023 is excluded; the result remains significantly negative at the 5% level (Column (6)).

As shown in Table 3, the impact of green agricultural development on urban carbon emissions remains significantly negative across all tests, confirming the robustness of the baseline regression results.

Table 3: Robustness Test Results

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	lnCE	lnCE	lnCE	lnCEI	lnCE	lnCE
did	-2.136**	-2.304***	-1.290*	-0.015***	-1.607*	-1.823**
	(-2.386)	(-2.605)	(-1.865)	(-2.870)	(-1.772)	(-2.085)
Cons	1598.852***	1594.152***	1677.930***	8.595***	1644.822***	1644.814***
	(41.681)	(31.141)	(51.914)	(28.040)	(46.312)	(46.238)
Control	Yes	Yes	Yes	Yes	Yes	Yes
City_FE	Yes	Yes	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes	Yes	Yes
N	2322	2016	2016	2583	2592	2592
R^2	0.990	0.993	0.994	0.984	0.991	0.991

4.4 Endogeneity Tests

4.4.1 PSM-DID Test

The establishment of National Agricultural Green Development Pilot Zones is not entirely random and may be influenced by human factors, potentially leading to endogeneity due to “selection bias” between the core explanatory variable (did) and the error term. Therefore, this study employs the Propensity Score Matching-

Difference-in-Differences (PSM-DID) method to address selection bias. Following previous studies [23], kernel matching is used, with all control variables as covariates. The matching results show that the standardized bias of all covariates is less than 10%, and the t-test results are insignificant for all covariates except lnURB. The regression results after matching are presented in Column (1) of Table 4, indicating that the conclusion remains robust.

4.4.2 Lagged Explanatory Variable

Although the regression results suggest that green agricultural development reduces urban carbon emissions, a potential two-way causal relationship may exist. Cities with lower carbon emissions may have better foundational conditions for green agricultural development and thus be more likely to be selected as pilot zones. To mitigate this reverse causality concern, the core explanatory variable is lagged by one period. As shown in Column (2) of Table 4, the coefficient of the one-period lagged green agriculture level (L.did) is -1.548, which is significant at the 10% level.

4.4.3 Alternative Estimation Model

When policy shocks have heterogeneous effects across individuals, traditional two-way fixed effects (TWFE) estimators may suffer from estimation bias [36]. To address this potential issue, this study further adopts the Sun and Abraham (2020) SA estimator for dynamic effect estimation. This estimator effectively corrects for bias caused by treatment effect heterogeneity. As shown in Figure 3 and Column (3) of Table 4, the SA estimator yields a coefficient of -2.342, which is significant at the 10% level. The result is close to the baseline regression and passes the parallel trends test, further confirming the robustness of the conclusions.

Figure 3: Parallel Trends Test Using the SA Estimator

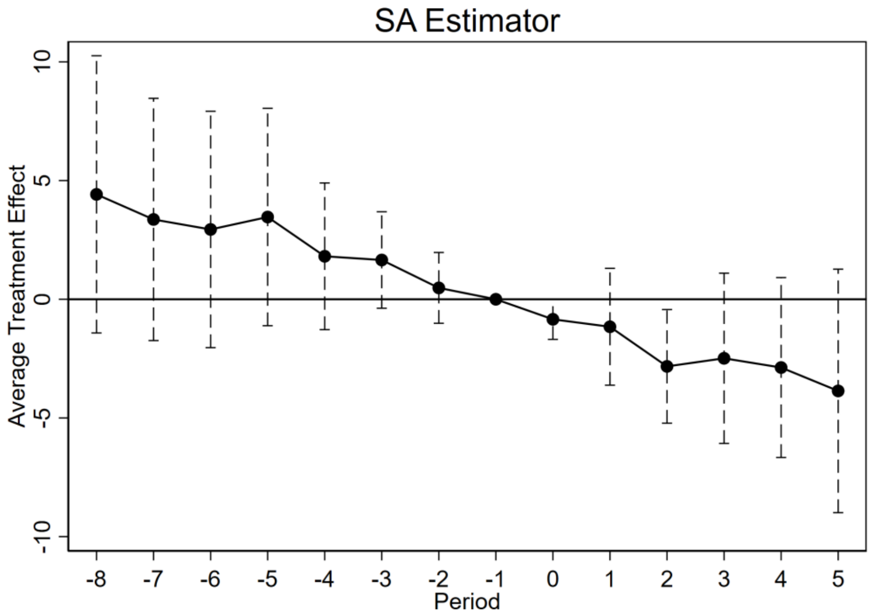


Table 4: Endogeneity Test Results

Variables	(1)	(2)	(3)
	lnCE	lnCE	lnCE
did	-2.278**		-2.342*
	(-2.005)		(-1.880)
L.did		-1.548*	
		(-1.673)	
Cons	1646.348***	1648.655***	/
	(27.294)	(38.640)	/
Control	Yes	Yes	Yes
City_FE	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes
N	2554	2304	2592

R^2	0.991	0.992	/

5. Mechanism Tests

This study argues that green agricultural development reduces urban carbon emissions through three channels: reducing agricultural fertilizer application, improving the development level of digital inclusive finance, and enhancing rural innovation and entrepreneurship.

5.1 Mechanism of Reducing Agricultural Fertilizer Application

The pilot zone policy can reduce agricultural fertilizer application by increasing the supply of organic fertilizer and promoting soil testing and formulated fertilization technology. Therefore, a regression is conducted on agricultural fertilizer application. The results are shown in Column (1) of Table 5. The coefficient is -0.021 and significant at the 5% level, indicating that green agricultural development can significantly reduce agricultural fertilizer application. Fertilizer application is one of the important sources of carbon emissions in agricultural activities. Its reduction directly lowers greenhouse gas emissions during agricultural production [37], thereby reducing urban carbon emissions. Hypothesis H2 is thus verified.

5.2 Mechanism of Digital Inclusive Finance Development

The pilot zone policy provides a broad rural market and lays a technological foundation for the development of digital inclusive finance, thereby promoting its growth. A regression is conducted on the Digital Inclusive Finance Index. The results are shown in Column (2) of Table 5. The coefficient is 1.585 and significant at the 1% level, indicating that green agricultural development promotes the development of digital inclusive finance. The development of digital inclusive finance effectively guides capital flows toward green and low-carbon industries and supports enterprises in conducting green technology research and development by lowering financing thresholds [24,25,26], thereby significantly reducing urban carbon emissions. Hypothesis H3 is thus verified.

5.3 Mechanism of Promoting Rural Innovation and Entrepreneurship

The pilot zone policy improves the level of rural innovation and entrepreneurship through subject cultivation and factor agglomeration. A regression is conducted on the level of rural innovation and entrepreneurship. The results are shown in Column (3) of Table 5. The coefficient is 0.554 and significant at the 10% level, indicating that green agricultural development has a positive effect on rural innovation and entrepreneurship. The improvement in rural innovation and entrepreneurship helps drive the transformation of production methods toward low-carbon practices, promotes efficient resource utilization, and advances sustainable development [27,28,38], thereby achieving urban carbon emission reduction. Hypothesis H4 is thus verified.

Table 5: Mechanism Test Results

Variables	(1)	(2)	(3)
	lnFI	DIFI	CREI
did	-0.021**	1.585***	0.554*
	(-2.415)	(4.089)	(1.883)
Cons	15.377***	18.149	7.435
	(13.607)	(0.718)	(0.461)
Control	Yes	Yes	Yes
City_FE	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes
N	2355	2576	2421
R^2	0.990	0.991	0.880

6. Heterogeneity Analysis

6.1 Heterogeneity Analysis by Geographical Location

Considering that cities in different geographical locations differ in economic development level, resource endowment, and degree of agricultural modernization, the sample is divided into eastern and central-western regions for grouped regressions. The results are shown in Columns (1) and (2) of Table 6. The results show that the impact of green agricultural development on urban carbon emissions is significantly negative in the eastern region, while it is negative but insignificant in the central-western region. This indicates that the carbon emission reduction effect of green agriculture is heterogeneous across regions and is stronger in eastern cities. The eastern region has a stronger economic foundation and greater fiscal capacity, enabling it to provide sufficient financial support for green agricultural development and effectively implement green technologies and infrastructure upgrades. In contrast, the central-western region faces fiscal constraints and infrastructure limitations, which may cause a time lag in the effectiveness of green agricultural development.

6.2 Heterogeneity Analysis by Topographic Conditions

Topographic conditions are an important factor affecting agricultural production methods and the promotion of green technologies. The impact of green agricultural development on urban carbon emissions may vary under different topographic conditions. Cities are divided into two groups based on terrain ruggedness. The grouped regression results are shown in Columns (3) and (4) of Table 6. The estimated coefficient of green agriculture level is significantly negative in the flat terrain group, while it is negative but insignificant in the rugged terrain group. This indicates that the carbon emission reduction effect of green agriculture is heterogeneous across cities with different terrains and is stronger in cities with flat terrain. Cities with flat terrain are more conducive to agricultural mechanization and large-scale operations, allowing better promotion and application of green agricultural technologies and reducing carbon emissions in the production process. In contrast, rugged terrain increases the difficulty of promoting green technologies and infrastructure construction, thereby limiting the carbon emission reduction effect of green agriculture.

6.3 Heterogeneity Analysis by Economic Development Level

Economic development level is a key factor affecting local governments' fiscal capacity and policy implementation effectiveness. The impact of green agricultural development on urban carbon emissions may differ depending on the level of economic development. Cities are divided into two groups based on annual regional GDP from 2015 to 2023. The grouped regression results are shown in Columns (1) and (2) of Table 7. The estimated coefficient of green agriculture level is significantly negative in the high-economic-level group, while it is negative but insignificant in the low-economic-level group. This indicates that the carbon emission reduction effect of green agriculture is heterogeneous across cities with different economic development levels and is stronger in high-economic-level cities. Cities with high economic development have better agricultural infrastructure, sufficient green technology reserves, stronger policy implementation capacity, and tend to place greater emphasis on ecological environmental protection, resulting in higher initiative and effectiveness in green agricultural development.

6.4 Heterogeneity Analysis by Agricultural Production Functional Zones

China's major grain-producing areas and non-major grain-producing areas undertake different missions in agricultural production. The impact of green agricultural development on urban carbon emissions may vary depending on the agricultural production functional zone. The sample is divided into major grain-producing areas and non-major grain-producing areas based on whether the province to which the city belongs is a major grain-producing province. The grouped regression results are shown in Columns (3) and (4) of Table 7. The results show that the impact of green agricultural development on urban carbon emissions is significantly negative in major grain-producing areas, while it is negative but insignificant in non-major grain-producing areas. This indicates that the carbon emission reduction effect of green agriculture is heterogeneous across different agricultural production functional zones and is stronger in cities located in major grain-producing areas. Major grain-producing areas have large-scale agricultural production and contiguous arable land, which is conducive to the large-scale promotion of green production technologies. They also face stricter requirements for arable land protection and agricultural non-point source pollution control, leading to higher motivation of local governments in implementing the pilot zone policy. As a result, green agricultural development performs better and significantly reduces urban carbon emissions.

Table 6: Heterogeneity Analysis Results Based on Geographical Conditions

Variables	Geographical Location		Topographic Conditions	
	(1) Eastern	(2) Central-Western	(3) Rugged Terrain	(4) Flat Terrain
did	-2.958***	-1.471	-1.412	-2.252**
	(-3.464)	(-1.247)	(-1.155)	(-2.371)
Cons	1667.865***	1623.695***	1598.136***	1642.687***
	(23.518)	(38.841)	(21.860)	(39.091)
Control	Yes	Yes	Yes	Yes
City_FE	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes
N	909	1683	1296	1296
R^2	0.995	0.989	0.989	0.994

Table 7: Heterogeneity Analysis Results Based on Socioeconomic Factors

Variables	Economic Development Level		Agricultural Production Functional Zones	
	(1) High Economic Level	(2) Low Economic Level	(3) Major Grain-Producing Areas	(4) Non-Major Grain-Producing Areas
did	-3.039***	-1.932	-2.442***	-2.234
	(-3.889)	(-1.303)	(-2.764)	(-1.516)
Cons	1777.357***	1513.756***	1646.363***	1817.117***
	(31.161)	(32.036)	(43.713)	(19.023)
Control	Yes	Yes	Yes	Yes
City_FE	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes
N	1291	1289	1530	1062
R^2	0.991	0.989	0.993	0.989

7. Research Conclusions and Policy Recommendations

7.1 Conclusions

The study finds that, first, green agricultural development significantly reduces urban carbon emissions, and this effect remains robust after a series of robustness and endogeneity tests. Second, mechanism tests show that green agricultural development reduces urban carbon emissions by decreasing agricultural fertilizer application, promoting the development of digital inclusive finance, and improving rural innovation and entrepreneurship. Finally, heterogeneity analysis indicates that the effect is influenced by geographical conditions and socioeconomic development, and is more pronounced in eastern regions, cities with flat terrain, cities with high economic development levels, and major grain-producing areas.

7.2 Policy Recommendations

Based on the research findings, this paper puts forward the following policy recommendations to promote green agricultural development and urban carbon emission reduction.

(1) Continuously advance the construction and performance evaluation of pilot zones. The results of this study show that green agricultural practices centered on National Agricultural Green Development Pilot Zones are an effective pathway for promoting urban carbon emission reduction. It is recommended to gradually expand the scope of pilot zone establishment based on a summary of existing construction experience, incorporating more qualified regions into the pilot program. Regular performance evaluations should be conducted; pilot cities that fail to meet the assessment requirements should have their pilot status revoked,

while well-performing pilot zones can be upgraded to demonstration zones. This will enhance the continuity and effectiveness of policy incentives and ensure that pilot zones truly play an exemplary and leading role.

(2) Deepen actions to reduce agricultural fertilizer application and promote the coordinated development of digital inclusive finance and rural innovation and entrepreneurship. Fertilizer reduction should continue to be incorporated into the performance evaluation systems of local governments and agricultural operators, with clear reduction targets and responsible entities. Rigid constraints should be imposed on excessive fertilizer use, while greater efforts should be made to promote organic fertilizer substitution and soil testing and formulated fertilization technologies, and to reduce the cost of organic fertilizer use. At the same time, rural digital financial infrastructure should be improved, green credit products should be innovated, financing thresholds for green projects should be lowered, financing needs of green agricultural entities should be accurately identified, and policies supporting entrepreneurship for returnees should be implemented. Family farms, cooperatives, and leading enterprises should be supported in adopting green production technologies. Technical sharing and service platforms should be established to facilitate the synergistic enhancement of green agricultural development and urban carbon emission reduction.

(3) Formulate differentiated green agricultural development strategies according to local conditions. The carbon emission reduction effect of green agriculture exhibits significant heterogeneity and is more pronounced in eastern regions, cities with flat terrain, cities with high economic development levels, and major grain-producing areas. Therefore, each region should formulate differentiated green agricultural promotion plans based on its own resource endowment and development stage. Central-western regions and cities with rugged terrain should prioritize addressing infrastructure shortcomings, increase fiscal transfer payments and technical assistance, and improve conditions for the application of green technologies. Eastern regions and cities with high economic development levels should leverage their advantages in technology, capital, and talent to explore new models for the deep integration of green agriculture and low-carbon industries, gradually narrowing the gap in carbon emission reduction capacity across regions.

References

[1] Lee, C. C., & Zhao, Y. N. (2023). Heterogeneity analysis of factors influencing CO2 emissions: The role of human capital, urbanization, and FDI. *Renewable and Sustainable Energy Reviews*, 185.

[2] Thio, E., Tan, M. X., Li, L., Salman, M., Long, X. L., Sun, H. P., & Zhu, B. Z. (2021). The estimation of influencing factors for carbon emissions based on EKC hypothesis and STIRPAT model: Evidence from top 10 countries. *Environment, Development and Sustainability*, 24(9), 1-34.

[3] Quan, C. G., Cheng, X. J., Yu, S. S., & Ye, X. (2020). Analysis on the influencing factors of carbon emission in China's logistics industry based on LMDI method. *Science of the Total Environment*, 734, Article 138473.

[4] Jiang, M. H., An, H. Z., Gao, X. Y., Liu, S. Y., & Xi, X. (2019). Factors driving global carbon emissions: A complex network perspective. *Resources, Conservation & Recycling*, 146, 431-440.

[5] Liu, X. Y., Song, M., Wang, S. Y., Xu, X. W., & Li, H. L. (2024). On innovation infrastructure and industrial carbon emissions: Nonlinear correlation and effect mechanism. *Applied Energy*, 375, Article 124079.

[6] Fan, W., Luo, X., Yu, J. B., & Dai, Y. Y. (2021). An empirical study of carbon emission impact factors based on the vector autoregression model. *Energies*, 14(22), Article 7797.

[7] Sun, B. W., & Zheng, S. L. (2024). The synergistic effect of environmental regulation on pollution and carbon reduction: Evidence from a quasi-natural experiment of clean production standards. *China Economic Quarterly*, 24(02), 624-642.

[8] Ouyang, W., Zhou, Y., & Wang, Y. (2025). Can command-and-control regulation reduce carbon emissions? Evidence from China. *Environmental Impact Assessment Review*, 112, Article 107802.

[9] Yao, Y. T., & Chen, W. M. (2010). Current status of agricultural greenhouse gas emissions and research on low-carbon agricultural development models. *Science and Technology Progress and Policy*, 27(22), 48-51.

[10] Qu, F. T., Lu, N., & Feng, S. Y. (2011). The impact of land use change on carbon emissions. *China Population, Resources and Environment*, 21(10), 76-83.

[11] Luo, Y., Xiong, T., Meng, D., Gao, A., & Chen, Y. (2023). Does the integrated development of agriculture and tourism promote farmers' income growth? Evidence from Southwestern China. *Agriculture*, 13(9), Article 1745.

[12] Jiang, F., Jiang, Y., Peng, J., Lv, Y., Wang, W., & Zhou, Z. (2023). Effects of rural collective economy policy on the common prosperity in China: Based on the mediating effect of farmland transfer. *Frontiers in Environmental Science*, 11, Article 1302545.

[13] Li, Z., Shi, Q., Hu, K., & Chen, Z. (2026). The impact of agricultural green development on common prosperity for farmers in rural areas. *Scientific Reports*, 16(1), Article 5844.

[14] Yu, F. (2016). Xi Jinping's new thought on green development and the green transformation development of agriculture. *China Rural Survey*, (05), 2-9+94.

[15] Sun, W., Wang, R., Jiang, Q., & Huang, S. (2019). Research on the connotation and evaluation of agricultural green development. *Chinese Journal of Agricultural Resources and Regional Planning*, 40(04), 14-21.

[16]Yin, C. (2016). Thoughts on accelerating the promotion of agricultural green and sustainable development. *Rural Work Newsletter*, (05), 7-9.

[17] School of Economics, Shandong Normal University, Jinan, 250358, China, School of Economics and Management, Chongqing Normal University, Chongqing, 401331, China, & School of Economics and Management, Chongqing Normal University, Chongqing, 401331, China. (2020). China's agricultural green total factor productivity based on carbon emission: An analysis of evolution trend and influencing factors. Journal of Cleaner Production.

[18] Yurak, V. V., & Fedorov, S. A. (2024). Review of natural and anthropogenic emissions of carbon dioxide into the earth's atmosphere. *International Journal of Environmental Science and Technology*, 22(4), 2719-2736.

[19] Yoro, K. O., & Daramola, M. O. (2020). CO2 emission sources, greenhouse gases, and the global warming effect. In Advances in carbon capture (pp. 3-28). Woodhead Publishing.

[20] Shi, S., & Yin, J. (2021). Global research on carbon footprint: A scientometric review. *Environmental Impact Assessment Review*, 89, Article 106580.

[21] Zhang, Z., Yang, Z., & Zhou, J. (2025). Evaluation of fertilizer reduction effect in National Agricultural Green Development Pilot Zones: Also on the relationship between fertilizer reduction and food security. *Chinese Journal of Agricultural Resources and Regional Planning*, 46(12), 103-116.

[22] Zhang, S., Yin, C., He, Y., & Xiao, X. (2020). Spatial differentiation and dynamic evolution of agricultural carbon emissions in China: An empirical study based on spatial and nonparametric estimation methods. *China Environmental Science*, 40(03), 1356-1363.

[23] Liu, H., Liu, S., & Shang, J. (2026). Research on the impact of the National Agricultural Green Development Pilot Zones policy on agricultural carbon emissions. *China Environmental Science*, 46(01), 555-567.

[24] Li, S., & Zhang, J. (2023). Digital inclusive finance, technological innovation, and urban carbon emission intensity. *Journal of East China Normal University (Philosophy and Social Sciences)*, 55(02), 161-172+178.

[25] Ji, X., & Feng, W. (2026). Digital inclusive finance, new quality productive forces, and regional carbon intensity. *Review of Economy and Management*, 42(02), 57-69.

[26] Xu, W., Zhou, J., & Liu, C. (2022). Spatial effects of digital economy development on urban carbon emissions. *Geographical Research*, 41(01), 111-129.

[27] Tian, R., Cao, G., Xiang, S., Gao, X., & Su, L. (2023). Research on the impact and spatial effects of regional innovation and entrepreneurship capacity on carbon emissions in the Yangtze River Economic Belt. *Resources and Environment in the Yangtze Basin*, 32(07), 1365-1378.

[28] Ruan, J., Yang, Q., Ye, W., & Zhang, Y. (2024). Development of rural innovation and entrepreneurship in China: Index construction and measurement analysis. *Economy and Management*, 38(05), 9-18.

[29] Wu, G., Chen, G., & Cheng, J. (2025). The impact of agricultural environmental regulation on urban-rural integrated development: Evidence from a quasi-natural experiment of National Agricultural Green Development Pilot Zones. *China Population, Resources and Environment*, 35(02), 171-184.

[30] Li, F., Duan, J., & Cheng, B. (2025). The impact of environmental regulation on carbon emissions in the Beijing-Tianjin-Hebei region. *Reform*, (10), 145-158.

[31] He, Y., Xie, Z., Xie, H., & Cheng, H. (2025). Geographical differentiation and spatial spillover of the impact of export trade on urban carbon emissions. *Resources Science*, 47(11), 2523-2536.

[32] Zhang, L., Nie, R., & Zhang, Y. (2025). The impact of the digital economy on carbon emissions and its spatial spillover effect. *Statistics and Decision*, 41(12), 113-117.

[33] Guo, F., Wang, J., Wang, F., Kong, T., Zhang, X., & Cheng, Z. (2020). Measuring the development of digital inclusive finance in China: Index compilation and spatial characteristics. *China Economic Quarterly*, 19(04), 1401-1418.

[34] Jiang, T. (2022). Mediation and moderation effects in empirical studies of causal inference. *China Industrial Economics*, (05), 100-120.

[35] Tang, H., Fang, S., & Jiang, D. (2022). Market performance of digital transformation: Can digital M&A enhance the market power of manufacturing enterprises? *Quantitative Economics and Technical Economics Research*, 39(12), 90-110.

[36] Sun, L., & Abraham, S. (2021). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of Econometrics*, 225(2), 175-199. (Note: Original publication year adjusted to 2021 based on standard citation; some sources list as 2020 online-first.)

[37] Ding, B., Zhao, Y., & Deng, J. (2022). Measurement, decoupling characteristics, and driving factors of carbon emissions from crop farming in China. *Chinese Journal of Agricultural Resources and Regional Planning*, 43(05), 1-11.

[38] Hu, C., Wei, Y., & Hu, W. (2018). Research on the relationship between agricultural policy, technological innovation, and agricultural carbon emissions. *Issues in Agricultural Economy*, (09), 66-75.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.

Open Access

This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.