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How Does Developing Green Agriculture Affect Poverty? Evidence from China's Prefecture-Level Cities

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Abstract: Eradicating poverty and improving human well-being are pivotal objectives for achieving global sustainable development. Sustainable agriculture, as a key domain, plays a crucial role in addressing poverty. However, to date, there remains insufficient research on the specific impact of agricultural green development on poverty. To bridge this gap, we utilize panel data from 273 prefecture-level cities in China from 2006 to 2022 to explore how agricultural green development affects poverty based on constructing a regional multidimensional poverty index and an index of green agriculture. Our study reveals that agricultural green development effectively reduces poverty, particularly in regions of deep poverty and the eastern part of China. Further mediating analysis indicates the alleviation of poverty by agricultural green development through the infrastructure, the industrial structure, and the green technology innovation effect. Our findings offer valuable insights for informing policies on agricultural green development and poverty reduction, as well as for improving government resource allocation and strengthening resilience in impoverished areas. By deepening our understanding of the link between green agriculture and poverty, this research significantly contributes to global agricultural sustainability and expedites poverty eradication worldwide.

Keywords: green agriculture; poverty alleviation; sustainable development; multidimensional poverty

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Citation: Jiang, X.; Sun, Y.; Shen, M.; Tang, L. How Does Developing Green Agriculture Affect Poverty? Evidence from China's Prefecture-Level Cities. *Agriculture* **2024**, *14*, 402. https://doi.org/10.3390/agriculture14030402

Academic Editors: Pan Dan and Fanbin Kong

Received: 6 February 2024
Revised: 26 February 2024
Accepted: 28 February 2024
Published: 1 March 2024

1. Introduction

Poverty is not just an economic challenge but a multifaceted social issue closely intertwined with education, health, housing, and more [1]. Despite significant progress in global economic development, many countries, especially those in the developing world, continue to struggle with the enduring challenge of poverty. According to the World Bank [2], around 700 million people worldwide still live in extreme poverty. Efforts to eradicate poverty, promote sustainable consumption and production, and improve health and well-being are not only central to sustainable development but also top priorities for governments worldwide.

In 2015, the United Nations Sustainable Development Goals (SDGs) committed to eradicating hunger and poverty by 2030, emphasizing the human imperative. Agriculture is a vital livelihood for 2.5 billion small-scale farmers and a crucial element in achieving this goal. However, to accommodate the continually expanding global population, projected to reach 9 to 10 billion by 2050, a 60% to 110% increase in global food production may be necessary [3]. Against the backdrop of ongoing deterioration in the global climate, the extensive use of materials such as pesticides, fertilizers, and membranes to achieve rapid growth in food production has made agriculture the leading factor contributing to escalating environmental risks globally [3].

The significance of agricultural green development in combating environmental degradation and poverty eradication has grown substantially [4]. This approach aims to minimize environmental impacts, enhance production efficiency, ensure food safety, and promote sustainable livelihoods for farmers, serving as an innovative and essential approach for achieving the harmonization of economic, social, and ecological benefits [5].

The Chinese government actively promotes agricultural green development. In 2017, the central government released the Opinions on Innovative Institutional Mechanisms to Promote Green Agricultural Development. This initiative advocates for the comprehensive establishment of an ecologically oriented institutional system, aligning with the concept of ecological civilization and embodying the principle that "green water and green mountains are golden silver mountains" [6]. The goal is to propel agriculture towards green practices characterized by high productivity, efficient resource utilization, and increased production efficiency. It also seeks to innovate pathways and modes of green development [7]. Therefore, examining the impact of China's agricultural green development on poverty reduction addresses coordination challenges in impoverished areas while significantly contributing to global sustainable development goals.

The impact of green development on poverty reduction remains a debated topic. Unfortunately, there is no consensus on them. Some scholars argue for its positive effects [8,9]. On the contrary, others contend that despite environmental benefits, green economic growth does not eliminate poverty [10–12]. Despite the theoretical emphasis on the role of green agriculture in sustainable development and poverty alleviation [7,13–16], limited empirical evidence supports its effectiveness in reducing poverty.

To address this gap, we utilize panel data from 273 Chinese cities (2006–2022), focusing on the relationship between agricultural green development and poverty. We calculate indices for both factors, considering mediation through infrastructure, industrial structure, and green technology innovation. Additionally, the study examines the heterogeneity of agricultural green development at various poverty levels and in different regions in China.

This study makes two key contributions. Firstly, it provides empirical evidence supporting the impact of agricultural green development on poverty reduction. The research delves into intermediary mechanisms such as infrastructure, industrial upgrading, and green technology innovation. This not only illuminates the significant influence of China's agricultural green growth on alleviating poverty but also offers new evidence for formulating specific poverty reduction policies amid improvements in infrastructure, industrial structure, and the promotion of green technology innovation. Secondly, recognizing the tendency of research to overlook the diverse impact of agricultural green development on poverty, we delved into its effects on poverty reduction across different regions and income levels, which fills a crucial gap in existing research, offering substantial theoretical and practical insights for advancing global agricultural green development, particularly in impoverished areas.

The rest of the paper is as follows: Section 2 provides a literature review and theoretical analysis; Section 3 presents the methodology and data; Section 4 shows the empirical results; Section 5 provides the discussion; and the remainder is conclusions and policy recommendations.

2. Literature Review and Theoretical Analysis

2.1. Literature Review

The eradication of poverty is a paramount concern for governments and scholars worldwide. Early perspectives, such as Malthus [17], emphasized increasing capital investment in impoverished regions to match national income growth. Schultz [18] contended that economic development hinges on human quality, advocating for enhanced human capital. Amartya Sen [19] and others also argued that economic development is a fundamental strategy in combating poverty.

However, excessive economic growth could bring about environmental degradation and worsening poverty issues [8]. So, some scholars advocate for green development or high labor productivity as a means to alleviate poverty [7,9,20]. Although green development helps mitigate environmental problems [15], its impact on poverty alleviation is debated. Research has suggested that implementing green development strategies could fight poverty, with spatial spillover effects [9]. Adeleke and Josue [21] highlighted the long-term impact of a green economy on poverty reduction. However, Dercon [10] warned that green growth may be environmentally sensitive, potentially disadvantaging the poor. Niazi [11] analyzed forty years of green development in Palestine and found that the "Green Revolution" there failed to alleviate hunger, unemployment, and poverty. Similarly, E.K. Sadanandan Nambiar [22] confirmed that green initiatives such as forest conservation did not lead to economic growth or poverty reduction in rural areas. These disparities may stem from the complexity inherent in poverty itself.

There is limited research on the influence of agricultural green development on poverty alleviation, with a focus on measuring green production efficiency and distribution. Various methods, including DEA [15], AHP [23], PCA [24], and EW [25], have been employed in studies. For example, Huang et al. [26] analyzed agricultural green productivity in China from 1998 to 2019 with DEA. However, most of these methods, relying on the quantitative relationship between the outputs and inputs of agriculture, ignored the quality and efficiency of agricultural resources. A more suitable approach involves a comprehensive evaluation, incorporating resource conservation elements to construct an Agriculture Green Development Index (AGDI). Moreover, several studies highlighted positive influences on green agriculture, such as green technology [16], industrial structure [15], and green trade [27]. Conversely, factors such as improper resource allocation [28], land policy reforms [29], and adverse climate conditions may have negative effects. Ahmed et al. [30] used panel data from 2005 to 2019 across 50 states in the US. Their findings showed that agricultural insurance, air pollution, and total factor productivity in agricultural green production are interconnected. Expanding agricultural insurance may increase green output but could worsen air pollution. However, severe air pollution does not enhance agricultural productivity. While green agriculture shows promise for poverty reduction, empirical data on this remain limited. The potential for poverty reduction through sustainable and organic agriculture has attracted attention from some scholars [10,31–33]. Bhutto et al. [31] argued that sustainable agriculture is a key driver of poverty reduction in rural Pakistan. They suggested that government priorities should include offering relaxed credit to small-scale farmers, improving irrigation efficiency, and promoting farmer education.

To bridge this research gap, using panel data from Chinese prefecture-level cities, we explore the impact of agricultural green development on poverty by redefining regional poverty and green agriculture development indices. We analyze mediating mechanisms, regional variations, and heterogeneity across different regions and poverty levels. Key questions are as: Does agricultural green development reduce poverty, and if so, how? Are there variations in its impact across China's eastern, central, and western regions? Is the impact consistent across regions with different poverty levels?

2.2. Theoretical Analysis

Poverty exists at regional, household, and individual levels. As Figure 1 shows, regional poverty arises from environmental vulnerability, frequent natural disasters, and unsustainable living conditions, hindering the conversion of ecological resources into sustainable regional development. Individuals in impoverished regions encounter challenges such as inadequate infrastructure, limited information, and insufficient capital to adapt to a dynamically changing living environment [7]. In a sustainable livelihood framework, poverty derives from the uneven development of natural, material, social, financial, and human capital within a fragile context [34]. Choosing livelihood strategies becomes intricate, particularly in effectively converting natural capital into market assets and products. This complexity leads to outcomes marked by material scarcity, inequality, dependence on welfare, and regions experiencing economic development delays, fragile geographical environments, and a monolithic industrial structure. These challenges obstruct the fulfillment of demands posed by population growth, thereby perpetuating a detrimental cycle of "negative cumulative accumulation" in poverty-related issues.

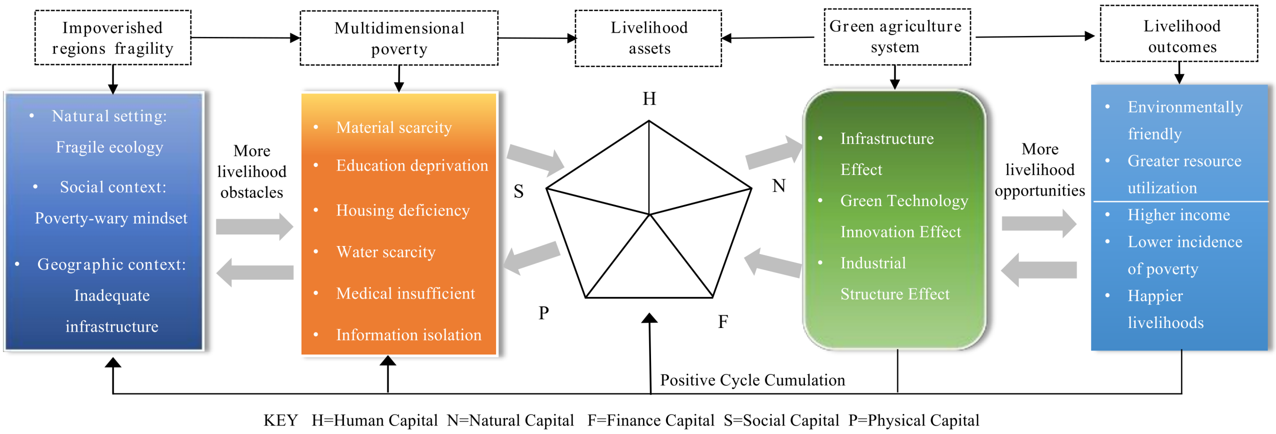

Figure 1. Impacts and mechanisms of green agriculture on poverty.

Agricultural green development is rooted in environmental capacity, guided by market principles, and involves harnessing regional resources to facilitate the transformation of ecological elements into productive assets. It reflects the degree of coordination between economic development resources and the environment [13]. As a foundation for high-quality economic development, agricultural green development prioritizes environmental protection and resource conservation [14,35]. It serves as a key pathway to break the "negative cumulative accumulation process" in impoverished areas.

Agricultural green development is supported by green financial policies [36], introduces innovative green technologies, optimizes industrial structures, rectifies land use, and preserves the natural environment [16]. This fosters the coordinated and orderly flow of resource, environmental, human, and economic elements, eliminating barriers to poverty, enhancing regional sustainable livelihood resilience, and achieving a positive cycle of accumulation in environmental optimization, income growth, and economic development. Ultimately, it promotes harmonious coexistence between humans and nature. Therefore, green development represents the core path towards achieving sustainable development [37].

This study holds that the advancement of agricultural green development significantly contributes to improving sustainable livelihoods and fighting poverty through specific pathways. Firstly, the growth of green agriculture often accompanies the upgrading of complementary infrastructure. This not only enhances economies of scale but also increases material capital in impoverished areas, a phenomenon referred to as the "infrastructure effect" [38].

Secondly, agricultural green development promotes the integrated development of various links in the agricultural industry chain by upgrading the industrial structure. This not only enhances the sustainable operation of agriculture, such as green tourism between green agriculture production, but also increases the added value of agricultural products through their healthy, environmentally friendly, and green characteristics. It creates more employment opportunities for farmers, thereby raising income levels [35]. This is referred to as the "industrial structure effect".

Thirdly, agricultural green development with innovative technologies not only reduces carbon emissions and environmental pollution [39] but also improves agricultural planting, production, and transportation processes, conserves resources, and enhances agricultural labor productivity. It facilitates the transfer of surplus rural labor to more stable and higher-income sectors, enriching household income sources and enhancing family material capital [40], known as the "green technology innovation effect". Therefore, this study proposes the following hypotheses:

Hypothesis 1. *Agricultural green development has a poverty alleviation effect.*

Hypothesis 2. *Agricultural green development realizes poverty reduction through the infrastructure effect.*

Hypothesis 3. *Agricultural green development realizes poverty reduction through the industrial structure upgrading effect.*

Hypothesis 4. *Agricultural green development realizes poverty reduction through the effect of green technology innovation.*

3. Methods and Data

3.1. Methods

3.1.1. Panel Data Model

In exploring the impact of agricultural green development on poverty, various methods are available, including panel data modeling, cross-sectional data regression analysis, and time series analysis. The panel data model, when compared to cross-sectional and time series approaches, provides a structured spatiotemporal framework, allowing for a more nuanced understanding of temporal and regional dynamics. This refinement boosts the reliability and resilience of research findings by reducing the impact of omitted variables, thereby facilitating a more accurate estimation of model parameters [41]. So, this paper establishes a panel data model to further explore the impact of green agriculture development on poverty. The equation is the following:

$$y_{it} = \alpha + \beta AGDI_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

Here, α is a constant term, and β is the coefficient of $AGDI_{it}$, which indicates the effect of agricultural green development on poverty, whose sign and significance will determine the direction and intensity of green agriculture's impact on poverty.

X_{it} is a matrix of control variables, such as the level of financial development, the level of consumption, foreign investment, and government environmental regulations, as well as their vector of coefficients γ.

μ_i represents region-fixed effects that do not vary over time, capturing region-specific unobserved factors. λ_t represents time effects controlling for the possibility of common externalities that may be experienced by all regions at the same time. ε_{it} represents random error terms.

3.1.2. Calculation of Multidimensional Poverty Index

Building on the works of Alkire and Foster [1,42] and Qi et al. [43], this study incorporates the dimension of information poverty. Information poverty is defined as the hindrance of individuals from fully leveraging society's abundant information resources due to insufficient opportunities and freedoms, resulting in obstructed information practices, lacking information capital, and unmet information needs [44]. In today's fast-paced information era, the ability to access and discern information is a critical skill for economic well-being. Therefore, this study includes six dimensions in the poverty index, as outlined in Table 1.

Table 1. Multidimensional poverty indicators.

Criteria Hierarchy	Indicator Hierarchy	Sources
Income	Per Capita Net Income of Rural Residents (RMB)	China Rural Poverty Monitoring Report
Education condition	Proportion of Full-Time Undergraduate Teachers in Rural Compulsory Education	
Medical condition	Number of Health Technical Personnel per Thousand Rural Population	
Safe water condition	Rate of Safe Drinking Water Coverage	
Housing condition	Per Capita Housing Area of Rural Residents	
Information condition	Proportion of Administrative Villages with Broadband Internet Access	

Firstly, standardize the raw data for each dimension to remove unit and scale differences. This is carried out by subtracting the mean and dividing by the standard deviation for each indicator.

Then, perform PCA to extract the main components. Compared to other evaluation methods, PCA can eliminate the intercorrelation among indicators, making indicator selection relatively straightforward and saving a significant amount of work. The weights of each principal component in PCA are based on their contributions to the original data, making the determination of weights objective and avoiding subjective judgment [24]. The Principal Component Score (*PC Score*) for each poverty dimension is calculated using the following formula:

$$PCScore_{kj} = a_{i1}Z_{j1} + a_{i2}Z_{j2} + \cdots + a_{ik}Z_{jn} \quad (2)$$

Here, i is the dimension of the poverty indicator; j is the observation; and Z_{ij} is the standardized value of the observation for the poverty indicator. a_{ik} is the loading weight of the poverty indicator on the principal component.

Finally, calculate the poverty index (*MPI*) for each observation by combining the scores with their corresponding weights:

$$MPI_j = \sum_{k=1}^{m} w_k \times PCScore_{kj} \quad (3)$$

Here, m represents the number of selected principal components, and w_k is the weight of the k-th principal component, typically determined by the explained variance ratio of that principal component.

3.1.3. Calculation Method of Agricultural Green Development

Expanding on previous studies [45,46], this research includes resource conservation as a new dimension in the *AGDI*. In addition to green production, ecological environment, and economic efficiency, resource conservation is considered essential for sustainable agriculture, reducing costs, improving overall economic benefits, and minimizing resource waste. The evaluation system is built on four dimensions, as presented in Table 2. Furthermore, the study employs the entropy method for the fair weighting of evaluation indicators. The entropy method is an objective weighting method that assigns weights based on the characteristics of the data itself, avoiding the influence of subjective factors. It can also handle the correlation between indicators by eliminating this influence through correlation analysis, thereby improving the accuracy of comprehensive evaluation [47].

Table 2. Measurement indicators for the *AGDI*.

Criteria Level	Indicator Level	Indicators Connotation
Resource Conservation	Replanting Index	Total cropped area of crops to arable land area
	Effective Irrigation Ratio	Effective irrigation area (thousand hectares) to total cropped area of crops
	Agricultural Machinery Utilization Efficiency	Total power of agricultural machinery to total cropped area of crops
Green Production Process	Intensity of Fertilizer Use	Application of chemical fertilizers (10,000 tons) to total cropped area of crops
	Intensity of Pesticide Use	Usage of pesticides per total planted area per crop
Environmental Conservation	Total Utilization Rate of Animal Manure	Proportion of administrative villages with animal manure treatment
	Rate of Sewage Treatment	Proportion of administrative villages with sewage treatment
	Rate of Garbage Treatment	Proportion of administrative villages with garbage treatment
Production Efficiency	Total Agricultural Value per Unit of Sown Area	Agricultural output value (billion yuan) to total cropped area of crops
	Agricultural Development Level	Proportion of value added of primary sector in GDP
	Total Agricultural Output Value	Value of addition to primary sector
	Grain Output per Unit Area	Total grain output to total cropped area of crops

First, the positive indicators were standardized:

$$X_{it} = \frac{x_{it} - \min(x_i)}{\max(x_i) - \min(x_i)} \tag{4}$$

For negative indicators, the following equation was used:

$$X_{it} = \frac{\max(x_i) - x_{it}}{\max(x_i) - \min(x_i)} \tag{5}$$

Further, the information entropy of the indicator is calculated, where m is the year of examination. The calculation formula is as follows:

$$e_i = \frac{-1}{\ln m} \sum_{t=1}^{m} w_{it} \cdot \ln w_{it} \tag{6}$$

Redundancy in information entropy was then calculated:

$$d_i = 1 - e_i \tag{7}$$

Indicator i was weighted:

$$w_i = \frac{d_i}{\sum_{t=1}^{m} d_i} \tag{8}$$

The indicators and their weights were weighted to obtain the *AGDI*.

3.1.4. Selection and Explanation of Variables

Dependent variable: *MPI*. Calculated from the index system constructed according to Section 3.1.2. Independent variable: *AGDI*. Calculated based on the indicator system constructed in Section 3.1.3. Controlling variables: Referring to the studies of Liu et al. [15] and Zhao et al. [48], controlling variables include ① the consumption level (*Con*), the ratio of the city's total social consumption to GDP; ② the urbanization level (*Urb1*), the ratio of urban population to total population; ③ foreign direct investment (*Fdi*), the total investment by foreign-invested enterprises; ④ government environmental regulation (*Gov1*), the ratio of government investment in environmental governance to the GDP; ⑤ the economic development level (*Pcg1*), the ratio of the total GDP to the city's total population; and ⑥ the financial development level (*Fin1*), the ratio of the sum of deposits and loans to the city's GDP.

Mediating variables: Drawing inspiration from the studies of Huang et al. [26] and Luo et al. [46], this study incorporates the following mediating variables: Infrastructure (*Inf*), represented by the rural per capita road area; industrial structure (*AIS1*), measured by the ratio of the sum of the GDP of the secondary and tertiary industries to the regional GDP; and green technology innovation (*LNgt1*), the number of green patents applied for in the current year. Table 3 provides the descriptive statistics for all selected variables.

Table 3. Descriptions and statistics of all the selected variables.

Variables	Definition	Obs.	Mean	Std. Dev.	Min	Max
MPI	Multidimensional poverty index calculation in Section 3.1.3	4641	0.599	0.162	0.009	1
AGDI	Green growth index calculated in Section 3.1.2	4641	0.187	0.073	0.019	0.800
Con	Ratio of the total social consumption amount to the city's GDP	4641	0.365	0.111	0	1.156
Urb1	Ratio of the urban population to the total population	4641	0.721	1.464	0	16.45

Table 3. *Cont.*

Variables	Definition	Obs.	Mean	Std. Dev.	Min	Max
Fdi	Total investment amount of foreign-invested enterprises in the city	4641	0.379	0.196	0.101	0.994
Gov1	Ratio of government environmental governance investment to GDP	4641	0.187	0.102	0.043	1.485
Pcg1	Ratio of the total GDP to the total population of the city	4641	4.621	3.271	0.010	46.78
Fin1	Ratio of the total balance of deposits and loans to the city's GDP	4641	0.973	0.624	0.020	9.622
Inf	Per capita road area in rural areas	4641	269.019	94.927	46.169	697.033
AIS1	Ratio of the sum of the values of the secondary and tertiary industries to GDP.	4641	4.461	0.981	3.914	4.604
LNgt1	Number of green patents applied for in the current year	4641	2.580	1.842	0	9.406

Notes: Obs. stands for the observations of the variables; mean refers to the average value of the variables. Dev. represents the standard deviation; min and max indicate the minimum and maximum values of the variables, respectively.

3.2. Data Sources

Due to insufficient data availability prior to 2006, the study uses data from 273 cities in mainland China (excluding Hong Kong, Macau, and Taiwan) spanning from 2006 to 2022. Index data were mainly gathered from sources such as the China Statistical Yearbook, China Rural Statistical Yearbook, China City Statistical Yearbook, and the National Economic and Social Development Statistical Bulletin. Multidimensional poverty data were obtained from the annual China Rural Poverty Alleviation Reports.

4. Results

4.1. Analysis of the Suitability of Quantitative Models

Before the empirical analysis, we conducted key auxiliary tests to validate the constructed econometric model: Firstly, a multicollinearity test showed low VIF values (max: 1.96; average: 1.44), indicating weak multicollinearity and minimal interference with subsequent estimation results. Secondly, a panel cointegration test using Westerlund and Pedroni–Kao methods (E-G two-step procedure) revealed a significant cointegrating relationship between agricultural green development and poverty. Detailed test results are shown in Table 4. Thirdly, the Hausman test results ($p < 0.01$) strongly reject the idea that coefficients have no systematic differences under the random effects model. This suggests that the fixed effects model is a better fit for our data. Hence, this study employs a two-way fixed effects model, incorporating fixed effects for both time and individual dimensions.

Table 4. Model adequacy test results.

Test Method	Results
Pedroni Residual-Based Cointegration Test	
Panel ρ-stat	19.882 ***
Panel PP-stat	−60.973 ***
Panel ADF-stat	−52.558 ***
Kao Residual-Based ADF Cointegration Test	−2.761 ***
Westerlund Test	−3.423 ***
Hausman Test	202.92 ***

Notes: *** $p < 0.01$.

4.2. Baseline Regression Analysis

Table 5 shows a regression analysis of agricultural green development on poverty. In Model (1), the baseline results without control variables show a negative significant coefficient of −0.165 at the 1% level. Model (2) introduces control variables, yielding a consistently negative and significant coefficient at the 1% level. Taking Model (2) as a more precise estimate, an increase of one unit in green development corresponds to an average reduction of 0.164 units in poverty levels, affirming the role of agricultural green development in poverty alleviation and validating Hypothesis 1 that agricultural green development has a poverty alleviation effect.

Table 5. Baseline regression analysis of green agriculture on MPI.

Variables	Model (1)	Model (2)
AGDI	−0.165 ***	−0.164 ***
	(0.019)	(0.019)
Con		−0.012
		(0.007)
Fdi		0.001
		(0.001)
Urb1		−0.009
		(0.010)
Gov1		0.006
		(0.012)
Pcg1		−0.002
		(0.0001)
Fin1		−0.002
		(0.0004)
Constant	0.640 ***	0.647 ***
	(0.005)	(0.007)
Obs.	4641	4641
R2	0.085	0.087
Year FE	YES	YES
Id FE	YES	YES

Notes: *** $p < 0.01$, Standard errors in parentheses.

4.3. Robustness Test

To ensure the robustness of the results, we employed five methods to explore the impact of poverty on agricultural green development, as presented in Table 6:

(1) In Model (3), the measurement of the independent variable was replaced. The *AGDI* was replaced with the commonly used Agricultural Green Total Factor Productivity. The regression results indicate a significant coefficient of −0.165 ($p < 0.01$) for the *AGDI*, suggesting a notable poverty reduction effect associated with the development of green agriculture.

(2) Model (4) excludes data before 2007, reducing the randomness in sample selection. The results demonstrate that the negative impact of *AGDI* remains significant ($\beta = -0.159$, $p < 0.01$), indicating a consistent influence of green agriculture on MPI within a shorter time frame.

(3) In Model (5), we conducted winsorization to mitigate the influence of extreme values. The results show that the negative impact of *AGDI* remains statistically significant ($\beta = -0.159$, $p < 0.01$), confirming the robustness of the main analysis results.

(4) In Model (6), we adjusted the control variables by introducing a one-period lag. The *AGDI* coefficient remains highly significant at −0.160 ($p < 0.01$), indicating a robust poverty reduction effect by green development.

(5) In Model (7), Two-Stage Least Squares (2SLS) was utilized to mitigate potential endogeneity. Analyzing the lagged values of the independent variable as instrumental variables, the highly significant coefficient of −1.430 ($p < 0.01$) confirms the substantial poverty reduction impact of agricultural green development.

Table 6. Robustness test analysis.

Variables	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)
AGDI	−0.165 ***	−0.159 ***	−0.159 ***	−0.160 ***	−1.430 ***
	(0.019)	(0.019)	(0.018)	(0.019)	(0.042)
Constant	0.649 ***	0.651 ***	0.646 ***	0.653 ***	1.057 ***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.016)
Controls	YES	YES	YES	YES	YES
Obs.	4641	4368	4641	4368	4368
R2	0.203	0.090	0.087	0.090	0.235

Notes: *** $p < 0.01$, Standard errors in parentheses.

In all, diverse robustness tests consistently support the conclusion that agricultural green development significantly reduces poverty, bolstering the study's reliability.

4.4. Mechanism Analysis

Table 7 illustrates the results of the mediation effect test of the relationship between agricultural green development and poverty. Through the Sobel and Goodman statistical method, the study found that three mediating variables, *Inf*, *AISI*, and *LNgt1*, played a significant mediating role.

Table 7. Results of mediation effect test.

Mediating Variable	Model (8)	Model (9)	Model (10)
	Inf	**AISI**	**LNgt1**
Sobel	−0.568 ***	0.105 ***	0.065 ***
	(0.030)	(0.015)	(0.009)
Goodman	−0.568 ***	0.105 ***	0.065 ***
	(0.030)	(0.015)	(0.009)
Controls	YES	YES	YES
Mediation Effect	−0.568 ***	0.105 ***	0.065 ***
	(0.030)	(0.015)	(0.009)
Direct Effect	−0.562 ***	−1.487 ***	−0.195 **
	(0.013)	(0.038)	(0.032)
Total Effect	−1.130 ***	−1.382 ***	−1.130 **
	(0.033)	(0.035)	(0.033)
Direct Effect	0.503	−0.076	−0.058

Notes: *** $p < 0.01$, ** $p < 0.05$, Standard errors in parentheses.

In Model (8), it is demonstrated that the mediation coefficient of *Inf* is −0.568 ($p < 0.01$), the coefficient of the direct effect is −0.562, the coefficient of the total effect is −1.130, and the mediation ratio of Inf is 0.503, which indicates that agricultural green development plays a role in poverty alleviation through the improvement of infrastructure, and it verifies Hypothesis 2 that agricultural green development realizes poverty reduction through the infrastructure effect. To propel agricultural green development, substantial government investment in improving agricultural infrastructure becomes imperative. Robust agricultural infrastructure optimizes conditions for farmers, including the refinement of irrigation systems, road improvements, field drainage enhancements, and efficient transportation. This not only facilitates the adoption of green agricultural technologies, reducing the labor intensity of agricultural production, but also elevates land utilization efficiency. Furthermore, a well-developed agricultural infrastructure contributes to the quality and safety of agricultural products. Scientific irrigation system management, for example, ensures sufficient moisture for crops, mitigating contamination by heavy metals in water [49]. Efficient transportation, enabled by well-constructed roads, minimizes product losses, elevates market value, and garners favor from consumers and investors. Consequently, this results in increased income for farmers and addresses rural poverty issues [50].

Model (9) reveals a significant mediation coefficient for *AISI* at 0.105 ($p < 0.01$). The direct effect coefficient is −1.487, the total effect coefficient is −1.382, and the *AISI* mediation ratio is 0.076. This indicates that *AISI* plays a mediating role in the poverty reduction impact of agricultural green development, affirming Hypothesis 3 that agricultural green development realizes poverty reduction through the industrial structure upgrading effect. Agricultural green development, by extending and integrating the agricultural industry chain, facilitates industrial structure upgrading, fostering integration with sectors such as agro-processing and eco-tourism. This convergence diversifies agricultural structures, enhances the market value of products, and uplifts farmers' income levels [51].

In Model (10), the mediation coefficient for *LNgt1* is 0.065, with a direct effect coefficient of −0.195 and a total effect coefficient of −1.130. The mediation ratio is −0.058, indicating that *LNgt1* acts as a mediator in the poverty reduction impact of agricultural green development, supporting Hypothesis 4 that agricultural green development realizes poverty reduction through the effect of green technology innovation. The advancement of green agriculture involves a technological revolution, raising the level of green agricultural technological innovation. This not only improves resource efficiency, reduces environmental impact, and enhances product value but also provides a sustainable development model for rural communities [32,39]. Furthermore, green technological innovation boosts labor productivity, facilitating the transfer of surplus rural labor to higher-income sectors and creating new agricultural employment opportunities. This diversifies economic sources for farmers, improves livelihoods, and mitigates poverty issues [40].

4.5. Heterogeneity Analysis

In Table 8, Models (11)–(13) present heterogeneous analyses of the impact of agricultural green development on poverty across the eastern, central, and western regions of China, respectively. It is evident from Table 8 that the poverty-alleviating effects of agricultural green development are most pronounced in the eastern region ($\beta = -0.214$, $p < 0.01$). In comparison, the central region ($\beta = -0.112$, $p < 0.01$) and the western region ($\beta = -0.181$, $p < 0.01$) exhibit relatively weaker outcomes. The eastern region, being China's economically developed area, features advanced agricultural infrastructure and a well-established market and often serves as a leader in technology and innovation, enabling a quicker adoption and dissemination of green agricultural technologies [16]. Consequently, the efficiency of agricultural production in the eastern region is higher, effectively mitigating economic hardships among rural residents [16]. Additionally, the government in the eastern region possesses stronger capabilities in supporting green finance policies, encouraging and propelling agricultural green development, thereby enhancing mechanisms for socioeconomic improvement.

Table 8. Heterogeneity analysis under the different regional and poverty levels.

Variables	Model (11)	Model (12)	Model (13)	Model (14)	Model (15)	Model (16)
	Western Region	**Midlands**	**Eastern Region**	**High-Poverty**	**Medium-Poverty**	**Low-Poverty**
AGDI	−0.181 ***	−0.112 ***	−0.214 ***	−0.168 ***	−0.073 ***	−0.081 **
	(0.030)	(0.031)	(0.041)	(0.022)	(0.021)	(0.035)
Constant	0.717 ***	0.703 ***	0.544 ***	0.676 ***	0.595 ***	0.490 ***
	(0.012)	(0.014)	(0.014)	(0.008)	(0.016)	(0.050)
Controls	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Id FE	YES	YES	YES	YES	YES	YES
N	1632	1360	1649	3298	1139	204
R2	0.082	0.062	0.141	0.087	0.094	0.209

Notes: *** $p < 0.01$, ** $p < 0.05$, Standard errors in parentheses.

In Models (14)–(16) of Table 8, the impact of agricultural green development on poverty is examined across regions with varying levels of poverty. According to the Chinese targeted poverty alleviation system, cities receiving assistance from developed regions are classified as high-poverty areas, those neither providing nor receiving assistance are considered moderate, and those helping are classified as low-poverty areas. The poverty-alleviating effect of the *AGDI* is most significant in high-poverty areas ($\beta = -0.168$, $p < 0.01$), whereas the effects are relatively smaller in moderately low-poverty ($\beta = -0.073$, $p < 0.01$) and low-poverty areas ($\beta = -0.081$, $p < 0.05$). High-poverty areas likely receive greater attention from the government, particularly with more resource allocation from the central government, including green agricultural projects and policies. This concentrated allocation of resources may result in a more significant implementation of green agricultural projects in high-poverty areas, leading to a more pronounced poverty reduction effect [7,9].

5. Discussion

Eliminating poverty and agricultural green development are crucial goals for achieving sustainable development. While previous studies have extensively explored the assessment and spatiotemporal distribution of green agricultural development, the mechanisms through which agricultural green development contributes to poverty alleviation remain unclear. To address this gap, our study utilizes panel data from 273 prefecture-level cities in China from 2006 to 2022. By reconstructing the regional *MPI* and *AGDI*, we delve into the poverty reduction effects and mechanisms of agricultural green development. This research provides a fresh perspective and data support for the practice of agricultural green development and combating poverty.

Our findings indicate that agricultural green development contributes to poverty reduction, aligning with the study by Pingali [8], who suggested that advancements in green genetic resource technology, crop improvement, and increased yields lead to poverty reduction and lower food prices. Similarly, research by Kassie et al. [52] reveals that improved peanut varieties (technology) significantly increase crop income and reduce poverty. However, our conclusions differ from the findings of Niazi [11], possibly due to variations in ecological environments, resource conditions, institutions, and technologies across countries.

This study unveils that the eastern region of China exhibits the most pronounced poverty reduction effect of agricultural green development, surpassing the significance observed in the western and central regions. The heightened level of green agricultural development and advanced infrastructure in the eastern region potentially foster the synergistic development of resource, environmental, cultural, and economic elements. This finding aligns with the research by Chen et al. [45], highlighting the eastern coastal areas' superior green agricultural development due to better resource endowments and higher agricultural technology levels compared to the central and western regions.

The study further illuminates variations in the poverty reduction effects of agricultural green development across different poverty levels. We observe that in areas experiencing deep poverty, the poverty reduction effect of agricultural green development is most significant. One plausible explanation is that deeply impoverished areas often concentrate on China's poverty, and the development of green agriculture generates spatial spillover effects. Closer interprovincial resource exchanges and collaborative efforts are more likely to promote the true sustainability of green poverty alleviation [9].

The study reveals that agricultural green development achieves poverty reduction through key pathways: infrastructure effects, industrial effects, and green technological innovation effects. This finding further validates Dercon's (2014) proposition that green agricultural growth can alleviate poverty through dual mechanisms. Firstly, through investments in infrastructure such as flood prevention measures and road optimization, environmental risks for impoverished populations are reduced, aiding their escape from spatial poverty traps. Secondly, by fostering employment growth, diminishing reliance on agriculture, reshaping livelihood strategies, creating more job opportunities in alternative sectors, and enabling engagement in higher-yield activities, poverty reduction is achieved [10]. Existing research confirms that optimizing agricultural infrastructure improves product quality and safety, reduces transportation costs, and increases market value, thereby enhancing farmers' income and alleviating rural poverty [50]. Furthermore, extending and integrating the green agricultural industry chain, merging agriculture with eco-tourism, deep processing, and other sectors, enhances value-added agricultural products and boosts farmers' incomes [51]. Additionally, green technological innovations improve resource utilization and labor productivity, facilitating the transition of the impoverished from agriculture to non-agricultural sectors and enhancing the resilience of sustainable livelihoods [32,53].

6. Conclusions and Policy Recommendations

6.1. Conclusions

This study conducts panel data from 273 prefecture-level cities in China from 2006 to 2022, exploring the poverty reduction mechanisms associated with agricultural green development through heterogeneity analysis and mediation effect mechanisms. The main findings are as follows:

Firstly, this paper confirms the significant poverty reduction by agricultural green development, validating Hypothesis 1 that agricultural green development has a poverty alleviation effect. This finding not only addresses the shortcomings in existing literature on the impact of agricultural green development on poverty reduction but also underscores the urgency and importance of poverty alleviation in promoting green agricultural development.

Secondly, we demonstrate that agricultural green development contributes to anti-poverty measures through three channels: the impact on infrastructure, the upgrading of industrial structure, and the innovation of green technologies. This supports Hypotheses 2–4, indicating that agricultural green development achieves poverty reduction through infrastructure effects, agricultural industrial structure upgrades, and green technology innovation effects, respectively. This highlights the intricate and diverse nature of poverty alleviation.

Finally, the study further confirms that in regions characterized by deep poverty, the poverty reduction effect of agricultural green development is more pronounced, particularly when compared to areas with medium and low poverty levels. Additionally, we find that the eastern region of China experiences a more significant poverty reduction effect from agricultural green development compared to the central and western regions, highlighting regional disparities.

As for our aggregation methods, this paper leaves several questions for subsequent studies to address. Some characteristics deserve further study. First, this study did not analyze the poverty reduction effects of agricultural green development on each dimension of regional poverty. In future research, a more in-depth analysis could be conducted on the mechanisms of poverty reduction in terms of regional economy, education, healthcare, housing, and information poverty resulting from agricultural green development. Second, the evidence in this paper is derived from China. Future research could further conduct cross-national comparative analyses with different poverty levels, geographical locations, and economic development levels.

6.2. Policy Recommendations

Based on the above conclusions, this study proposes the following policy recommendations. To begin with, the government should prioritize enhancing infrastructure development. Efforts should be directed towards formulating a comprehensive plan for rural infrastructure improvement, ensuring the efficient allocation of resources. Special attention should be given to digital infrastructure, including expanding rural internet coverage and implementing information technology applications, to improve the technological sophistication of agricultural production.

Secondly, considering the role of agricultural industrial structure upgrading in poverty reduction, the government should provide more financial support to optimize agricultural industrial structure. This involves promoting the integration of green agricultural industries across primary, secondary, and tertiary sectors to enhance the added value of agricultural products. Market-oriented policies should be implemented to incentivize enterprises to upgrade to green industries and meet domestic and international market demands. Additionally, fostering integration between agricultural production and cultural tourism through mechanisms such as establishing green production cooperatives and cultural tourism cooperatives can facilitate the comprehensive development of industries. Furthermore, the government should introduce specialized loan policies for green agriculture to reduce financing costs and risks for agricultural producers, encouraging their participation in upgrading the agricultural industrial structure towards greener practices.

Thirdly, considering the significant value of green technological innovation in poverty reduction, efforts should be increased in agricultural technology innovation. Green innovative technologies play a crucial role in enhancing agricultural labor productivity and resource utilization efficiency. The government should actively support innovation in green agriculture in impoverished regions, encouraging research and development. Establishing an Agricultural Technology Innovation Fund to finance projects and promoting collaboration between research institutions and farmers will facilitate the development and adoption of green agricultural technologies.

Finally, given the complexity of addressing poverty in underdeveloped western regions, it is critical to implement targeted development policies. Priority should be given to infrastructure construction in these areas to narrow the urban–rural development gap and elevate agricultural productivity. Establishing a comprehensive support system encompassing education, training, finance, and social security is essential for reinforcing sustainable livelihoods. Increased investment in rural education and training can enhance awareness and skills related to green agriculture, facilitating the widespread adoption of green agricultural technologies.

Author Contributions: X.J.: Conceptualization, data curation, formal analysis, methodology, writing—original draft, writing—review and editing, funding acquisition. Y.S.: conceptualization, data curation, methodology, supervision, writing—review and editing. M.S.: conceptualization, data curation, methodology, supervision, writing—review and editing. L.T.: conceptualization, supervision, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Social Science Foundation of China (Grant Number: CGA210241).

Institutional Review Board Statement: The research included in the current submission does not involve human or animal subjects or involve pathological reports, etc.

Data Availability Statement: The data analysis code is available from the corresponding author.

Acknowledgments: We gratefully thank the anonymous reviewers and the editor for their constructive comments on an earlier version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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