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Original Research

Does Rural Industrial Integration Promote the Green Development of Agriculture? – Based on Data from 30 Provinces in China from 2010 to 2021

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Abstract

Because the integrated development of rural industry promotes the application of the agricultural green production mode, it inevitably has an impact on the green development of agriculture. Analysing the influence of rural industry integration on agricultural green development is of great significance for realizing agricultural modernization and sustainable development. Based on panel data of 30 provinces in China during 2010-2021, the entropy weight TOPSIS method was used to estimate the agricultural green development level (AGD) and the rural industrial integration level (RII). The influence of agricultural industry integration (AII) on the level of agricultural green development (AGD) and its nonlinear characteristics were analysed by constructing a fixed model, intermediary effect model and threshold effect model. The results show the following. (1) A significant positive relationship exists between the RII and the AGD; that is, the development of rural industry integration can effectively promote the green development of agriculture. Regarding the three regions in China, the integration of rural industries in eastern China plays the most prominent role in the green development of agriculture. (2) Rural industrial integration has significant scale, capital and technology effects; that is, rural industrial integration mainly promotes AGD indirectly by promoting agricultural scale management and agricultural technological progress and improving rural human capital. (3) Rural industrial integration has a significant nonlinear marginal increasing effect on AGD. In the dynamic process of AGD changing from low to high, the effect of the marginal utility of rural industrial integration on AGD is gradually enhanced. Therefore, China should strengthen the deeply integrated development of rural industries, ensure the appropriate scale operation of agriculture and adjustments to the planting

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structure, accelerate agricultural technology innovation and rural human capital accumulation, and realize a win–win situation for rural economic and ecological conservation.

Keywords: rural industry integration, green development of agriculture, impact, mechanism

Introduction

As one of the world's largest grain producers, China has made great progress in agriculture since its reform and opening up policy. Agricultural mechanization, advances in agricultural science and technology, and developing irrigation and water conservancy have continuously promoted agricultural development. China's total grain production increased from 430.7 million tons in 2003 to 686.53 million tons in 2022, realizing 19 years of steady growth [1]. However, during the rapid development of agricultural modernization, excessive agricultural production activities degrade the land, cause water pollution, destroy the ecological environment and create other problems, putting pressure on the sustainable development of agriculture [2]. The "anti-ecological" effect of petroleum agriculture has become increasingly prominent. According to the National Agricultural Sustainable Development Plan (2015-2030), the utilization rate of chemical fertilizers and pesticides is less than 1/3, and the recovery rate of agricultural film is less than 2/3, resulting in serious endogenous agricultural pollution [3]. High-productivity agriculture is vital for food security and economic development, particularly in a country such as China, which comprises 20% of the world's population but only 8% of the arable land.

An inefficient production mode is the direct cause of high agricultural carbon emissions and the deterioration of the rural ecological environment [4]. The transformation and upgrading of the agricultural development mode ultimately depends on the transformation of the rural production mode. As a major innovation in the development of rural productivity in the new development stage, rural industrial integration has broken the boundaries of traditional rural industries, and new agriculture based on the development of resources, folk culture, the economy and infrastructure in different regions has greatly improved farmers' income levels and promoted the economic development of rural areas. Industrial integration is the cross-border penetration and cross-integration of capital, labour, technology and other factors, which is conducive to improving the comprehensive efficiency of factor allocation and realizing the transformation of the power of agricultural economic growth [5]. While improving social and economic benefits, industrial integration inevitably has a certain impact on the environment in rural areas. Especially at present, China is in a critical period of transformation from traditional to modern agriculture. Whether industrial integration can promote rural economic growth while considering rural environmental protection and agricultural green development is worth considering.

However, a review of the literature shows that scholars mainly focus on the economic effect of rural industrial integration, and few studies focus on its environmental effect. Theoretically, industrial integration is the cross-border penetration and cross-integration of capital, labour, technology and other factors, which is conducive to improving the comprehensive efficiency of factor allocation, promoting the realization of green and energy-saving agricultural production modes, and inevitably having an impact on the green development of agriculture. However, at the empirical level, there is no proof of this. Therefore, can rural industrial integration promote the green development of agriculture? How does rural industrial integration influence the green development of agriculture? The answers to these questions help clarify the environmental effects of rural industrial integration and its mechanism and promote the green development of agriculture. Therefore, we use empirical tools to investigate the impact of rural industry integration on agricultural green development and its mechanism to provide a reference for promoting rural industry integration development and sustainable agricultural development.

Possible contributions of this paper are as follows. (1) Based on panel data of 30 provinces in China from 2010 to 2021, the dual-fixed model is used to analyse the effect of rural industrial integration on the level of agricultural green development to provide a reference for realizing sustainable agricultural development and achieving the "dual-carbon" goal and to expand the analysis framework of the rural industrial integration effect. (2) Based on the "scale-capital-technology" analysis framework, we analyse the mechanism of rural industry integration that promotes China's agricultural green development, clarify the logic of rural industry integration that affects agricultural green development and conduct empirical tests, which is helpful to further understanding the ecological effects of rural industry integration. (3) The threshold effect model was used to demonstrate the influence characteristics of rural industry integration on AGD and to reveal the nonlinear influence of rural industry integration on the green development of agriculture.

The remaining parts of this paper are structured as follows. Section 2 provides a literature review on rural industrial integration and agricultural green development. Section 3 describes the materials and methods. Section 4 presents the empirical results and discusses them in detail. Finally, we put forward precise policy implications for promoting rural industrial integration and agricultural green development based on the findings.

Literature Review and Theoretical Analysis

Literature Review

Rural Industrial Integration (RII)

In the 1990s, Japanese scholar Naratomi Imamura proposed Japan's six industries theory to solve the problems of a lack of agricultural successors and the rural decline in Japan, which is the earliest research on the integration of agricultural industries [6]. The research group of the Macro Institute of the National Development and Reform Commission and the Department of Agricultural Economics in China believes that rural industrial integration is a process of promoting the organic combination of agriculture and secondary and tertiary industries through the extension of the industrial chain, the expansion of industrial functions, the agglomeration of factors, the penetration of technologies and the innovation of the organizational system. Then, the goal of agricultural modernization is achieved, and farmers' income is increased [7].

Previous studies on the impact of industrial integration on rural development have mainly focused on its economic effect, such as increasing household income and narrowing the gap between urban and rural areas. Scholars have generally noted that industrial integration has a positive impact on farmers' income. The development of agricultural industrialization increases farmers' household income by more than 50%; however, this effect has regional heterogeneity [8]. Furthermore, industrial integration can not only promote an increase in farmers' income but also narrow the income gap between farmers at different income levels; upgrading the agricultural industrial structure is an important channel [9]. Regarding the gap between urban and rural areas, agricultural industrialization is the basis for narrowing the income gap between urban and rural areas in China, while the low degree of industrialization is the main reason for the slow growth in farmers' income and the large gap between urban and rural income. Rural industrial integration can mainly narrow the urban-rural income gap through two mechanisms: promoting economic growth and increasing the urbanization rate [10]. At present, while the literature directly examining the environmental effects of industrial integration has mainly focused on the relationship between industrial agglomeration and environmental pollution, the research conclusions have been quite different. Although there are differences in the conclusions of previous studies, it is an indisputable fact that industrial agglomeration is closely related to environmental pollution.

Agricultural Green Development (AGD)

The overall objective of agricultural green development (AGD) is to coordinate "green" with "development" to transform existing agriculture characterized by high resource consumption and high environmental costs into green agriculture and countrysides with high productivity, high resource use efficiency and low environmental impact [3]. The influencing factors of agricultural green development are mainly divided into economic, policy, technology and other factors. For example, Zhou et al. (2023) noted that green technology is an important factor in promoting the green development of agriculture [11]. Yang and Wei (2022) pointed out that industrial agglomeration has a positive effect on the level of agricultural green development [12]. Fan et al. (2021) used a comprehensive evaluation method to simultaneously calculate the influence of the digitalization level on the agricultural green development level and empirically found that the digitalization level has an inverted U-shaped relationship with the agricultural green development level [13]. Oenenma et al. (2021) pointed out that the green development of agriculture must have three aspects to develop well: agricultural practices, rural environments and rural populations [14]. Shen verified the agricultural production process from the perspective of duality theory and noted that the green development of agriculture can enhance income distribution, help farmers reduce production risks and costs, and realize agricultural ecological innovation [3].

Otherwise, many scholars have measured the level of agricultural green development. Hall et al. (1991) first proposed the concept of the "green index" and constructed the index system of green development [15]. Starting from the connotation of agricultural green development, some scholars have introduced the DPSIR model to build the index system of China's agricultural green development, have preliminarily assessed the level of agricultural green development in China and various provinces, and have used the Theil index to analyse the difference [16]. Some scholars have used principal component analysis [17], the AHP method [18], the entropy value method [19], the entropy weight-TOPSIS method [20] and so on to calculate the agricultural green development level in different regions in China.

Impacts of RII on AGD

Scholars have mostly discussed the relationship between rural industry integration and agricultural green development from a specific form of rural industry integration but have rarely combined the two systems to systematically analyse their correlation, the empirical research and impact mechanism research on the relationship between the two systems is lacking. Zhang (2020) combined planting and breeding in agriculture in the Netherlands and promoted the green transformation of agriculture using sustainable development methods such as green recycling technology [21]. Giurea et al. (2017) used leisure agriculture in Sibiu County of Romania as an example and noted that the development of leisure agriculture had both positive and negative effects [22]. The development of agro-tourism will attract part of the agricultural labour force and provide funds for farmers to adopt innovative technologies, such as fertilizers, allowing farmers to expand production without increasing tillage frequency or clearing new land to indirectly reduce environmental degradation [23]. However, drawing labour from agriculture may also lead to the loss of farmers with land management skills, hindering the green development of agriculture [24]. In short, previous studies have reached opposite conclusions; therefore, whether the integration of rural industries can promote agricultural green development needs to be further verified.

Theoretical Analysis

Industrial integration not only promotes rural economic development and improves economic benefits but also expands the scale of agricultural operations and improves rural human capital, promoting agricultural technological progress and the use of green agricultural production methods. Thus, industrial integration inevitably has an impact on agricultural green development (AGD). Therefore, rural industrial integration can indirectly affect agricultural green development through the scale, capital and technology effects, as reflected as follows.

(1) Rural industrial integration can expand the scale of agricultural operations. The rapid development of industrial integration allows for the reuse of unused land in rural areas and improvements in land transfer efficiency [25]. Expansions in the scope of land transfers further gives birth to additional large professional households and family farms, leading agricultural enterprises and other new business entities, thus accelerating the realization of large-scale agricultural land management. Specifically, the integrated development of rural industries has given rise to a series of new business forms, has created more nonagricultural employment opportunities, and has allowed a large number of part-time farmers to achieve a stable employment environment, reducing their dependence on land. In addition, idle land resources can be used efficiently. At the same time, the market information advantage formed by industrial integration can effectively guide farmers to allocate land resources, help improve the degree of land mismatches, transfer idle land into cooperatives or family farms and other new agricultural operating entities, and expand the scale of agricultural operations [11]. Generally, a positive relationship exists between the scale of agricultural operations and the agricultural ecological environment, and a scaled operation is conducive to promoting the green development of agriculture. In addition, an expansion in the scale of operations can enhance farmers' awareness of green production, encourage farmers to adopt green production technology, enrich farmers' social capital, broaden information acquisition channels, increase the application of organic fertilizer, and improve the agricultural ecological environment [26].

(2) Rural industrial integration can improve rural human capital. On the one hand, while narrowing the income gap between urban and rural areas, industrial integrated development strengthens the incentive for farmers to invest in education, improves the structure of rural human capital, and plays a positive role in promoting the accumulation of rural human capital [27]. Specifically, industrial integration lays out the industrial chain in rural areas, maintaining not only industrial interests in rural areas but also high-quality labour forces in rural areas and deepening rural human capital [28]. At the same time, many nonagricultural transferred labourers are attracted to the countryside to engage in agricultural production and operation activities and become new, professional farmers. Relying on industrial integration and innovation, these labourers continue to learn professional knowledge and management experience, improve their own knowledge structure, and enhance the human capital structure in rural areas as a whole. On the other hand, studies have indicated that an increase in gross school enrolment and literacy rates helps reduce environmental pollution [29]. Generally, farmers with a high human capital often use innovative management methods and production and operation modes, which can effectively avoid unnecessary resource waste, improve the labour production and use efficiency of polluting factors, obtain higher agricultural output with less production factor inputs, reduce the use of inputs such as fertilizers and pesticides, and promote green agricultural production [30]. At the same time, skill training and other human capital investments can effectively reduce the amount of pesticides applied by farmers and alleviate environmental pollution.

(3) Rural industrial integration can promote the agricultural technology progress. The integrated development of rural industries can accelerate the technological penetration between industries, improving the progress of agricultural science and technology. The degree of concentration of upstream and downstream enterprises in the rural industrial chain has deepened, and interindustry technology transfer and collaborative innovation have accelerated, further improving the agricultural technology innovation ability and efficiency related to realizing industrial linkages and business model innovation [17]. Among the many factors affecting agricultural green development, agricultural technology progress is the main way to optimize the traditional factor input structure and reduce agricultural carbon emission intensity [31]. Agricultural technological progress can bring about scientific decision making, improve farmers' accumulation of experience and knowledge, and help farmers master green agricultural technologies such as soil testing, formula fertilization

and completing fine operations, such as precise drug use and precise fertilization, thereby improving resource utilization and effectively reducing the emission of pollutants from agricultural nonpoint sources.

Materials and Methods

Model Elaboration

Fixed Effect Model

Unobserved factors in the model causes missing variable bias, which can be effectively solved by using a fixed effects model. Therefore, we use a two-way, fixed-effect panel model to test the linear relationship between rural industry integration and AGD. The model is set as Formula (1):

$$AGD_{it} = \alpha_0 + \beta_1 RII_{it} + \sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \upsilon_t + \xi_{it} \tag{1}$$

In the above formula, the explained variable is AGD_{it}, the explanatory variable is RII_{it}, $Col_{it,k}$, is a set of control variables. Subscripts i and t represent province and year, respectively, and μ_i is the individual effect. ξ_{it} represents the random error term, which is subject to a normal distribution.

Mediating Effect Model

To verify the mediating role of the operating scale, human capital and technological progress in the relationship between RII and AGD, we construct a mediation effect model based on the step-up testing method proposed by Baron and Kenny (1986) [32]. The test of the intermediary effect requires three steps. First, the impact of RII on AGD is tested, which is consistent with Formula (1). Second, the influence of RII on the mediating variable Med_{it} is tested, as shown in Formula (2). Finally, RII and mediating variables are included in the regression model, in which AGD is the explained variable, as shown in Formula (3). The specific model settings are as follows:

$$Med_{it} = \alpha_0 + \beta_1 RII_{it} + \sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \upsilon_t + \xi_{it} \tag{2}$$

$$AGD_{it} = \alpha_0 + \beta_1 RII_{it} + \beta_2 Med_{it} + \sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \upsilon_t + \xi_{it} \tag{3}$$

where Med_{it} represents different mediating variables, and the other variables in Formula (3) are the same as in Formula (1).

Threshold Regression Model

Given the continuous deepening of rural industrial integration, the ecological premium of agriculture will be fully realized, further strengthening the green production behaviour of producers and further improving the green development of agriculture. Therefore, the influence of rural industrial integration on AGD may be enhanced by increasing integration. That is, the influence of rural industry integration on AGD may have a nonlinear relationship. Here, the level of rural industry integration is used as the threshold variable to test this nonlinear relationship, and the threshold regression model is finally established, as shown in the Formula (4):

$$\begin{aligned} AGD_{it} &= \alpha_0 + \beta_{11} RII_{it} I(RII_{it} \le \theta_1) + \beta_{12} RII_{it} I(\theta_1 < RII_{it} \le \theta_2) \\ &+ \cdots + \beta_{1,n} RII_{it} I(\theta_{n-1} < RII_{it} \le \theta_n) + \beta_{1,n+1} RII_{it} I(RII_{it} > \theta_n) \\ &+ \sum_{k=1}^{n} \lambda_k Con_{it,k} + \mu_i + \nu_t + \xi_{it} \end{aligned} \tag{4}$$

In the above equation, θ_1, θ_2 and θ_n are threshold values, and β_{11}, β_{12}, and $\beta_{1,n}$ are regression coefficients of different threshold intervals. I(·) is the indicative function, and other variables are interpreted in the same way as in Formula (1). If there is only one threshold value, the above formula can be simplified as follows:

$$\begin{aligned} AGD_{it} &= \alpha_0 + \beta_1 RII_{it} (RII_{it} \le \theta) + \beta_2 RII_{it} I(RII_{it} > \theta) \\ &+ \sum_{k=1}^{n} \lambda_k Con_{it,k} + \mu_i + \nu_t + \xi_{it} \end{aligned} \tag{5}$$

The Entropy Weight TOPSIS Method

There are many multicriteria decision-making (MCDM) methods, of which the technique for order preference by similarity to an ideal solution (TOPSIS) method is effective at ranking and selecting a number of possible alternatives [33]. For MCDM, the weight of the index is crucial to measuring the importance of the index. The weight is usually divided into two types. One is determined by the knowledge and experience of experts or individuals and is called the subjective weight; the other is based on statistical properties and measurement data and is called the objective weight, which can effectively eliminate the influence of subjective factors, such as the entropy weight (EW) method. In this paper, the entropy weight is defined and constructed based on the information entropy and data. Therefore, the TOPSIS method with EW is used to determine the level of the evaluation object.

1) Standardize the evaluation matrix:

If the evaluation index is positive:

$$y_{ij} = \frac{x_{ij} - \min x_j}{\max x_j - \min x_j} \tag{6}$$

If the evaluation index is negative:

$$y_{ij} = \frac{x_{max} - x_j}{\max x_j - \min x_j} \quad (7)$$

2) Calculate the information entropy:

$$H_j = -k\sum_{i=1}^{m} p_{ij} Inp_{ij} \text{ (where } p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}, k = \frac{1}{Inm}) \quad (8)$$

Define the weight of the *jth* indictor as:

$$W_j = \frac{1 - H_j}{\sum_{j=1}^{n}(1 - H_j)} \text{ (where } W_j \in [0,1]\text{, and } \sum_{j=1}^{n} W_j = 1) \quad (9)$$

3) Construct the weight normalization matrix:

$$R = (r_{ij})_{m\times n},\ r_{ij} = W_j \cdot y_{ij}\ (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \quad (10)$$

4) Determine the positive and negative ideal solutions S_J^+ and S_J^-, respectively:

$$S_J^+ = \max(r_{1j}, r_{2j}, \cdots, r_{nj}) \quad (11)$$

$$S_J^- = \min(r_{1j}, r_{2j}, \cdots, r_{nj}) \quad (12)$$

5) Calculate the Euclidean distance between each scheme:

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(S_i^+ - r_{ij})^2} \quad (13)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}(S_i^- - r_{ij})^2} \quad (14)$$

6) Calculate the degree of closeness to the comprehensive level of agricultural green development LX_i:

$$LX_i = d_i^- / (d_i^- + d_i^+) \quad (15)$$

In the above formula, $LX_i \in (0,1)$. The closer the value of LX_i is to 1, the better the evaluation object is, that is, the higher the level of evaluation object is, and vice versa.

Measurement of Variable

Explained Variable

Based on the studies of Zhao et al. (2019), Huang (2021) and He (2021) [19, 35-36] and following the principles of comprehensiveness and representativeness, the index system of the agricultural green development level is constructed from four aspects: resource conservation, environmental friendliness, ecological conservation and efficient output. Resource conservation includes four indicators: cultivated land multiple cropping index, water-saving irrigation rate, total mechanical power per unit of cultivated land area, and water consumption per unit of agricultural output value. Environmental friendliness includes four indicators: pesticide application intensity, chemical fertilizer application intensity, agricultural film application intensity and agricultural COD emission intensity. Ecological conservation includes four indicators, including the proportion of nature reserve area, forest coverage rate, wetland coverage rate and soil loss control rate. Efficient output includes three indicators, namely, disposable income, proportion of agricultural output value and land productivity. All indictors are provided in Table 1.

Explanatory Variable

The integrated development of rural industry (RII) is the core explanatory variable of this study. At present, few comprehensive index system can reflect the level and quality of the integrated development of rural industries [10]. On the basis of the above research and considering the availability of regional-level data, we construct a comprehensive evaluation index system for the integrated development level of rural industries from five aspects: extension of the agricultural industrial chain, expansion of agricultural multifunction, cultivation of new agricultural business forms, integrated development of the agricultural service industry and improvement in the interest linkage mechanism (Table 2).

Mediating and Controlling Variables

In the test of the influence mechanism, agricultural operation scale (*AOS*), rural human capital (*RHC*) and agricultural technology progress (*ATP*) are used as the intermediate variables. The agricultural operation scale (*AOS*) is expressed by per capita crop sown area, which is calculated as the logarithm of the ratio of crop sown area to agricultural employees. Rural human capital (*RHC*) is measured as the average years of schooling of the rural population. Agricultural technical progress (*ATP*) is measured as agricultural total factor productivity using the DEA-Malquist index method according to Han and Zhang (2019) [36].

In addition to rural industrial integration, other important variables also have an impact on AGD. In this paper, the following variables are selected as control variables: 1) Rural infrastructure (*RIC*): the improvement in rural infrastructure is conducive to the promotion and utilization of advanced agricultural machinery and equipment, thus promoting the green development of agriculture [11]. Here, the ratio of rural fixed asset investment to total social fixed asset investment indicates the level of the rural infrastructure.

Table 1. Evaluation index system of agricultural green development level.

First-grade indicators	Second-grade indicators	Measurement of the indicators	Unit	Indicator attribute
Resource conservation	Cultivated land replanting index	Total sown area/cultivated area of crops	—	-
	Water saving irrigation rate	Water saving irrigation area/effective irrigation area	%	+
	Total mechanical power per unit of cultivated land area	Total power of agricultural machinery/arable area	kW/ha	-
	Agricultural water efficiency	Agricultural water consumption/total agricultural output value	Tons/billion	-
Environmental friendliness	Pesticide application intensity	The amount of pesticide used/the area of cultivated land	Tons/ha	-
	Fertilizer application intensity	The amount of aagricultural fertilizer used/ area under cultivation	Tons/ha	-
	Strength of agricultural film application	The amount of aagricultural film used /total crop sown area	Tons/ha	-
	Agricultural COD emission intensity	Agricultural COD discharge/gross agricultural product	Tons/billion	-
Ecological conservation	Nature reserve area share	Nature reserve area/area of jurisdiction	%	+
	Forest cover	Forest area, wetland area/area of jurisdiction	%	+
	Wetland coverage	Area of wetland/area of jurisdiction	%	+
	Soil erosion control rate	Soil erosion control area/area of jurisdiction	%	+
Efficient output	Disposable income	Data drawn from CHINA RURAL STATISTICAL YEARBOOK	Yuan	+
	Share of agricultural output	Agricultural output value/total output value of agriculture, forestry, husbandry and fishery	%	+
	Land productivity	Agricultural output value/crop sown area	Billion RMB/ha	+

Table 2. Indicators of the level of rural industrial integration.

Measure objective	First-grade index	Second-grade index	Unit
The level of RII	Extension of agricultural industry chain	Main business income of agricultural processing industry/ total agricultural output value	%
	Multifunctional development of agriculture	Annual business income of leisure agriculture/total output value of primary industry	%
	Cultivation of new agricultural forms of business	Total area of facility agriculture/arable land	%
	Integrated development of agricultural and service industries	Total output value of agriculture, forestry, husbandry and fishery services/total output value of primary industry	%
	The mechanism for linking interests has been improved	The number of specialized farmer cooperatives per 10,000 people in rural areas	The number

2) Financial support for agriculture (*FIS*) reflects the influence of government interventions on agricultural green development [17]. At present, China's financial support for agriculture is largely inclined to be input subsidies of agricultural resources, such as fertilizers, pesticides and agricultural machinery, which restricts the green development of agriculture to a certain extent. This factor is expressed as the proportion of expenditures on agriculture, forestry and water affairs in local fiscal expenditures. 3) The higher the level of industrialization (*IND*) is, the higher the degree of development of petroleum agriculture may be, so the level of green development of agriculture may have a negative impact [5]. In this paper, the proportion of regional industrial output value to gross regional product is used to reflect the level of industrialization. 4) The higher the level of rural economic development (*RED*) is, the more solid is the material foundation

Table 3. Variables and Calculation methods.

Variables	Variable name	Calculation method	Unit	Mean	Standard deviation
Explained variable	AGD	Super-SBM method	—	0.649	0.074
Core explanatory variable	RII	Comprehensive index method and entropy method	—	0.588	0.053
Mediating variables	Scale of agricultural operations (AOS)	Total sown area of crops/practitioners of agriculture, forestry, animal husbandry and fishery	Mu /person	1.482	1.003
	Rural human capital (RHC)	The average time-length of schooling of the rural population	Year	7.977	0.487
	Agricultural technology Progress (ATP)	DEA-Malquist method	—	1.498	0.387
Control variables	Agricultural infrastructure (RIC)	Rural fixed assets investment/total social fixed assets investment	%	0.123	0.059
	Rural Economic Development (RED)	Total output value of agriculture, forestry, animal husbandry and fishery/ rural population at year-end	10,000 Yuan/person	1.659	0.736
	Level of financial support for agriculture (FIS)	Agriculture, forestry and water affairs expenditure/general budget expenditure of local finance	%	0.112	0.031
	Industrialization level (IND)	Industrial added value/gross domestic production	%	0.376	0.082
	Agricultural planting structure (APS)	Grain sown area/total sown area of crops	%	0.653	0.127

of agricultural green development, and the more conducive it is to the application of energy-efficient green production technology [16]. Per capita agricultural added value is used to measure the level of agricultural economic development. 5) If the agricultural planting structure (*APS*) is different, its scale efficiency will be different, resulting in different green development levels of agriculture [25].

The specific measurement methods of all of the variables and their descriptive statistical results are shown in Table 3.

Data Source

In this paper, data from 30 Chinese provinces from 2010 to 2021 are used for empirical analysis. Due to the lack of data on Hong Kong, Macao, Taiwan and the Tibet Autonomous Region, these three provinces and regions are not included as research samples for the time being. The data mainly come from the China Statistical Yearbook, China Rural Statistical Yearbook, China Agricultural Yearbook, China Population and Employment Statistical Yearbook, China Agricultural Trade Report, China Agricultural Yearbook, etc. In addition, the official websites of the National Bureau of Statistics, the Ministry of Agriculture and Rural Affairs and the provincial level also serve as supplementary data sources. All data measured in monetary units are deflated from the 2010 base, and quantitative analysis and model estimation are performed using SPSS and R language software.

Characteristics of AGD and RII in China

Using the dataset and the information entropy weight TOPSIS model, the *AGD* and RII of each province from 2010 to 2021 are calculated. The basic annual averages of *AGD* and *RII* in the study area from 2010-2021 are shown in Table 4. Overall, the *AGD* from 2010-2021 continuously improved over time, with an average annual growth rate of 3.819%. In recent years, the central government of China has attached great importance to the sustainable development of agriculture; therefore, *AGD* has improved greatly. During the study period, the average annual growth rates of *AGD* in the eastern, central and western regions were 3.836%, 3.860% and 3.834%, respectively. The growth rate of *AGD* in the eastern region has been higher than that in other regions, which may be related to the region's good economic foundation. Superior economic conditions are conducive to the spread of advanced green production technology.

Calculations show that the annual average RII in the whole study area has been increasing over time at an average annual growth rate of 4.584%. Because the integration of rural industries plays a significant role in promoting income and employment, it is also strongly

Table 4. Mean values of AGD and RII in China from 2010-2021.

Year	The eastern region		The central region		The western region		The whole area	
	AGD	RII	AGD	RII	AGD	RII	AGD	RII
2010	0.565	0.479	0.498	0.437	0.512	0.421	0.525	0.442
2011	0.591	0.506	0.512	0.450	0.537	0.436	0.547	0.464
2012	0.603	0.544	0.547	0.481	0.537	0.462	0.562	0.496
2013	0.612	0.569	0.549	0.539	0.565	0.487	0.575	0.532
2014	0.637	0.597	0.558	0.559	0.582	0.514	0.592	0.557
2015	0.643	0.614	0.601	0.590	0.619	0.535	0.621	0.580
2016	0.698	0.637	0.621	0.626	0.659	0.557	0.659	0.607
2017	0.701	0.652	0.673	0.647	0.68	0.589	0.685	0.630
2018	0.751	0.675	0.684	0.654	0.679	0.614	0.705	0.648
2019	0.798	0.698	0.703	0.699	0.732	0.637	0.744	0.678
2020	0.834	0.722	0.732	0.719	0.743	0.657	0.770	0.699
2021	0.852	0.747	0.753	0.725	0.772	0.698	0.792	0.724

supported by governments at all levels. Regarding subregions, the mean *RII* of the eastern region is the highest, while the mean *RII* of the western region is relatively low. The eastern region has a sound economic foundation, comprehensive transportation infrastructure and public service conditions, and high rural integration driven by key factors, such as the regional economic development level and market demand. Relatively, these driving factors are not prominent in the western region.

Results and Discussion

Results and Analysis of the Fixed-Effect Model

As panel data are used, it is necessary to discuss whether mixed effects, random effects or fixed effects are more suitable for analysing the impact of *RII* on *AGD*. The BP test showed that the random effect was more suitable than the mixed effect. Hausman's test found that fixed effects are more appropriate than random effects. At the same time, to avoid the influence of unobserved time changes on the estimation results, a two-way fixed effect model is selected for the empirical analysis.

The estimation results of *RII*'s influence on *AGD* based on the two-way fixed effect model are shown in Table 5. Combined with the estimation results of the different models in Table 6, the influence of rural industry integration on *AGD* passes the hypothesis test at the 1% significance level. The coefficient is positive, indicating that rural industry integration has a significant promoting effect on *AGD*. Overall, the influence coefficient of *RII* on *AGD* is 0.213 ($P<5\%$). The development of rural industry integration is conducive to the promotion of *AGD*; that is, the development of rural industry integration has a strong environmental effect and promotes the development of the rural economy. The reason is that the integrated development of rural industries rearranges production factors such as labour and land in rural areas, improves agricultural production efficiency, and reduces the input level of polluting factors such as fertilizers and pesticides, thus enhancing the agricultural system's sustainable development ability.

Regarding the control variables, changes in the agricultural planting structure can significantly increase *AGD*. This is mainly because compared with other crops; food crop planting has less demand for polluting inputs such as fertilizers, pesticides and agricultural film. Therefore, increasing the proportion of food crop planting can further reduce agricultural carbon emissions and nonpoint source pollution. In addition, the rapid developments of the rural economy and improvements in the rural education level have further reduced the intensity of pesticide and agricultural film use, which is conducive to improvements in *AGD*. In addition, the level of industrialization inhibits the promotion of *AGD*. China's industrialization started with the support of agriculture, and industrialization created factors, technologies, product markets and other conditions for agricultural development. The development of industrialization is especially beneficial to the development of petroleum agriculture. Given the development of industrialization, the development of petroleum agriculture is also deepening, which has a strong negative impact on *AGD*. The effect of fiscal support for agriculture on *AGD* is also negative and significant; indicating that fiscal support for agriculture inhibits the increase in *AGD*. To a large extent, China's fiscal support for agriculture tends

Table 5. Model estimation results.

Variable	Fixed effect models				Dynamic panel model based on the whole area	
	The whole area	The Eastern region	The Central region	The Western region	SYS-GMM Model I	DIF-GMM Model II
RII_{it}	0.213** (2.943)	0.254** (2.738)	0.189** (3.153)	0.162** (3.074)	0.208** (2.984)	0.161** (3.118)
RIC	0.164*** (4.183)	0.162** (3.023)	0.131*** (3.995)	0.214*** (3.721)	0.112** (2.919)	0.138** (3.136)
RED	1.275* (2.187)	1.214** (2.984)	1.134* (2.068)	1.163* (2.241)	1.014** (3.087)	1.020 (0.418)
FIS	-0.193*** (-3.921)	-0.184** (-3.157)	-0.176** (-3.084)	-0.264** (-2.663)	-0.107** (-2.814)	-0.148** (-3.136)
IND	-0.262** (-3.132)	-0.234** (-3.136)	-0.215** (-3.221)	-0.309** (-3.042)	-0.211*** (-4.643)	-0.154*** (-5.418)
APS	0.187** (3.114)	0.272* (2.415)	0.181** (3.064)	0.109 (1.513)	0.093** (3.117)	0.051* (2.089)
$AGD_{i,t-1}$					0.521*** (4.011)	0.408*** (5.871)
AR(1)					0.000	0.001
AR(2)					0.293	0.482
Sargan					0.121	0.108
F Test	22.871**					
Hausman _Test	51.496***					

Note: *, **, *** denote significance at 10%, 5% and 1% level, respectively with T values shown in brackets.

to subsidize petroleum agricultural factors. such as chemical fertilizers, pesticides and agricultural machinery, which has a negative effect on agricultural ecological efficiency. The coefficient of this variable for the whole area is -0.193, possibly because financial support for agriculture, which tends to encourage the development of petroleum agricultural models, which strongly restricts the green development of agriculture. Therefore, attention should be paid to the reform of the financial support for agricultural structures and trends.

Given the large differences in the development of rural industries in different regions of China, the whole research region is divided into eastern, central and western regions for the fixed effect model estimation. As Table 5 shows, the estimated results of each region are basically consistent with the results of the whole study area, indicating the relative robustness of these research results. Among them, the influence coefficient of *RII* on *AGD* in the eastern region is the largest of the three regions. Rural areas in eastern China have a good economic foundation, which supports the green development of agriculture. Meanwhile, farmers in these areas generally have a strong sense of innovative development. Therefore, it is feasible to promote the green development of agriculture through the integration of rural industries.

Endogeneity and the Solution

Rural industrial integration can promote the green development of agriculture; conversely, the green development of agriculture may also promote the integration of agriculture industries. Therefore, there may be an endogeneity problem of mutual causation. To alleviate the endogeneity problem, we construct a dynamic panel model and use the generalized moment estimation method (GMM) to estimate it. The GMM can be divided into the difference generalized method of moments estimation (difference GMM) and the system generalized method of moments estimation (system GMM). Compared with the difference GMM estimation method, the system GMM estimation method has fewer bias problems and improved efficiency under the condition of finite samples. The system GMM estimation method can address weak instrumental variables, alleviate the bias problem in the results in the difference GMM estimation method, and improve the robustness of the model estimation. As the weight of the GMM estimation method in the two-step system relies heavily on parameter estimation, and the standard error exhibits a downward bias, the standard error of the regression coefficient will be seriously underestimated, resulting in overly significant regression results. Therefore, we choose a one-step systematic GMM estimation method for endogeneity processing. In addition, to ensure the robustness of the results, the regression results of the difference GMM (DIF-GMM, Model I) based on the whole study area are reported in Table 5.

The system GMM estimation method requires that the instrumental variables are strictly exogenous and that no first-order autocorrelation exists for the perturbation term and no second-order autocorrelation exists for the perturbation term after differencing. Therefore, it is necessary to carry out the Sargan instrumental variable validity test and Arellana-Bond sequence correlation test. According to the results of the system GMM (Model II) estimation method in Table 5, the P value of the first-order sequence autocorrelation test (AR1) is less than 0.05 and that of the second-order sequence autocorrelation test (AR2) is greater than 0.1. These results indicate no first-order or second-order sequence autocorrelation of the disturbance term. The P value of Sargan's overidentification test is greater than 0.1, indicating that the instrumental variable selection is effective and that the endogeneity problem is well eliminated. The estimation results show that the *AGD* lags one period has a positive impact on the *AGD* of the current period; moreover, this result is significant at the 1% level. These results indicate that the agricultural green development of the current period is affected by that of the previous period, which can be viewed as typical path dependence and inertia effects. The estimated coefficient of agricultural industrial integration is 0.208 (P<5%), indicating that the promoting effect of agricultural industrial integration on agricultural green development is still valid after eliminating the endogeneity problem.

Robustness Tests

To ensure the robustness of the benchmarking regression results, the following methods are selected for robustness tests:

(1) Using the instrumental variable method (Model III). To solve the model's endogeneity problem, we incorporate into the model the lagged terms of the explained variables to build a dynamic panel model (that is, Model III); the instrumental variable method can also be used to eliminate this problem. In this paper, agricultural and tourism integration lagged by one and two periods are selected as instrumental variables for two-stage least squares (2SLS) estimation. Since the number of instrumental variables is larger than the number of endogenous variables, FE transformation is first performed in the first-stage estimation; then, GMM estimation is performed in the second stage, which could improve the model's estimation efficiency [5]. In the 2SLS estimation process, the validity of the instrumental variable setting needs to be tested. The results of the under identification, weak identification and over recognition tests all show that the two selected instrumental variables are effective and that there is no problem of weak instrumental variables and over recognition.

(2) Obtaining the robust standard error based on the self-help method (Model IV). Panel data usually reflect the assumption that the disturbance terms among different individuals are independent of each other and that the same individual is not auto-correlated with the disturbance terms of the same period. Based on the consideration of heteroscedasticity and autocorrelation, the robust standard errors clustered at the provincial level are not accurate enough in small samples; however, the self-help method can obtain more accurate results. Therefore, Model IV replaces clustered robust standard errors with self-help standard errors. In the calculation process of Model IV, the number of bootstrap iterations is set to 500.

(3) Changing the sample size (Model V). In general, municipalities directly under the central government enjoy greater national policy preferences and stronger autonomy. In this context, municipalities directly under the central government can improve how quickly decisions are made in economic construction, promote urban renewal based on local conditions, develop the deeper potential of cities and activate their development potential. Regarding economic development, the four municipalities (Beijing, Shanghai, Tianjin, and Chongqing) directly under the central government have formed three important economic growth poles: the Beijing-Tianjin-Hebei region, the Yangtze River Delta and the Chengdu-Chongqing twin city economic circle. Therefore, samples for these four municipalities were removed, and then the fixed effect estimation (Model V) was used.

The regression results of Models III, IV and V are shown in Table 6. The relationship between the integration of rural industries and agricultural green development did not change, and the significance of these three models did not change. Therefore, the benchmarking regression results are robust and the conclusions are reliable.

Results and Analysis of the Influential Mechanism Model

The abovementioned empirical results fully show that the development of rural industrial integration significantly promotes improvements in agricultural green development. However, further clarifying its internal mechanism to better understand the environmental effect of industrial integration is still necessary. Therefore, the following analysis starts with the scale, capital and technology effects and uses

Table 6. Results of robustness test.

Variable	Model III	Model IV	Model V
RII	0.146^{***} (4.093)	0.117^{**} (2.917)	0.196^{**} (3.123)
Control Variables	Control	Control	Control

Note: ** denote significance at 5%.

the intermediate effect test method to further verify the specific mechanism of industrial integration to promote agricultural green development.

(1) The scale effect of *RII*. Column 2 of Table 7 shows that the influence coefficient of rural industrial integration on the scale of agricultural operations is 0.081 (P<10%), indicating a significant positive relationship between rural industrial integration and the scale of agricultural operations. Given the continuous improvement in the integrated development level of rural industries, idle land resources can be used efficiently and promote agricultural scale management. The results in Column 4 show that after adding the agricultural operation scale variable into the fixed effect benchmark model, both variables are significant at least at the 10% significance level, and the coefficients are positive, indicating that the scale of the agricultural operations has a partial mediating effect in the rural industrial integration process that improves in *AGD*; the calculated mediating effect proportion is 14.032%.

(2) The capital effect of *RII*. Column 5 of Table 7 shows that the influence coefficient of rural industrial integration at the rural human capital level is 0.077 (P<10%), indicating a significant positive relationship between rural industrial integration and rural human capital. Rural industries' integrated development can improve the structure and raise the level of rural human capital. After the rural human capital variable is added to the benchmark model, the regression coefficients of the two variables are significantly positive at the 1% significance level, indicating that rural human capital has a partial mediating effect in the rural industrial integration process that promotes *AGD* and is 7.808%.

(3) The technology effect of *RII*. Column 8 of Table 7 shows that the influence coefficient of rural industrial integration on agricultural technology progress is 0.092 (P<10%), indicating that the improvement in the industrial integration development level has accelerated the integration and integrated application of agricultural technology, further promoted the progress of agricultural technology, and prompted producers to adopt the latest science and technology to realize agricultural modernization. After adding the agricultural technology progress variable into the fixed effect benchmark model, both influence coefficients of rural industry integration and agricultural technology progress on *AGD* are significantly positive, indicating that both rural industry integration and agricultural technology progress can improve *AGD*. Furthermore, the mediating effect of the technology effect is significant, and the mediating effect proportion is 17.709%. Improving factor utilization efficiency, reducing agricultural carbon emission intensity and reducing harmful factor inputs by relying on agricultural technological progress are important ways to improve agricultural green development.

Results and Analysis of the Threshold Effect Model

To demonstrate whether the impact of rural industrial integration on agricultural green development has nonlinear characteristics, the threshold effect regression model is used for testing. The first step of this test is to determine the number of threshold values and threshold variables. For this reason, the bootstrap method is used 300 times for self-sampling, and the final *RII* threshold value is shown in Table 8. The F statistic of the single threshold value of *RII* passes the test at the 1% significance level, and the corresponding threshold value is 0.497. Since neither the double threshold nor the three threshold values pass the significance test, the single threshold panel model is the most reasonable for estimation [16]. When the *RII* of the whole study area is less than or equal to the threshold value of 0.497, the regression coefficient is 0.198 (P<5%). When the *RII* exceeds 0.497, the regression coefficient is 0.267 (P<5%). This indicates that as the level of rural industrial integration (*RII*) increases, its influence on *AGD* increases as a whole. Therefore, the influence of rural industrial integration on *AGD* has a threshold characteristic.

At the same time, the threshold effects of three different regions are estimated, and the number of threshold values and threshold variables in different regions are determined. Each of the three regions has only one threshold, which is shown in Table 9. As shown in Table 9, the eastern region has the lowest threshold (*RII*=0.388). When the RII is less than the threshold, its regression coefficient is 0.211 (P<5%), and when the RII exceeds the threshold, its regression coefficient

Table 7. Regression results of mediating effect.

Scale effect			Capital effect			Technical effect		
Variable	*AOS*	AGD	Variable	RHC	AGD	Variable	ATP	AGD
RII	0.081^{*} (2.131)	0.183^{**} (2.783)	RII	0.077^{*} (2.053)	0.196^{**} (2.943)	RII	0.092^{*} (2.134)	0.209^{**} (2.738)
AOS	—	0.369^{*} (2.233)	RHC	—	0.216^{**} (2.621)	ATP	—	0.410^{**} (2.473)
Mediating effect ratio	—	14.032%	Mediating effect ratio	—	7.808%	Mediating effect ratio	—	17.709%

Note: *, **, *** denote significance at 10%, 5% and 1% level, respectively.

Table 8. Threshold characteristics test.

Threshold variable	Model test	Threshold value	F statistics	P value	Critical value		
					1%	5%	10%
RII	Single threshold	0.497	21.954***	0.001	28.943	14.321	6.765
	Double thresholds	Threshold 1: 0.378 Threshold 2: 0.588	6.644	0.232	11.134	6.654	2.431
	Three thresholds	—	2.670	0.108	6.658	4.054	1.021

Note: *, **, *** denote significance at 10%, 5% and 1% level, respectively.

Table 9. Threshold effect estimation results.

Region	Explanatory variable	Threshold estimate	Coefficient	T-Value	Standard error
The whole region	*RII*	*RII*≤0.497	0.198**	3.035	0.001
		RII>0.497	0.267**	2.986	0.025
The eastern region	*RII*	*RII*≤0.388	0.211***	5.098	0.007
		RII>0.388	0.304***	3.805	0.087
The central region	*RII*	*RII*≤0.551	0.118***	4.981	0.002
		RII>0.551	0.191***	3.912	0.011
The western region	*RII*	*RII*≤0.612	0.089	1.093	0.132
		RII>0.612	0.229**	2.775	0.014

Note: *, **, *** denote significance at 10%, 5% and 1% level, respectively.

increases to 0.304 (P<5%). The eastern region has convenient transportation, a suitable climate, a high degree of urbanization and a high economic level, and residents have high demand for agricultural processing products and agro-ecological leisure products. The western region has the highest threshold (*RII* = 0.612), and when *RII* is less than the threshold, its influence coefficient is not significant. When the *RII* exceeds the threshold, its coefficient increases to 0.229 (P<5%). This indicates that the integration of rural industrial areas cannot significantly promote the growth in agricultural total factor productivity when the development level of agricultural industrial integration is low in western China. Only when *RII* increases is its influence on improving *AGD* significant. This is mainly because most of the western provinces are economically underdeveloped, it is difficult to popularize advanced agricultural technology, the market space for agricultural processing products and agricultural leisure products is relatively limited, and the rural industrial integration development power is insufficient. Therefore, in the early stage of integration, RII has no significant effect on *AGD*. When *RII* exceeds the 0.612 threshold, agro-ecological or agro-processed products can create more value for agricultural producers, prompting them to pay more attention to the green development of agriculture, consciously reducing the input of harmful environmental factors in the production process, and finally promoting improvements in *AGD*.

Conclusion and Policy Recommendations

Rural industrial integration not only has an economic effect on promoting agricultural income but also has an effect on improving rural human capital, promoting agricultural scale production and applying green agricultural production methods, which are of great significance for the green development of agriculture. However, while existing studies have focused on the economic effect of rural industrial integration, there is little evidence that they have paid enough attention to its environmental effect. In view of this, we analyse the theoretical logic of the impact of rural industrial integration on agricultural green development from the three aspects of scale management, human capital and technological progress. On this basis, the two-way fixed effect model, intermediary effect model and threshold model are used to investigate the influence of rural industry integration on *AGD* and its mechanism. The results show the following.

First, both the level of rural industrial integration (*RII*) and the level of agricultural green development (*AGD*) of the whole research area have continuously improved over time, at average annual growth rates of 3.819% and 4.584%, respectively. Overall, the *RII* and *AGD* in the eastern region are higher than those in the central and western regions.

Second, rural industrial integration plays a positive role in promoting agricultural green development.

The integrated development of rural industries always adheres to the ecological development concept with agriculture and the rural environment as the basic support. Therefore, this integrated development can promote agricultural intensification and clean production and management, contributing to the green development of agriculture.

Third, rural industrial integration has significant scale, capital and technology effects; that is, industrial integration can indirectly enhance *AGD* by expanding the scale of agricultural operations, improving rural human capital and promoting agricultural technological progress. Panel threshold analysis shows that the relationship between rural industrial integration and agricultural green development is not a simple linear relationship. Given improvements in the development of rural industrial integration, its promoting effect on *AGD* is increasingly prominent.

This study provides theoretical logic and empirical evidence for understanding the environmental effects of rural industrial integration, and the following policy implications are offered.

First, we should further accelerate the integration of rural industries, leverage the green leading role of industrial integration, focus on cultivating new industries and business forms such as eco-agriculture with high added value, and create a sound environment for the integrated development of rural industries. While promoting agricultural income, we should leverage the advantages of industrial integration in improving the ecological environment to add new driving forces to agricultural modernization.

Second, we should promote the appropriate scale of agriculture operations and use science and technology to unleash agricultural productivity. We should improve the structure of agricultural industries, guide households to shift from decentralized to appropriately scaled operations, encourage farmers to transfer or manage their land contiguously, and actively cultivate new types of large-scale agricultural operations to fully mobilize their enthusiasm and initiative. We should continue to transform the agricultural production mode, view the "double carbon" goal as an opportunity, leverage the role of modern science and technology in enabling agricultural production, and realize the low-carbon development of agricultural production.

Third, vocational education and high-quality farmer training should be used to strengthen farmers' training in production skills and knowledge, accelerate the transformation of "new farmers", expand the stock of rural labour and human capital, strengthen the ability of talent to support the integrated development of rural industries, and reduce agricultural carbon emissions through scientific agricultural production.

In general, in this paper, we demonstrate the relationship between rural industry integration and agricultural green development by quantitatively measuring their levels, which is conducive to expanding the research content of the rural industry integration effect and provides insights for exploring the influencing factors of agricultural green development. Limited by the availability of data, we attempt to conduct empirical studies based on provincial panel data and pay insufficient attention to micro regions. In the future, microanalysis will be carried out by selecting typical case sites, such as industrial integration demonstration sites, to improve the accuracy of the research conclusions.

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Conflict of Interest

The authors declare no conflict of interest.

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