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*Original Research*

# The Impact and Mechanism of Rural Industrial Integration Development on Agricultural Green Total Factor Productivity

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**Abstract**

Realizing the green development of agriculture is an important foundation for the sustainable development of the economy and society. In China, rural industrial integration is a major innovation in the development of rural productivity in the new development stage, which is of great significance for promoting the green development of agriculture and enhancing the green total factor productivity of agriculture. Based on the panel data of 30 provinces in China from 2010 to 2021, the super-SBM method was used to estimate agricultural green total factor productivity (AGTFP), and the comprehensive index method and entropy method were used to measure the level of rural industrial integration. Based on the spatial autoregressive model with a spatial autoregressive error term (SARAR model), intermediary effect model and threshold effect model with a spatial autoregressive error term, the influence and mechanism of rural industry integration on AGTFP were demonstrated. The results show that (1) there is a significant positive relationship between the development level of rural industry integration and AGTFP; that is, the development of rural industry integration can effectively promote the improvement of AGTFP and promote the green development of agriculture. Considering the spatial effect and endogeneity, the robustness test based on the generalized spatial two-stage least square method (GS2SLS) further strengthens the above mentioned conclusion. (2) Rural industrial integration has a significant scale effect, capital effect and technology effect; that is, rural industrial integration mainly promotes AGTFP indirectly by promoting agricultural scale management, improving rural human capital and promoting agricultural technological progress. (3) The influence of rural industry convergence on AGTFP has the characteristics of a single threshold. With the improvement of the integration level, the influence of rural industry convergence on AGTFP shows an increasing trend. Therefore, China should strengthen the deeply integrated development of rural industries, promote the appropriate scale operation of agriculture and the adjustment of planting structure, accelerate the process of agricultural technology innovation and rural human capital accumulation, and realize

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the win-win situation of rural economic and ecological construction.

**Keywords**: rural industry integration, agricultural green total factor productivity, SARAR model, intermediary effect model, threshold effect model

## Introduction

Agriculture is a major global source of greenhouse gas emissions, and agricultural production has become one of the major sources of environmental pollution in China. As a traditional agricultural country, China has made remarkable achievements in agriculture since the implementation of reform and opening up. As the world's most populous developing country, China feeds nearly 21% of the world's population with only 9% of the world's arable land [1]. China's total grain output rose from 430.7 million tons in 2003 to 686.53 million tons in 2022, representing 19 consecutive years of growth [2]. However, in the process of the rapid development of agricultural modernization, the massive consumption of fossil energy, the excessive use of pesticides, the destruction of soil and other problems have led to serious agricultural nonpoint source pollution and carbon emissions. Thus, it is inevitable to promote the transformation of agricultural production from the traditional extensive growth mode of high input, high consumption and high yield to the mode of green, low-carbon and sustainable development. An inefficient production mode is the direct cause of high agricultural carbon emissions and the deterioration of the rural ecological environment [3]. To realize the transformation and upgrading of the agricultural development mode, the transformation of the rural production mode is still needed.

As an important way to promote the transformation of the rural production mode in the new development stage in China, rural industrial integration has an important impact on rural economic growth and social prosperity. To this end, the Chinese government has introduced a series of policies to support the integrated development of rural industries. In 2015, the No. 1 Document of the Central Committee proposed for the first time to "promote the integrated development of the primary, secondary and tertiary industries in rural areas". In the same year, The General Office of the State Council issued the Guiding Opinions on Promoting the Integrated Development of the Primary, Secondary and Tertiary Industries in Rural Areas. The integration of rural industries has broken the boundaries of traditional rural industries, and multifunctional and modern agriculture based on the development of resources, folk culture, economic development and infrastructure in different regions has greatly improved the income level of farmers and promoted the economic development of rural areas [4]. In particular, China is currently in a critical period of transformation from traditional agriculture to modern agriculture. Whether industrial integration can promote economic growth in rural areas while taking into account rural environmental protection, reduce agricultural carbon emissions and reduce harmful agricultural output should be given more attention.

However, a review of the literature shows that the economic effect of rural industrial integration has aroused an extensive amount of attention from scholars, but less attention has been given to its environmental effect. Agricultural green total factor productivity (AGTFP) is an objective index reflecting sustainable agricultural development that aims to maximize agricultural output productivity and minimize agricultural pollution emissions under the premise of determining agricultural input factors [5-6]. As a large agricultural country, it is imperative that China improve its AGTFP to solve the dilemma that the crude oil production mode dominates Chinese agriculture. 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, thereby promoting the realization of a green and energy-saving agricultural production mode; such integration will inevitably have an impact on agricultural green total factor productivity. However, only at the empirical level have scholars paid little attention to it. Thus, as an advanced form of agricultural industrialization, does rural industry integration have an impact on AGTFP? How does rural industry integration influence AGTFP? Answers to these questions will help clarify the ecological and environmental effects of rural industry integration and its mechanism, promote agricultural carbon emission reduction, and promote the green development of agriculture. Therefore, this paper will use empirical tools to investigate the impact of rural industry integration on AGTFP and its mechanism to provide implications for promoting rural industry integration development and agricultural green sustainable development.

Given the context above, the main purposes of this paper are as follows: (1) to assess the levels of agricultural total factor productivity (AGTFP) and agricultural industry integration (RII) in China based on data from 30 provinces among 2010-2021; (2) to demonstrate the impacts of agricultural industry integration on AGTFP and the characteristics of this effect; (3) to construct the influence mechanism framework of rural industrial integration on AGTFP and empirically illustrate the influence mechanism; and (4) to provide implications for improving the level of rural industrial integration and its role in promoting AGTFP. Possible contributions of this paper are as follows. First, based on panel data from 30 provinces in China, this paper uses a two-way fixed effect model, SARAR model and intermediary effect model to investigate the impact of rural industrial integration on AGTFP to provide empirical evidence and recommendations for achieving coordination between economic and social development and ecological environment improvement and promoting the final "carbon peaking and carbon neutrality goals" (also known as "double carbon goals"). Second, based on the "scale-capital-technology" framework, the mechanism of AGTFP improvement promoted by rural industrial integration in China is clarified, which is helpful to further understand the environmental effects of rural industrial integration. Moreover, based on the SARAR model and threshold effect model, the influence characteristics of rural industry integration on AGTFP are demonstrated, which can reveal the influence of rural industry integration on AGTFP more scientifically and accurately.

## Literature Review

### Rural Industry Integration

In the 1990s, Japanese scholar Naratomi Imamura proposed Japan's six industries theory to solve the problem of lack of agricultural successors and rural decline in Japan, which is the earliest research involving the integration of agricultural industries [7]. 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 the 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 [8].

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 generally believe that industrial integration has a positive impact on farmers' income. The development of agricultural industrialization promotes an increase in farmers' household income by more than 50%, but this promotion effect has regional heterogeneity [9]. Furthermore, industrial integration can not only promote an increase in farmers' income but also narrow the income gap between farmers with different income levels; promoting the upgrading of the agricultural industrial structure is an important channel [10]. In terms of 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 of 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 [11]. At present, while the literature directly examining the environmental effects of industrial integration mainly focuses on the relationship between industrial agglomeration and environmental pollution, the research conclusions are 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 Total Factor Productivity

Achievements have been made in AGTFP research, which mainly focuses on the calculation of AGTFP. In the calculation method, stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are mainly used. Emrouznejad and Yang (2018) reviewed the literature from 1978 to 2016 and found that the DEA method has high applicability in measuring agricultural production efficiency [12]. Tone (2001) proposed the slack-based measurement (SBM) standard effect model to solve the problem that the DEA model cannot be applied to the non-proportional variation of input or output indicators [13]. However, when the standard SBM model has more than two effective units in the same period, it cannot sort them; thus, the superefficient SBM model comes into being [14].

In terms of index selection for measuring AGTFP using the DEA-SBM model, some studies take agricultural nonpoint source pollution as an unexpected output and include it in the measurement of agricultural green total factor productivity [15-17]. Some studies take carbon emissions in agricultural production processes as unexpected outputs to measure agricultural green total factor productivity [18-20]. However, in general, due to the deviation in the selection angle of undesirable output in existing studies, the calculation results of AGTFP are also different [21]. Therefore, it is necessary to comprehensively consider various pollution types, such as agricultural nonpoint source pollution and agricultural carbon emissions, to measure AGTFP more comprehensively and accurately.

With the improvement of AGTFP measurement methods, scholars have begun to pay attention to the factors affecting AGTFP. Ye et al. argued that the influence of agricultural fiscal expenditure on agricultural green total factor productivity has a certain lag [21]. Zhang et al. posited that the fertilizer application rate, total power of agricultural machinery, and farmland water conservancy facilities have a significant promoting effect on AGTFP [22]. Gao et al. argued that the improvement of the agricultural informatization level is conducive to the growth of AGTFP [23].

The authors also found that regional characteristics are one of the factors affecting the growth of AGTFP. Other studies have found that agricultural tax relief [24], rural financial development and environmental regulation [26] can promote AGTFP growth, while urbanization can inhibit AGTFP growth [25-27]. However, few studies have examined the effect of rural industrial integration on AGTFP.

## Materials and Methods

### Theoretical Analysis

Industrial integration not only promotes rural economic development and improves economic benefits but also expands the agricultural operation scale, improves rural human capital and promotes agricultural technological progress by integrating and optimizing land, capital, technology and other elements, thus inevitably having an impact on the rural ecological environment [28]. Therefore, this paper pays special attention to the scale effect, capital effect and technology effect of rural industry integration development and its influence on AGTFP.

(1) Rural industrial integration can expand the scale of agricultural operations. The rapid development of industrial integration reuses unused land in rural areas and improves land transfer efficiency [29]. The expansion of land transfer scope further gives birth to more large professional households, family farms, leading agricultural enterprises and other new business entities, accelerating the realization of large-scale agricultural land management. 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 mismatch, transfer idle land into cooperatives or family farms and other new agricultural operating entities, and expand the scale of agricultural operation [30]. Generally, there is a positive relationship between agricultural scale operation and the agricultural ecological environment, and scale operation is conducive to promoting the green development of agriculture. Meanwhile, the expansion of operation scale can enhance farmers' awareness of green production, promote farmers to adopt green production technology, enrich farmers' social capital, broaden the channels of information acquisition, increase the application of organic fertilizer, and realize the improvement of the agricultural ecological environment [31].

(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' education investment, improves the structure of rural human capital, and plays a positive role in promoting the accumulation of rural human capital [32]. Specifically, industrial integration will layout the industrial chain in rural areas, not only keeping industrial interests in rural areas but also keeping high-quality labour forces in rural areas and promoting the deepening of rural human capital. At the same time, many non-agricultural 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 will help reduce environmental pollution. Generally, farmers with a high level of human capital often have innovative management methods and production and operation modes, which can effectively avoid unnecessary waste of resources, improve labour production efficiency and use efficiency of polluting factors, obtain higher agricultural output with less input of production factors, reduce the use of inputs such as fertilizers and pesticides, and promote green agricultural production [33].

(3) Rural industrial integration can promote the progress of agricultural technology. The integrated development of rural industries can accelerate the process of technological penetration between industries, promoting the progress of agricultural science and technology. Chen et al. (2022) proved that promoting agricultural technological progress is one of the important ways to improve AGTFP through rural industry integration [34]. The concentration degree of upstream and downstream enterprises in the rural industrial chain is deepened, and inter-industry technology transfer and collaborative innovation are accelerated, which further improves the agricultural technology innovation ability related to realizing industrial linkage and business model innovation. Among the many factors affecting the rural environment, agricultural technology progress is the main way to optimize the traditional factor input structure and reduce agricultural carbon emission intensity [35]. Agricultural technological progress can bring about scientific decision-making, improve the accumulation of experience and knowledge of farmers, 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 the utilization of resources, and effectively reducing the emission of pollutants from agricultural nonpoint sources.

### Variables and Data

#### *Explained Variable: AGTFP*

In this paper, agricultural green total factor productivity (AGTFP) is taken as the explained variable. When considering undesired outputs, AGTFP is usually

Table 1. Agricultural input-output indicators.

| Variables | Iindicators | measure indicators | Unit |
|---|---|---|---|
| Input indicators | Agricultural machinery input | Total power of agricultural machinery | 10 thousand kw |
| | Agricultural labour input | Agricultural employment | 10 thousand people |
| | Agricultural land input | Sown area of the crops | 1 thousand hectares |
| | Agricultural resource input | Application amount of pure chemical fertilizer | 10 thousand tons |
| | | Pesticide usage | 10 thousand tons |
| | | Agricultural film usage | 10 thousand tons |
| | | Effective irrigated area | 10 thousand tons |
| | | Agricultural diesel use | 1 thousand hectares |
| Output indicators | Desirable output | Agricultural output value | 100 million Yuan |
| | Undesirable output | Agricultural carbon emissions | 10 thousand tons |
| | | Pollution from nonpoint agricultural sources | 10 thousand tons |

measured using a superefficient SBM model containing undesired outputs. To this end, it is necessary to determine the input index, the expected output index and the unexpected output index. As agriculture, forestry, animal husbandry and fishery industries differ greatly in terms of environmental pollutant emissions, the narrow sense of agriculture (namely, the planting industry) is taken as the research object according to the study of Zhu et al. (2021) [36]. The specific indicators are shown in Table 1. Here, expected output indicators are measured in terms of total agricultural output. Agricultural unexpected output mainly considers agricultural nonpoint source pollution and the agricultural carbon emission index. Agricultural nonpoint source pollution mainly involves pesticide residues, agricultural film residues and fertilizer residues. The pollution amount of a pollution source is equal to the total pollution amount obtained by adding the product of polluting input and its pollution coefficient. According to the relevant literature, the residual coefficient of chemical fertilizer, the loss coefficient of pesticide and the residual coefficient of agricultural film are 0.75, 0.5 and 0.1, respectively [36]. According to West and Marland (2002), agricultural carbon emissions mainly come from the use of fertilizers, pesticides, agricultural machinery power, agricultural irrigation and other channels. The carbon emission coefficient above is 0.90 (kg/kg) for chemical fertilizer, 4.93 (kg/kg) for pesticide, 0.18 (kg/kW) for total power of agricultural machinery and 20.48 (kg/ha) for agricultural irrigation [37], according to which the total agricultural carbon emission is calculated.

Compared with the radial and angular DEA model and SBM model, the super-SBM model can evaluate and rank multiple fully effective decision units effectively. Therefore, the super-SBM model is used to calculate the AGTFP in China in this study. Here, 360 decision-making units (DUS) of 30 provinces from 2010 to 2021 are used. Suppose the *kth* decision unit ($j$ = 1, 2..., n) has input vector $x \in R^M$, expected output vector $y^g \in R^{s_1}$, and undesired output vector $y^g \in R^{s_2}$. Additionally, we define the matrixes as follows: $X = [x_1, x_2, ..., x_n] \in R^m \times n$, $Y^g = [y_1^g, y_2^g, ..., y_n^g] \in R^{s_1} \times n$ and $Y^b = [y_1^b, y_2^b, ..., y_n^b] \in R^{s_2} \times n$. For the measured decision unit k, we have Formula (1) as follows:

$$\min \rho = \frac{1 + \frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{x_k}}{1 - \frac{1}{s_1+s_2}\left(\sum_{r=1}^{S_1} s_r^g \big/ y_k^g + \sum_{t=1}^{S_2} s_t^b \big/ y_k^b\right)}$$

$$s.t. \sum_{j=1, j\neq k}^{n} x_j \lambda_j - s_i^- \le x_k$$

$$\sum_{j=1, j\neq k}^{n} y_j \lambda_j + s_r^g \ge y_k^g$$

$$\sum_{j=1, j\neq k}^{n} y_j \lambda_j - s_t^b \le y_k^b$$

$$\lambda \ge 0, s^g \ge 0, s^b \ge 0, s^- \ge 0 \quad (1)$$

In Formula (1), $\lambda$ is the weight vector, and $s_i^-$, $s_r^g$, and $s_t^b$ are slack variables. $\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}$ represents the average inefficiency of the inputs, $\frac{1}{s_1+s_2}(\sum_{r=1}^{s_1} S_r^g / y_{rk}^g + \sum_{t=1}^{s_2} S_t^b / y_{tk}^b)$ represents the average inefficiency of the outputs. $\rho$ is the efficiency value of the decision unit and can be greater than 1; Thus, the effective decision unit can be distinguished.

### *Core Explanatory Variable*

The integrated development of rural industry (RII) is the core explanatory variable of this study. At present, there no comprehensive index system that can reflect the level and quality of the integrated development of rural industries. Only Li et al. (2017) have constructed

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

| Measure objective | First-grade index | Second-grade index | Unit |
|---|---|---|---|
| The level of rural industrial integration | 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 |

a comprehensive evaluation index system that can reflect the level of rural industrial integration [38]. On the basis of the abovementioned research and considering the availability of data at the regional level, this paper constructs a comprehensive evaluation index system for the integrated development level of rural industries from five aspects: the extension of agricultural industrial chain, the expansion of agricultural multifunction, the cultivation of new agricultural business forms, the integrated development of agricultural service industry and the improvement of interest linkage mechanism (Table 2).

In this paper, the integrated development index of rural industries is measured based on the comprehensive index and entropy value method. First, the above indices are standardized to eliminate the influence of different dimensions of data. Referring to Wang et al. (2016)[39], the calculation formula of standardized processing is as follows:

$$U_{ij} = (V_{ij} - V_{\min(j)})/(V_{\max(j)} - V_{\min(j)}) \times 10 \quad (2)$$

where $U_{ij}$ represents the standardized data of the *jth* indicator of the *ith* province, and $V_{ij}$ represents the original data. Based on the standardized data, the linear weighted summation method is used to calculate the comprehensive index of the rural industry integration development level of each province during 2010-2021. The formula is as follows:

$$AII_i = \sum_{j=1}^{n} \omega_{ij} U_{ij}, \sum_{j=1}^{n} \omega_{ij} = 1 \quad (3)$$

In Formula (3), $\omega_{ij}$ is the weight of each secondary index. To avoid subjective influence as much as possible, the entropy weighting method is adopted in this paper to determine the weight of each secondary index. The main steps are as follows. First, specific gravity transformation is performed on standardized data, and the formula is as follows:

$$W_{ij} = U_{ij} / \sum_{j=1}^{m} U_{ij} \quad (4)$$

Second, calculate the entropy value of the *jth* index, and the formula is as follows:

$$E_j = -(\text{In}m)^{-1} \sum_{i=1}^{m} W_{ij} \text{InW}_{ij}, 0 \le E_{ij} \le 1 \quad (5)$$

Finally, the information utility value $d_j$ and weight $\omega_j$ of the entropy value of the *jth* index are calculated, and the formula is as follows:

$$\omega_j = d_j / \sum_{j=1}^{n} d_j, d_j = 1 - E_j \quad (6)$$

*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. Agricultural operation scale (*AOS*) is expressed by per capita crop sown area, which is obtained by taking the ratio of the sown area of the crops to the agricultural employees and then applying logarithmic treatment. Rural human capital (*RHC*) is measured by the average years of schooling of the rural population. Agricultural technical progress (*ATP*) is measured by agricultural total factor productivity, which is measured by the DEA-Malquist index method according to Han and Zhang (2019) [40].

In addition to rural industrial integration, there are other important variables that will also have an impact on AGTFP. In this paper, rural infrastructure (*RIC*), rural economic development (*RED*), level of financial support for agriculture (*FIS*), level of industrialization (*IND*), and agricultural planting structure (*APS*) are selected as control variables. The specific measurement methods are shown in Table 3. The descriptive statistical results of all variables in the empirical test model are also shown in Table 3.

Table 3. Variables and calculation method.

| Variables | Variable name | Calculation method | Unit | Mean | Standard deviation |
|---|---|---|---|---|---|
| Explained variable | AGTFP | Super-SBM method | — | 1.067 | 0.074 |
| Core explanatory variable | RII | Comprehensive index method and entropy method | — | 5.256 | 3.093 |
| 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 |

*Characteristics of AGTFP and RII in China*

According to the results of the super-SBM model used to calculate the AGTFP, the change trend of the annual mean AGTFP in 30 provinces and four regions from 2010-2021 is shown in Fig. 1. From 2010-2021, the annual mean value of AGTFP fluctuated between approximately 0.979 and 1.189 and reached its maximum value in 2021. In recent years, the central government has attached great importance to environmental protection. To reduce agricultural pollution, governments at all levels have formulated a series of treatment measures, and cleaner agricultural production technologies have been effectively promoted. In general, China's AGTFP showed an upwards trend from 2010 to 2021, with an average annual growth rate of 1.81%. The AGTFP of the three different regions was greater than 1 in most years. During the study period, the average annual growth rates of AGTFP in the eastern, central and western regions were 1.73%, 1.67%, 2.53% and 2.06%, respectively. The growth rate of AGTFP in western regions has been higher than that in other regions, which

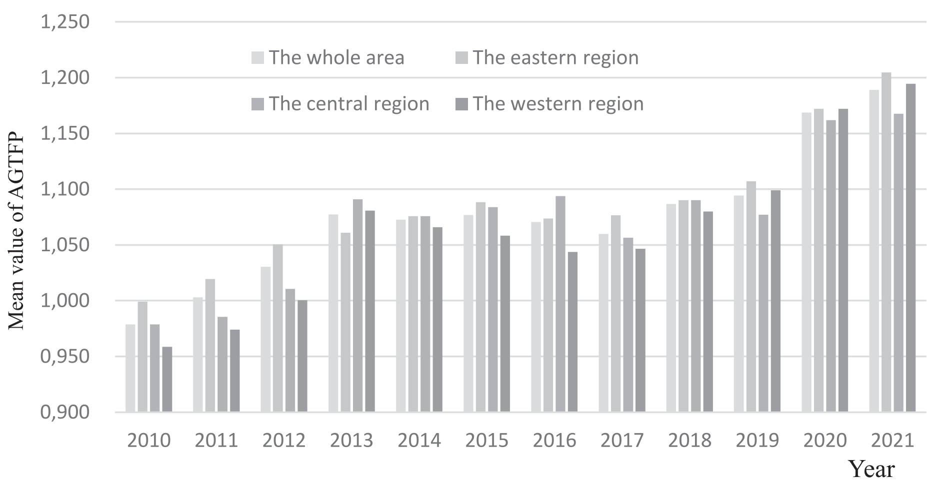


Fig. 1. The development trend of AGTFP in China from 2010-2021.

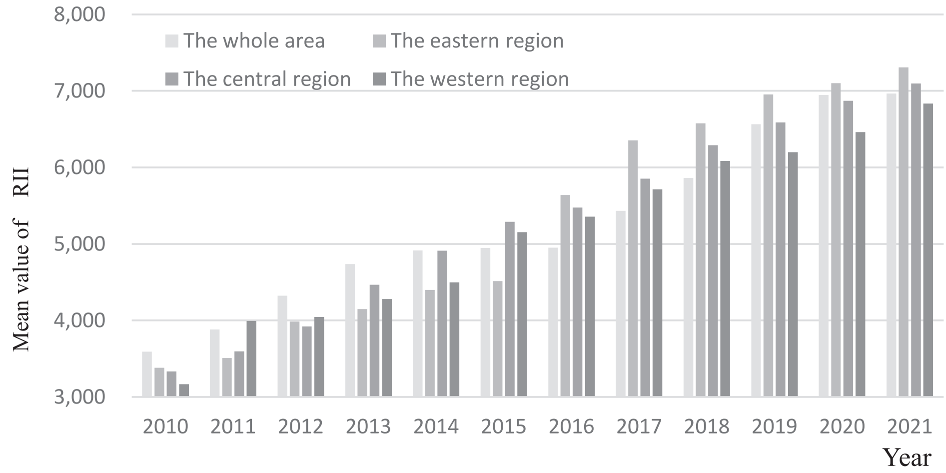


Fig. 2. The development trend of RII in China from 2010-2021.

may be related to the long-term backwards development level of agricultural production in western provinces. In recent years, with the introduction of advanced green production technology, AGTFP has been growing rapidly in this area.

The integration of rural industries plays a significant role in promoting income and employment; thus, it is also strongly supported by governments at all levels. Through calculation, the annual average of RII in the whole study area is found to have been increasing over time, with an average annual growth rate of 6.293%. In terms of subregions, the mean RII of the eastern region is the highest, while the mean RII of the western region is relatively low (Fig. 2). The eastern region has a sound economic foundation, complete transportation infrastructure and public service conditions, and a high level of rural integration driven by key factors such as regional economic development level and market demand. Relatively speaking, these driving factors are not prominent in the western region.

### *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 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 R language and GeoDa software.

## Methodology

### *Panel Unit Root Tests*

Before using the econometric model for empirical testing, it is necessary to test the stationarity of the sample data to avoid the phenomenon of pseudo-regression as much as possible. In this paper, three methods (IPS, LLC and ADF-Fisher) are adopted to conduct a panel unit root test for all variables [41]; the test results are shown in Table 4. As seen from Table 4,

Table 4. The Panel unit roots test.

| Variables | *AGTFP* | *RII* | *AOS* | *RHC* | *ATP* |
|---|---|---|---|---|---|
| IPS | -2.988** | -6.934*** | -4.530*** | -5.412*** | -5.296*** |
| LLC | -5.305*** | -4.436*** | -7.086*** | -3.862*** | -2.908** |
| ADF-Fisher | 13.936*** | 28.941*** | 19.547*** | 39.754*** | 23.552*** |
| Variables | *RIC* | *RED* | *FIS* | *IND* | *APS* |
| IPS | -4.651** | -3.004*** | -3.462*** | -7.198*** | -4.076*** |
| LLC | -7. 531*** | -3.421*** | -9.756*** | -5.981*** | -7.064** |

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

all variables pass the panel unit root test, and the panel data are stable, thus meeting the basic requirements of econometric modelling. Therefore, the established econometric model has good explanatory power.

*Fixed Effect Model*

If there are unobserved factors in the model, it will lead to missing variable bias, which can be effectively solved by using a fixed effects model. Based on this, the two-way fixed-effect panel model is used to test the linear relationship between rural industry convergence and AGTFP. The model is set as follows:

$$AGTFP_{it} = \alpha_0 + \beta_1 RII_{it} + \sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \upsilon_t + \xi_{it} \tag{7}$$

In the above formula, the explained variable is $AGTFP_{it}$; the explanatory variable is $RII_{it}$, which is the level of rural industry integration; and $Col_{it,k}$ is a set of control variables. Subscripts $i$ and $t$ represent province and year, respectively, and $\mu_i$ is the individual effect. $\xi_{it}$ represents the random error term, which is subject to a normal distribution.

*Mediation Effect Model*

To verify the mediating role of operating scale, human capital and technological progress in the relationship between rural industrial integration and AGTFP, this paper constructs the mediation effect model according to the step-up testing method proposed by Baron and Kenny (1986) [42]. The test of the intermediary effect requires three steps. First, the impact of RII on AGTFP is tested, which is consistent with Model (1). Second, the influence of RII on mediating variable $Med_{it}$ is tested, as shown in Model (8). Finally, RII and mediating variables are included in the regression model, in which AGTFP is the explained variable, as shown in Model (9). Specific model settings are as follows:

$$Med_{it} = \alpha_0 + \beta_1 RII_{it} + \sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \upsilon_t + \xi_{it} \tag{8}$$

$$AGTFP_{it} = \alpha_0 + \beta_1 RII_{it} + \beta_2 Med_{it} + \sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \upsilon_t + \xi_{it} \tag{9}$$

where $Med_{it}$ represents different mediating variables, and the other variables in Formula (9) are the same as in Formula (7).

*Spatial Economic Models*

(1) Spatial autocorrelation test

Spatial autocorrelation measures the degree of correlation shown by specific attributes of adjacent geographic units in space, which can be divided into global spatial autocorrelation and local spatial autocorrelation. The former is the test of overall correlation, and the latter is the test of local regional correlation. In this paper, *Moran's I* index of global spatial autocorrelation is used to test whether AGTFP has spatial correlation.

$$Moran' I_{global} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}(Y_i - \bar{Y})(Y_j - \bar{Y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}} \tag{10}$$

In the above formula, I is the global *Moran's I* index, ranging between [-1, 1]. When $I$ is greater than 0, it indicates that $Y$ has a positive spatial correlation. When $I$ is less than 0, it indicates there is a negative spatial correlation. $Y_i$ *and* $Y_j$ represent the observed value of the integration level of agricultural industries. $W_{ij}$ is the spatial weight matrix.

Here, two kinds of spatial weight matrices are used for model estimation. First, for the geographical distance spatial matrix (W1), the calculation formula is $W_{ij} = 1/d_{ij}^2 (i \neq j)$. $d_{ij}$ is the direct distance between two provincial capitals. The geographical distance space matrix is taken as the reference matrix. Second, for the economic geography nested space weight matrix (W2), the calculation formula is $W_{ij} = 1/|\bar{Y}_i - \bar{Y}_j + 1| e^{-d_{ij}}, (i \neq j)$. $\bar{Y}_i$ and $\bar{Y}_j$ represent the per capita GDP of provinces $i$ and $j$, respectively, and $d_{ij}$ is defined as described above. The nested spatial weight matrix of economic geography is mainly used for robustness analysis.

(2) The Spatial Panel Model

The spatial autoregressive spatial autoregressive model with a spatial autoregressive error term (SARAR) can not only reflect the spatial autocorrelation of the dependent variable but also take into account other influencing factors with correlation in the spatial disturbance term. At the same time, the SARAR model has the advantages of both a spatial autoregressive model and spatial error model, which means that its application scope is relatively wider. The SARAR model in matrix form is set as follows:

$$AGTFP_{it} = \alpha_0 + \beta_1 RII_{it} + \sum_{k=1}^{n} \lambda_k Con_{it,k} + \chi_i + \nu_t + \mu_{it}$$
$$\mu_{it} = \theta W \mu_{it} + \varepsilon_{it} \tag{11}$$

In the above equation, $\rho$ is the spatial autoregressive coefficient of AGTFP, $\theta$ is the spatial error coefficient, and $W$ is the spatial weight matrix. β and $\lambda$ are the parameters to be estimated; $\chi_i$ and $v_i$ represent the spatial and temporal effects, respectively; and $\varepsilon_{it}$ follows the spatial error term of the independent distribution. For the above model, the maximum likelihood estimator (MLE) is used for estimation.

*Threshold Regression Model*

With the continuous deepening of rural industrial integration, the ecological premium of agriculture will be fully realized, which will further strengthen the green production behaviour of producers and further improve the green total factor productivity of agriculture. Therefore, the influence of rural industry integration on AGTFP may be enhanced with an increase in the level of integration. Therefore, the influence of rural industry convergence on AGTFP may have a nonlinear relationship. Here, the level of rural industry convergence is taken as the threshold variable to test this nonlinear relationship, and the threshold regression model is finally established, as shown in the equation below:

$$AGTFP_{it} = \alpha_0 + \beta_{11}RII_{it}I(RII_{it} \le \theta_1) + \beta_{12}RII_{it}I(\theta_1 < RII_{it} \le \theta_2) + \cdots + \beta_{1,n}RII_{it}I(\theta_{n-1} < RII_{it} \le \theta_n) + \beta_{1,n+1}RII_{it}I(RII_{it} > \theta_n) + \sum_{k=1}^{n} \lambda_k Con_{it,k} + \mu_i + \nu_t + \xi_{it} \quad (12)$$

In the above equation, $\theta_1$, $\theta_2$ and $\theta_n$ are threshold values, and $\beta_{11}$, $\beta_{12}$ 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 Formula (7). If there is only one threshold value, the above formula can be simplified as follows:

$$AGTFP_{it} = \alpha_0 + \beta_1 RII_{it}(RII_{it} \le \theta) + \beta_2 RII_{it}I(RII_{it} > \theta) + \sum_{k=1}^{n} \lambda_k Con_{it,k} + \mu_i + \nu_t + \xi_{it} \quad (13)$$

## Results and Discussion

### Baseline Regression Results

*Spatial Correlation Test*

In this paper, the spatial autocorrelation test of AGTFP in 30 provinces is conducted by using the global Moreland index. Through testing, it is found that the global Moran's I index is greater than 0 over the years and is significant at the significance level of at least 10%, indicating that the AGTFP of each province has a significantly positive spatial autocorrelation, which suggests the phenomenon of spatial agglomeration. Therefore, this study is suitable and needs to use the spatial econometric model for analysis. In addition, the geographical distance weight matrix (W1) and economic and geographical distance nested spatial weight matrix (W2) are used to calculate the Moran's I index. Compared with the geographical distance matrix, the economic and geographical distance nested spatial weight matrix also considers the geographical distance and economic relations of spatial units, which can reflect the spatial correlation between provinces more comprehensively.

*Estimation Results of the Econometric 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 AGTFP. The BP test shows that the random effect model is more suitable than the mixed effect model. Hausman's test finds 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, the two-way fixed effect model is selected for empirical analysis.

The estimation results of RII's influence on AGTFP based on the bidirectional fixed effect model and SARAR model are shown in Table 6. Combined with the estimation results of the different models shown in Table 6, the influence of rural industry integration on AGTFP passes the hypothesis test at the significance level of 1%, and the coefficient is positive, indicating that rural industry integration has a significant promoting effect on AGTFP. Specifically, taking the SARAR Model (Model (2)) as an example, the influence coefficient of the level of rural industry integration on AGTFP is 0.175 ($P<5\%$). The development of rural industry integration is conducive to the promotion of AGTFP; that is, the development of rural industry integration has a strong environmental effect while promoting 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 sustainable development ability of agricultural systems.

In terms of control variables, changes in agricultural planting structure can also significantly increase AGTFP. 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 development of the rural economy and the improvement of the rural education level have further reduced the intensity of pesticide and agricultural film use, which is conducive to the improvement of AGTFP. In addition, the level of industrialization inhibits the promotion of AGTFP. China's industrialization started with the support of agriculture, and industrialization has created factors, technologies, product markets and other conditions for agricultural development. The development of industrialization is especially beneficial to the development of petroleum agriculture. With the development of industrialization, the development degree of petroleum agriculture is also deepening,

Table 5. Global *Moran's I* values of AGTFP from 2010-2021.

| Spatial Weight Matrix = W1 | | | | Spatial Weight Matrix = W2 | | | |
|---|---|---|---|---|---|---|---|
| Year | Moran's I | Year | Moran's I | Year | Moran's I | Year | Moran's I |
| 2010 | 0.334** | 2016 | 0.369** | 2010 | 0.328* | 2016 | 0.387* |
| 2011 | 0.339*** | 2017 | 0.373** | 2011 | 0.335* | 2017 | 0.400** |
| 2012 | 0.343* | 2018 | 0.376*** | 2012 | 0.341** | 2018 | 0.412** |
| 2013 | 0.347* | 2019 | 0.409*** | 2013 | 0.363** | 2019 | 0.410** |
| 2014 | 0.356** | 2020 | 0.408*** | 2014 | 0.374** | 2020 | 0.420*** |
| 2015 | 0.359*** | 2021 | 0.419*** | 2015 | 0.369** | 2021 | 0.457** |

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

which has a strong negative impact on AGTFP. The effect of fiscal support for agriculture on AGTFP is negative and significant, which indicates that the level of fiscal support for agriculture inhibits the increase in AGTFP. To a large extent, China's fiscal support for agriculture tends 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 in regression (4) is -0.815, which means, to some extent, that financial support for agriculture, which tends to encourage the development of the petroleum agricultural model, has formed a strong restriction on the improvement of agricultural ecological efficiency; thus, to promote the ecological development of agriculture, attention should be given to the reform of financial support for agriculture structure and trend.

The spatial autoregressive coefficient $\rho$ is positive under both estimation methods and passes the significance test at the level of at least 5%, indicating not only that the agricultural green development of this province is positively affected by the agricultural green development of neighbouring provinces but also the agricultural green development has a certain positive

Table 6. Model estimation results.

| Variable | Two-ways fixed model Model (1) | SARAR models (The whole study area) | | SARAR models (3 different region) | | |
|---|---|---|---|---|---|---|
| | | Model (2) (W1) | Model (3)(W2) | Eastern region Model (4) | Central region Model (5) | Western region Model (6) |
| $RII_{it}$ | 0.253** (2.943) | 0.175** (2.997) | 0.202*** (4.315) | 0.193** (2.738) | 0.224** (3.153) | 0.189** (3.074) |
| RIC | 0.161*** (4.183) | 0.145*** (4.086) | 0.128*** (4.191) | 0.162** (3.023) | 0.131*** (3.995) | 0.214*** (3.721) |
| RED | 1.272* (2.187) | 1.196* (1.969) | 1.175* (2.139) | 1.214** (2.984) | 1.134* (2.068) | 1.163* (2.241) |
| FIS | -0.198*** (-3.925) | -0.235*** (-3.321) | -0.173** (-3.173) | -0.181** (-3.157) | -0.176** (-3.084) | -0.264** (-2.663) |
| IND | -0.262** (-3.132) | -0.201** (-2.180) | -0.234** (-2.143) | -0.232* (-2.108) | -0.215** (-3.221) | -0.309** (-3.042) |
| APS | 0.187** (3.114) | 0.143** (3.096) | 0.185** (2.989) | 0.372* (2.415) | 0.161** (3.064) | 0.109 (1.255) |
| F Test | 19.781** | — | — | — | — | — |
| Hausman_Test | 41.964*** | — | — | — | — | — |
| $\rho$ | — | 0.221** (2.841) | 0.206** (3.235) | 0.314*** (3.281) | 0.254** (2.353) | 0.165* (1.997) |
| $\theta$ | — | 0.021* (2.481) | 0.016* (2.235) | 0.014** (3.213) | 0.045* (2.353) | 0.065** (2.697) |
| Observations | 360 | 360 | 360 | 132 | 96 | 132 |

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

spillover. The spatial error coefficient $\theta$ is positive under the two estimation methods and passes the significance test at the level of at least 10%, indicating that other variables not included in the existing explanatory variables but with spatial correlation have a significant positive impact on the agricultural green development of this province.

In view of 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 SARAR model estimation, and W1 is taken as the spatial weight matrix. As shown in Table 6, the estimated results of each region are basically consistent with the sample results of the whole study area, which indicates that the above research results are relatively robust. Among them, the marginal effect of the integrated development of rural industries in the central region is more prominent, which may be because the resource base of the integrated development of rural industries in the central region is better, while AGTFP is not high; thus, the marginal effect of RII on AGTFP is more prominent. In addition, the influence coefficient of RII on AGTFP in the eastern region is the largest among the three regions, and the spatial autoregressive coefficient is larger. This may be because the eastern region has a better economic foundation and infrastructure conditions, and the flow of talent, information and factors can interact conveniently and efficiently. Therefore, the spillover effect of AGTFP is more prominent in the eastern region.

## Robustness Test

In the above mentioned regression equation, there may be reverse causality; that is, AGTFP may also negatively affect the integrated development of rural industries through some channels, thus leading to endogeneity problems. Traditional methods may affect the accuracy of estimation results. Therefore, to alleviate the endogeneity problem as much as possible, this paper will use the generalized space two-stage least square method (GS2SLS) for estimation. GS2SLS can use all explanatory variables and their spatial lag terms as instrumental variables without introducing external instrumental variables and estimate the spatial panel model based on the 2SLS method to reduce the bias caused by endogeneity to the estimation results [43]. As shown in Table 3, the coefficients of the spatial lag terms of the explained variables are significantly positive, indicating that AGTFP has an obvious spatial agglomeration feature. This may be because neighbouring provinces often have similar terrain, climate and other natural resource endowment conditions; plant similar types of crops; have similar levels of economic development; and have consistent agricultural production methods. Therefore, to promote the green development of agriculture in provinces, cooperation is needed to better realize the coordinated development of the rural economy and ecology.

Table 7. GS2SLS Estimation results.

| Variable | W1 | W2 |
|---|---|---|
| W*AGTFP | 0.166**(2.732) | 0.124**(3.221) |
| RII | 0.148**(3.003) | 0.101*(2.669) |
| Control variables | Yes | Yes |
| Observations | 360 | 360 |

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

As seen from the estimated results in Table 7, the estimated coefficients of the variables of rural industry integration are significantly positive, indicating that the integrated development of rural industry can still significantly promote the improvement of AGTFP even when considering the spatial influence and endogenous problems. This is consistent with the above benchmark regression results, indicating that the research results in this paper are robust.

## Analysis of the Impact Mechanism

The abovementioned empirical results fully show that the development of rural industrial integration significantly promotes the improvement of agricultural green total factor productivity. However, it is still necessary to further clarify its internal mechanism to further understand the environmental effect of industrial integration. Therefore, the following will start with the scale effect, capital effect and technology effect and use the intermediate effect test method to further verify the specific mechanism of industrial integration in promoting agricultural green development.

(1) The action path of the scale effect. Column 3 of Table 8 shows that the influence coefficient of rural industry integration on agricultural operation scale is positive, indicating that there is a significant positive relationship between rural industry integration and agricultural operation scale. With the continuous improvement of 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 variable of agricultural operation scale into the fixed effect benchmark model, both variables are significant at least at the significance level of 10%, and the coefficients are positive, indicating that the agricultural operation scale has a partial mediating effect in the process of rural industry integration promoting the improvement of AGTFP; the proportion of the calculated mediating effect is 10.11%.

(2) The action path of the capital effect. Column 7 of Table 8 shows that the influence coefficient of rural industrial integration on the level of rural human capital is positive and significant at the significance level of 5%, indicating that there is a significant positive relationship

Table 8. Regression results of mediating effect estimation.

| Scale effect | | | Capital effect | | | Technical effect | | |
|---|---|---|---|---|---|---|---|---|
| Variable | *AOS* | AGTFP | Variable | RHC | AGTFP | Variable | ATP | AGTFP |
| RII | 0.082* (2.138) | 0.227** (2.738) | RII | 0.097* (2.053) | 0.253** (2.943) | RII | 0.108* (2.133) | 0.217** (2.738) |
| AOS | — | 0.312* (2.003) | RHC | — | 0.126** (2.321) | ATP | — | 0.329** (2.473) |
| Mediating effect ratio | — | 10.11% | Mediating effect ratio | — | 4.83% | Mediating effect ratio | — | 14.04% |

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

Table 9. Threshold characteristics test.

| Threshold variable | model test | Threshold value | F statistics | P value | Critical value | | |
|---|---|---|---|---|---|---|---|
| | | | | | 1% | 5% | 10% |
| RII | Single threshold | 4.679 | 18.987*** | 0.001 | 26.907 | 16.685 | 7.542 |
| | Double thresholds | Threshold 1: 3.786<br>Threshold 2: 5.883 | 5.043 | 0.284 | 10.814 | 5.932 | 2.541 |
| | Three thresholds | — | 2.760 | 0.118 | 6.998 | 4.754 | 2.025 |

Note: *** denote significance at 1% level.

between rural industrial integration and rural human capital. The integrated development of rural industries can improve the structure and raise the level of rural human capital. After the rural human capital variable is added into the benchmark model, the regression coefficients of the two variables are significantly positive at the significance level of 1%, which indicates that rural human capital has a partial mediating effect in the process of rural industrial integration promoting AGTFP. In addition, it is calculated that the mediating effect of rural human capital in the process of rural industrial integration promoting AGTFP is 4.83%.

(3) The action path of the technology effect. Column 11 of Table 8 shows that the influence coefficient of rural industrial integration on agricultural technology progress is significantly positive, indicating that the improvement of 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 variable of agricultural technology progress into the fixed effect benchmark model, the influence coefficients of rural industry convergence and agricultural technology progress on AGTFP are both significantly positive, indicating that both rural industry convergence and agricultural technology progress can promote the improvement of AGTFP; furthermore, the mediating effect of the technology effect is significant, and the proportion of the mediating effect is 14.04%. It can be seen that improving factor utilization efficiency, reducing agricultural carbon emission intensity and reducing harmful factor input by relying on agricultural technological progress is an important way to improve AGTFP.

## Test Results and Analysis of the Threshold Effect

To demonstrate whether the influence of rural industry integration on agricultural green total factor productivity has nonlinear characteristics, the threshold effect regression model based on two-ways fixed effect is used for testing. The first step of the threshold effect regression model test is to determine the number of threshold values and threshold variables [44]. For this reason, the bootstrap method is used 300 times for self-sampling, and the final RII threshold value is shown in Table 9. The results show that the F statistic of the single threshold value of RII passes the test at the significance level of 1%, and the corresponding threshold value is 4.679. Since neither the double threshold nor the three threshold values passes the significance test, the single threshold panel model is the most reasonable one for estimation. When the RII of the whole study area is less than or equal to the threshold value of 4.679, the regression coefficient is 0.144 ($P<0.05$). When the RII exceeds 4.679, the regression coefficient is 0.201 ($P<0.05$). This indicates that as the level of rural industry integration (RII) increases, its influence on AGTFP increases as a whole. Therefore, the influence of rural industry integration on AGTFP has a threshold characteristic.

## Conclusion and Policy Recommendations

Rural industrial integration not only has the economic effect of promoting agricultural income but also has the effect of reducing agricultural carbon emissions and nonpoint source pollution, which is of great significance for the green development of agriculture and rural areas. However, while most researchers focus on the economic effect of rural industrial integration; they do not pay enough attention to its environmental effect and lack empirical evidence. In view of this, this paper analyses the theoretical logic of the impact of rural industrial integration on the rural ecological environment from aspects of scale management, human capital and technological progress. On this basis, the two-way fixed effect model, SARAR model and intermediary effect model are used to investigate the influence of rural industrial integration on AGTFP and its mechanism. The results show that first, the improvement of the industrial integration development level can improve the AGTFP indicating that relying on rural industrial integration to achieve rural environmental improvement and the "double carbon" goal is a feasible path. Second, the analysis of the intermediary mechanism shows that rural industrial integration has a significant scale effect, capital effect and technology effect; that is, industrial integration can indirectly boost the promotion of AGTFP by expanding the scale of agricultural operation, improving rural human capital and promoting agricultural technological progress. Third, panel threshold analysis shows that the relationship between rural industry integration and AGTFP is not a simple linear relationship. With the improvement of the development level of rural industry integration, its promoting effect on AGTFP is increasingly prominent.

This study provides theoretical logic and empirical evidence for understanding the environmental effects of rural industrial integration, proposing implications as follows: First, we should further accelerate the integration of rural industries, give full play to 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. Second, we should promote the appropriate scale operation of agriculture and use science and technology to unleash agricultural productivity. We should improve the structure of agricultural industries, guide households to shift from decentralized operations 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, take the "double carbon" goal as an opportunity, give full play to the role of modern science and technology, and realize the low-carbon development of agricultural production. Third, vocational education and high-quality farmer training should be used to strengthen the training of production skills and knowledge for farmers, accelerate the transformation of "new farmers", expand the stock of rural labour human capital, strengthen the ability of talent to support the integrated development of rural industries, and reduce agricultural carbon emissions through scientific agricultural production.

## Note

The research area in China is divided into three regions, which are as follows. The eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan and Liaoning; the central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Heilongjiang and Jilin; and the western region includes Chongqing, Sichuan, Guizhou, Guangxi, Yunnan, Shaanxi, Inner Mongolia, Gansu, Ningxia, Qinghai and Xinjiang.

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## Data Availability Statement

The data presented in this study are available upon request from the corresponding author.

## Conflicts of Interest

The authors declare no conflict of interest.

## Reference

1. HAN Y., WANG X., ZHE C. The Impact of Economic Agglomeration on Green Total Factor Productivity: An Empirical Analysis from China's Yellow River Basin. Polish Journal of Environmental Studies, **32** (1), 61, **2022**.
2. YUAN B., XIANG Q. Environmental regulation, industrial innovation and green development of Chinese manufacturing: Based on an extended CDM model. Journal of Cleaner Production, **176**, 895, **2018**.
3. HOU L., ZHANG Y., ZHAN J., GLAUBEN T. Marginal revenue of land and total factor productivity in Chinese

agriculture: Evidence from spatial analysis. Journal of Geographical Sciences, **22** (1), 167, **2012**.
4. OHE Y. Research note: Evaluating integrated on-farm tourism activity after rural road inauguration - The case of pick-your-own fruit farming in Gunma, Japan. Tourism Economics, **16** (3), 731, **2010**.
5. WANG J., ZHOU F., CHEN C., LUO Z. Does the integration of agriculture and tourism promote agricultural green total factor productivity? – Province-level evidence from China, **March**, 1, **2023**.
6. ZHOU X., CHEN T., ZHANG B. Research on the Impact of Digital Agriculture Development on Agricultural Green Total Factor Productivity. Land, **12** (**1**), 195, **2023**.
7. ZHANG L., WEN T., LIU Y. Rural Industry Integration development and farmers' income Growth: Theoretical mechanism and Empirical judgment Leading innovation and entrepreneurship with six industrial Theories. Journal of Southwest University(Social Science Edition), **46** (05), 42, **2020**.
8. XIAO W.D., DU Z.X. Integration of primary, secondary and tertiary industries in rural areas: connotation analysis, development status and future thinking. Journal of Northwest Agriculture & Forest University (Social Science Edition), **19** (06), 120, **2019**.
9. HAO A.M., TAN J.Y. The mechanism and effect measure of rural industry convergence enabling agricultural toughness. Agricultural Technical Economics, (04), 1, **2022**.
10. CAI J., LIU F., XIA X.L. Rural industrial integration, Non-agricultural employment and household income Increase: A micro-empirical study based on Liupan Mountain. Journal of Arid Land Resources and Environment, **34** (02), 73, **2020**.
11. LI X.L., RAN G.H. How the integrated development of rural industries affects the income gap between Urban and rural areas: Based on the dual perspective of rural economic growth and urbanization. Journal of Agrotechnical Economics, **292** (08), 17, **2019**.
12. EMROUZNEJAD A., YANG G. A survey and analysis of the first 40 years of scholarly literature in DEA: 1978-2016. Socio-Economic Planning Sciences, **61**, 4, **2018**.
13. TONE K. A slacks-based measure of super-efficiency in data envelopment analysis. European Journal of Operational Research, **143** (1), 32, **2002**.
14. TONE K., TSUTSUI M. Dynamic DEA: A slacks-based measure approach. Omega, **38** (3-4), 145, **2010**.
15. LI G. The Green Productivity Revolution in Chinese Agriculture: 1978-2008. Economics (Quarterly Review), **13** (02), 537, **2014**.
16. DU J., WANG R., WANG X.H. Environmental total factor productivity and agricultural growth: a two-stage analysis based on DEA-GML index and Panel Tobit model. Chinese Rural Economy, (03), 65, **2019**.
17. MENG X.H., ZHOU H.C., DU L.Y. Changes in agricultural environmental technology efficiency and green total factor productivity growth in China: A reexamination from the perspective of combination of planting and cultivation. Problems in Agricultural Economy, (06), 9, **2019**.
18. GE P.F., WANG S.J., HUANG X.L. Agricultural green total factor productivity measurement in China. China Population, Resources and Environment, **28** (5), 66, **2018**.
19. XU L., LUO D.L., LIU A.J. Evaluation and comparison of agricultural eco-efficiency in major grain-producing provinces (regions) in China: Based on DEA and Malmquist index. Journal of Hunan Agricultural University (Social Science Edition), **15** (04), 76, **2014**.
20. WU H.Y., HE Y.Q., CHEN W.K. Spatial effects and influencing factors of agricultural carbon offsetting rate in China: Based on spatial Durbin model. Journal of Agrotechnical Economics, (03), 110, **2020**.
21. YE C.S., HUI L. The influence degree of agricultural production pollution on economic growth performance – Based on the analysis of environmental total factor productivity. China Population, Resources and Environment, **26** (4), 116, **2016**.
22. ZHANG Y.Q., ZHOU N., ZHANG X.F. Study on Total Factor Productivity and its Influencing Factors in Chinese agriculture: Based on resource and environmental constraints. Resource Development & Market, (06), 672, **2017**.
23. GAO Y., NIU Z.H. Agricultural informatization, spatial spillover effect and agricultural green total factor productivity: Based on SBM-ML index method and spatial Dubin model. Statistics and Information Forum, 33 (10), 66, **2018**.
24. LIANG J., LONG S.H. China's agricultural green total factor productivity growth and its affecting factor. Journal of South China Agricultural University (Social Science Edition) **14** (3), 1, **2019**.
25. WANG L., TANG J., TANG M., SU M., GUO L. Scale of Operation, Financial Support, and Agricultural Green Total Factor Productivity: Evidence from China. International Journal of Environmental Research and Public Health, **19** (15), **2022**.
26. MA G., DAI X., LUO Y. The Effect of Farmland Transfer on Agricultural Green Total Factor Productivity: Evidence from Rural China. International Journal of Environmental Research and Public Health, **20** (3), **2023**.
27. CUI W., CHEN J., YUAN Y., SHEN H., ZHOU Q. Exploration on the Process of Rural Three-Industry Integration through the Stage of Symbiosis. Wireless Communications and Mobile Computing, **1**, **2022**.
28. JUNG H. Estimating the social value of multifunctional agriculture (Mfa) with choice experiment. Agricultural Economics (Czech Republic), **66** (3), 120. **2020**.
29. YANG G., ZHOU C., ZHANG J. Does industry convergence between agriculture and related sectors alleviate rural poverty: evidence from China. Environment, Development and Sustainability, **01**, **2022**.
30. GAO J., WU B. Revitalizing traditional villages through rural tourism: A case study of Yuanjia Village, Shaanxi Province, China. Tourism Management, **63**, 223, **2018**.
31. HSU S.M., HSIEH P.H., YUAN S.T. Roles of "small- and medium-sized enterprises" in service industry innovation: A case study on leisure agriculture service in tourism regional innovation. Service Industries Journal, 33 (**11**), 1068, **2013**.
32. SUN Y. Environmental regulation, agricultural green technology innovation, and agricultural green total factor productivity. Frontiers in Environmental Science, **10**, 1, **2022**.
33. XIAO Q., ZHOU Z., LUO Q. Study on agricultural green production efficiency and its spatial-temporal differentiation in the Yangtze River Economic Belt. Agricultural Resources and Regionalization in China, **41** (10), 15, **2020**.
34. CHEN Y., MIAO J., ZHU Z. Measuring green total factor productivity of China's agricultural sector: A three-stage SBM-DEA model with non-point source pollution and $CO_2$ emissions. Journal of Cleaner Production, 318 (**18**), 128543, **2021**.

35. WANG F., DU L., TIAN M. Does Agricultural Credit Input Promote Agricultural Green Total Factor Productivity? Evidence from Spatial Panel Data of 30 Provinces in China. International Journal of Environmental Research and Public Health, **20** (1), **2023**.
36. ZHU L., SHI R., MI L., LIU P., WANG G. Spatial Distribution and Convergence of Agricultural Green Total Factor Productivity in China. International Journal of Environmental Research and Public Health, **19** (14), **2022**.
37. WEST T.O., MARLAND G. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: Comparing tillage practices in the United States. Agriculture, Ecosystems and Environment, **91** (1-3), 217, **2002**.
38. LI Y., CHEN J.H., CHEN C. Research on Evaluation index system of agricultural industry Integration and its application to Beijing. Science and Technology Management Research, **37** (4), 55, **2017**.
39. WANG X.L., FAN G., YU J.W. China by province marketization index report. Beijing: Social Sciences Academic Press, **2016**.
40. HAN H.B., ZHANG L. Analysis of threshold effect of agricultural informatization on agricultural total factor productivity growth. Chinese Rural Economy, (08), 23, **2015**.
41. IM K.S., PESARAN M.H., SHIN Y. Testing for unit roots in heterogeneous panels. Journal of Econometrics, **115** (1), 53, **2003**.
42. BARAN R.M., KENNY D.A. The moderator-mediator variable distinction in social psychological research:conceptual, strategic, and statistical consideration, Chapman and Hall, (06) 34, **1987**.
43. GE P., LIU T., WU X., HUANG X. Heterogenous Urbanization and Agricultural Green Development Efficiency: Evidence from China. Sustainability (Switzerland), **15** (**7**), 1, **2023**.
44. ZHANG H., ZHANG J., SONG J. Analysis of the threshold effect of agricultural industrial agglomeration and industrial structure upgrading on sustainable agricultural development in China. Journal of Cleaner Production, **341**, 130818, **2022**.