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Original Research

The Effect of Agricultural Industrial Agglomeration on the Efficiency of Agricultural Green Development: Empirical Evidence from China

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Abstract

Agricultural industry agglomeration is an important driving force for the green and high-quality development of agriculture. Based on the perspective of agricultural industry agglomeration, this paper discusses the impact of agricultural industry agglomeration on the level of green development of agriculture, which is of great significance for the realization of sustainable development of agriculture and the implementation of the "double carbon" goal. Based on the panel data of 30 provinces (municipalities) and autonomous regions in China from 2011 to 2020, the non-expected Super-SBM model and location entropy index method were used to measure the efficiency of agricultural green development and the level of agricultural industry agglomeration. The spatial Dubin model, tradition and spatial Markov chain were used to demonstrate the influence of agricultural industrial agglomeration on agricultural green development efficiency and its spatio-temporal dynamic evolution.The results showed that: (1) There was spatial autocorrelation in agricultural green development efficiency. Areas with higher agricultural green development efficiency will drive the improvement of agricultural green development efficiency in surrounding areas, with a positive spillover effect. (2) Industrial agglomeration can improve the efficiency of agricultural green development, and this enhancement has spatial spillover. (3) The influence of agricultural industrial agglomeration on agricultural green development efficiency and its spatial spillover have regional heterogeneity. The spillover effect of AIA to AGDE in the eastern region is greater than that in the central and western regions. Based on this, it is necessary to grasp the spatial correlation law of provincial agriculture, promote the sustainable development of regional agriculture, optimize the allocation of resources, and put forward policy

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implications for the improvement of agricultural green efficiency from the aspects of financial support, industrialization, human capital and urbanization.

Keywords: agricultural industry agglomeration, Agricultural green development efficiency, spatial durbin model, spatial Markov chain

Introduction

The United Nations Sustainable Development Goals clearly put forward "improving nutrition and promoting sustainable agricultural development". With the increasing global attention to sustainable development and environmental protection, the green development of agriculture has become an important goal to achieve agricultural sustainability. China is one of the largest agricultural countries in the world. Since the reform and opening up, China's agricultural development has made remarkable achievements. By 2020, China's total grain output has reached 1,339 billion jin, achieving 17 consecutive years of growth, and the per capita grain consumption is close to 480kg, far exceeding the international average level. However, in the process of rapid development of modern agriculture, excessive pursuit of economic benefits, ignoring the protection of agricultural ecological environment. Data show that by 2020, the use of chemical fertilizers in China is 52.51 million tons, the use of pesticides and agricultural film is 1.31 million tons and 2.39 million tons, respectively. The large consumption of fossil energy, the excessive use of pesticides, the irrational use of agricultural waste, the destruction of soil and other problems have led to serious agricultural ecological environment pollution. The traditional "extensive" agricultural development mode with high pollution and high consumption has not adapted to the requirements of sustainable agricultural development. The No. 1 document of the Central Committee in 2022 clearly points out that in order to promote the green development of agriculture and rural areas, it is necessary to strengthen the comprehensive control of agricultural non-point source pollution. In order to achieve sustainable reduction of agricultural pollution, it is necessary to fundamentally promote the transformation from petroleum agriculture to ecological agriculture and improve the efficiency of agricultural green development.

As a typical phenomenon of industrial distribution and the trend of industrial development and evolution, industrial agglomeration plays an important role in the improvement of international competitiveness, the high-quality development of national economy and the efficiency of resource allocation. With the in-depth development of China's agricultural supply-side structural reform, it has become an inevitable trend of agricultural modernization to promote agricultural industry agglomeration, achieve moderate scale agricultural management, and pursue high efficiency of agricultural production while taking into account the agricultural ecological environment. At present, China has formed 34 rural characteristic industrial clusters and more than 7,000 agricultural industrialization consortiums. Agricultural industry agglomeration not only has an important impact on economic growth and industrial competitiveness, but also has a potential role in promoting the efficiency of agricultural green development. Therefore, clarifying the relationship between agricultural industry agglomeration and agricultural green development efficiency has important theoretical and practical significance for accelerating the construction of ecological civilization and promoting the green development of agriculture.

Through literature review, it is found that most scholars have conducted extensive research on the economic effects of agricultural industrial agglomeration, but lack of research on its environmental effects. Few sources include agricultural industrial agglomeration into the analysis framework and focus on the empirical analysis of agricultural green development efficiency. So, what impact will agricultural industry agglomeration have on the efficiency of agricultural green development? Is there regional heterogeneity in the influence of agricultural industrial agglomeration on agricultural green development efficiency? Is there spatial spillover? The research on these problems is an important subject to realize the sustainable development of agriculture. Based on the above problems, this paper uses an empirical model to study the combination of agricultural industrial agglomeration and agricultural green development efficiency, integrates industrial agglomeration and agricultural green development efficiency into each other's analysis framework, and investigates the relationship between the two.

The marginal contribution of this study is mainly reflected in: (1) The in-depth analysis of the efficiency of agricultural green development from the perspective of agricultural industry agglomeration is conducive to giving full play to the important role of agricultural industry agglomeration and transforming its externalities into the driving force in the process of agricultural green development. (2) This paper empirically verified the impact of agricultural industry agglomeration on the efficiency of agricultural green development, providing a new perspective for exploring factors conducive to the green development of agriculture. (3) On the basis of clarifying the impact mechanism of agricultural industry agglomeration on green development efficiency, using the provincial agricultural development data of China from 2011 to 2020 and incorporating spatial factors into the empirical research framework, a spatial econometric model is constructed to analyze the impact of agricultural industry agglomeration on green development efficiency, which can further enrich relevant research materials and make up for the shortcomings of existing studies. More scientific demonstration of the relationship between agricultural industry agglomeration and agricultural green development, to provide reference for improving the efficiency of agricultural green development.

Literature Review

Agglomeration of Agricultural Industry

Agricultural industry agglomeration refers to the phenomenon or process in which farmers, enterprises and related supporting institutions gather in a specific region due to commonness or complementarity, and form an organic network system through mutual correlation and cooperation [1]. Existing scholars mainly analyze from the aspects of agricultural output growth, efficiency improvement, and competitiveness enhancement. Agricultural industry agglomeration can produce scale economy effect [2], but only when the industrial cluster is in the growth stage, it can promote the growth of agricultural economy [3]. Agricultural industrial agglomeration can improve the technical efficiency of agricultural production [4]. Agricultural industry agglomeration can continuously improve labor productivity by increasing returns to scale through internal economies of scale at the farmer level, localization economy at the industrial level and urbanization economy at the city level [5]. On the other hand, agricultural industrial agglomeration can effectively stimulate the innovation behavior of micro-entities [6], and thus achieve the improvement of agricultural green production efficiency by attracting capital inflow and enhancing industrial competitiveness [7]. However, there may also be an inverted U-shaped curve relationship between agricultural efficiency and agricultural industrial agglomeration [8].

Agricultural Green Development Efficiency

In recent years, green development efficiency has been widely concerned by scholars, mainly from the aspects of connotation, evaluation index, influencing factors, driving mechanism and so on. In terms of evaluation indicators of agricultural green development, Mac (1994) believes that green agricultural development includes five evaluation indicators: agricultural resources, per capita cultivated land area, land planning and utilization, fertilizer use and pesticide use [9]. Valizadeh (2020) established an indicator system for assessing the level of agricultural sustainable development, and tested the feasibility of this indicator system in Iran [10]. Lu Xian and Xiong Jiao (2020) measured the efficiency of agricultural green development in Hunan Province by constructing four dimensions: local economic development level, human capital, industrialization level and urbanization [11]. Meng Han et al. (2020) measured the development of green agriculture in Hebei Province from three aspects: resource conservation, environmental protection and output return [12]. Stochastic frontier Analysis (SFA) and data envelopment analysis (DEA) are the main methods used to measure the efficiency of green development. For the study of green development efficiency, scholars mostly use the methods of EI-LCA model [13], sustainable evaluation model [14], RAM model [15] and DEA model [16] to study the green development efficiency of countries such as the United States, Malaysia and the European Union. Research on the efficiency level of agricultural green development Scholars mostly adopt EBM model [17], DEA-Malmquist index [18], Super-SBM model [19], SBM-Undesirable model [20], SBM-Undesir-able model [21] and Malmquist-Luenberger index [22] and other research methods analyzed the efficiency level of agricultural green development in the Yellow River basin, the Yangtze River Economic Belt, Shandong Province, Northeast China and other regions.

From the existing research, there are abundant researches on the influencing factors of agricultural green total factor productivity, but few scholars have studied the possible impact of agricultural industry agglomeration on agricultural green development efficiency. Relevant studies on the impact of agricultural industrial agglomeration on agricultural green total factor productivity are mainly concentrated at the theoretical level, and the research based on empirical test is relatively lacking, so it is difficult to deeply analyze the specific impact of agricultural industrial agglomeration on agricultural green total factor productivity. In view of this, with the help of panel data of 30 provinces (municipalities) and autonomous regions in China from 2011 to 2020, this paper adopts non-expected Super-SBM model, spatial Durbin model, intermediary effect model and threshold effect model to analyze the impact of agricultural industrial agglomeration on the efficiency of agricultural green development. The conclusion can provide theoretical basis and decision-making reference for realizing agricultural sustainable development.

Material and Methods

Theoretical Analysis and Research Hypothesis

Agricultural production is highly dependent on natural conditions such as climate, soil and water resources, and there may be similar natural conditions such as climate, soil and water resources between neighboring regions, which have a direct impact on agricultural production and green development efficiency. Similar agricultural location conditions may lead to a tendency of convergence in agricultural production conditions, crop varieties, production modes and development history in neighboring provinces.

With the further improvement of infrastructure such as transportation, Internet and logistics system, cross-regional operations of capital, technology and labor become increasingly frequent, and agricultural production links between neighboring regions become increasingly close, which will lead to greater spatial spillover of agricultural green production. Therefore, the following hypothesis is proposed:

H1: There is spatial autocorrelation of agricultural green development efficiency in the region.

Agricultural industry agglomeration can bring about economies of scale. When agricultural production and related industries gather in a specific area, resources and supply chains can be organized more centrally and efficiently to achieve optimal allocation and efficient utilization of resources, reduce production costs, and improve the efficiency of agricultural green development [23]. The agglomeration of agricultural industry can bring about competition effect. The agglomeration of agricultural industry makes the market competition environment more intense, and the competition mechanism will force agricultural operators to continuously improve their own agricultural production technology [24], improve the quality and market competitiveness of agricultural products, and promote the efficiency of agricultural green development. Agricultural industry agglomeration can bring about spillover effects of technological innovation and knowledge dissemination. When agricultural practitioners and related industries interact closely in the agglomeration area, technological innovation opportunities will be increased and knowledge exchange will be promoted. New agricultural green technologies and management practices can be disseminated through cooperation and exchange among enterprises, institutions and people within the cluster. This spillover effect of technological innovation and knowledge dissemination can spread to neighboring regions, thereby improving the efficiency of their agricultural green development. Accordingly, the following hypothesis is proposed:

H2: Agricultural industry agglomeration can improve the efficiency of agricultural green development, and this enhancement has spatial spillover.

China has a vast territory, high in the west and low in the east, and a wide range across latitudes. This geographical feature leads to great differences in hydrothermal conditions and agricultural resource endowments in different regions. Moreover, the types of land resources in China are complex and diverse, and the distribution of cultivated land is uneven, which presents a complicated and changeable situation in land use. As a result, there are significant differences in agricultural productivity between different regions. In addition, due to the differences in inter-regional economies of scale, knowledge and technological innovation level, industrial chain development and policy and institutional environment, the effect of agricultural industrial agglomeration on agricultural green development efficiency is different among regions. Therefore, the following hypothesis is proposed:

H3: The influence of agricultural industrial agglomeration on agricultural green development efficiency and its spatial spillover have regional heterogeneity.

Variables and Data

Data Source

This study selects the panel data of 30 provinces (autonomous regions and municipalities) in China from 2011 to 2020 for analysis, and the data comes from China Statistical Yearbook, China Rural Statistical Yearbook, China Agricultural Statistical Yearbook, China Environmental Statistical Yearbook and provincial statistical yearbook over the years. In order to improve the reliability of the data and the accuracy of the model fitting, we carried out logarithmic processing on the main explanatory variable data.

Explained Variable

Agricultural green development efficiency (AGDE) refers to the efficiency value between input and output, so consider selecting variables from the perspective of input and output. Based on the research of, Zhao Huijie [25], Wei Qi [26] and other scholars, and considering the systematic, scientific and available data, the input-output index system was established based on the agricultural green development goal of "resource saving, environmental friendliness and high output efficiency" (Table 1). The input indicators mainly include: (1) Labor input, calculated according to the employees of agriculture, forestry, animal husbandry and fishery, the formula is: employees of agriculture, forestry, animal husbandry and fishery × (total output value of agriculture/total output value of agriculture, forestry, animal husbandry and fishery); (2) Land input is measured by the total sown area of agriculture (compared with the cultivated land area, the total sown area of agriculture can more accurately measure the actual utilization rate of land); (3) Pesticide input. Measured by pesticide use. (4) Fertilizer input. Fertilizer is measured using reduced fertilizer use. (5) Irrigation input, measured by effective irrigation area; (6) Mechanical power input, measured by the total power of machinery. Output indicators are divided into expected output and unexpected output. Expected output refers to the environmentally friendly output in the agricultural production process and is measured by the total agricultural output value. The non-expected output is the output that is harmful to the environment in the process of agricultural production, mainly considering the carbon emissions brought by agricultural production, which mainly comes from: fertilizer, pesticide, agricultural irrigation and agricultural machinery power. The four types of carbon emission coefficient

Table 1. Input-output index of agricultural green development efficiency.

Primary index	Secondary index	Variable
Input index	Labor input	Agricultural employees (10,000 people)
	Land input	Total agricultural sown area (thousand hectares)
	Fertilizer input	Fertilizer use (10,000 tons)
	Pesticide input	Pesticide use (10,000 tons)
	Irrigation input	Effective irrigated area (ten thousand hectares)
	Mechanical input	Total power of machinery (million kW/h)
Expected output indicator	Gross agricultural output value	Total agricultural output value (100 million yuan)
Indicators of undesirable output	Agricultural carbon emission	Total agricultural carbon emissions (tons)

are respectively 0.90 (kg/kg) for fertilizers, 4.93 (kg/kg) for pesticides, 20.48 (kg/ha) for agricultural irrigation, and 0.18 (kg/kW) for total mechanical power [27]. The formula of agricultural carbon emission is:

$$E = \sum T_i \times \delta_i \tag{1}$$

In the formula, *E* is the total carbon emission, *T* is the source of carbon emission, *δ* is the carbon emission coefficient, and i is the type i carbon emission source.

In the process of agricultural production, the application of some chemicals will pollute the soil and atmosphere, and this pollution is often ignored, so the non-expected Super-SBM model is used to measure the efficiency of agricultural green development [28]. Compared with the traditional DEA model, the simple SBM model adds the relaxation improvement part to solve the problem that the DEA model cannot incorporate the unexpected output [29]. The Super-SBM model proposed by Tone combines the advantages of SBM model and super-efficiency DEA. Based on the SBM model, the efficiency value is greater than 1[30], and the efficiency value of multiple effective DUS can be compared and sorted [31]. The specific expression of Super-SBM model is as follows:

$$\min \mathrm{p} = \frac{1 - \frac{1}{M}\sum_{m=1}^{M}\frac{S_m^x}{x_{m0}}}{1 + \frac{1}{N+1}\left(\sum_{n=1}^{N}\frac{S_n^y}{y_{n0}} + \sum_{i=1}^{I}\frac{S_i^u}{u_{i0}}\right)} \tag{2}$$

$$\text{s.t.}\sum_{K=1}^{K} z_k x_{mk} + s_m^x = x_{m0}, m = 1,2,..., M \tag{3}$$

$$\sum_{K=1}^{K} z_k y_{nk} + s_n^y ;= y_{n0}, n = 1.2.... , N \tag{4}$$

$$\sum_{k=1}^{k} z_k u_{ik} + S_i^u = u_{i0}, i = 1,2,..., I; z_k \geq 0; S_m^x \geq 0; \quad S_n^y \geq 0; S_i^u \geq 0 \tag{5}$$

M, N and I represent input factors, expected output and unexpected output respectively. m, n, and i represent the m, n, and i elements respectively. $S^x{}_m$, $S^y{}_n$, $S^u{}_i$ represents the redundancy of input and output, the deficiency of expected output and the redundancy of non-expected output respectively. x_{m0}, y_{n0}, u_{i0} represents the amount of input factors, expected output, and non-expected output in each decision unit.ρ*is the efficiency value. Because the model is a super-efficiency model, the efficiency value of agricultural green development is not limited to 0 to 1.

Core Explanatory Variable

Agricultural Industry Cluster (AIA). Considering the availability of data and other factors, the study of Li Wenhua et al. [32] was used to measure the level of agricultural industrial agglomeration by using location entropy, which is expressed by dividing the ratio of agricultural output value of a certain region and the national agricultural output value by the ratio of the gross domestic product of the province and the national gross domestic product. Location entropy can reflect the spatial distribution of geographical factors well, and can effectively measure the level of agricultural industry agglomeration at provincial spatial scale. The specific expression is as follows:

$$AIA_{LEit} = \frac{A_{it} / G_{it}}{A_t / G_t} \tag{6}$$

In the formula, AIA_{LEit} represents the agricultural industry agglomeration in year t of region i calculated by the location entropy method; the larger the value is, the more agricultural industry agglomeration is; A_{it} and G_{it} respectively represent the total output value and GDP of agriculture, forestry, animal husbandry and fishery in year t of region i; A_t and G_t respectively represent the total output value and GDP of national agriculture, forestry, animal husbandry and fishery in year t.

Control Variable

Referring to the relevant studies of scholars Tang Jian [33] and Wu Chuanqing [34], this paper selected four control variables, namely financial support level for agriculture (FSA), industrialization (IND), human capital (HC) and urbanization (URB). Financial support for Agriculture (FSA), expressed by the proportion of financial support for agriculture in its total financial expenditure; Industrialization (IND), expressed as the share of industrial value added in its gross regional product; Human capital (HC), expressed as years of schooling per capita; Urbanization (URB), expressed as the proportion of urban population in its total population.

Methodology

Spatial Markov Chain

Markov chain can accurately estimate the state transfer trend of the research object and explore the characteristics of the dynamic evolution of the research object. Firstly, the development level of agricultural green development efficiency is divided into k types based on the set criteria, and the judgment is made based on the natural breakpoint method. Secondly, the N×N Markov probability transfer matrix was constructed to determine the dynamic development characteristics of agricultural green development efficiency. In order to further analyze the mutual influence of agricultural green development efficiency development between neighboring regions, the spatial lag effect was incorporated into the traditional Markov transfer matrix. The relevant formula is as follows [35]:

$$lag = \sum y_i w_{ij} \tag{7}$$

Where, *lag* is the spatial lag value, which is used to judge the agricultural green development efficiency of adjacent spatial areas, and its hierarchy is still divided by the natural breakpoint method. *yi* represents the agricultural green development efficiency of i city; *Wij* represents the spatial weight matrix.

Spatial Autocorrelation Test Model

Moran's I index can reflect the spatial agglomeration characteristics of research objects at the global spatial level. This paper uses Global Moran's I index to test. Moran's I index is calculated as follows:

$$Moran'I_{global} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}(Y_i - \overline{Y})(Y_j - \overline{Y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}} \tag{8}$$

In the formula, I is the global Moran index with the value range [-1,1]. When I>0, it indicates that there is a positive spatial correlation; When I<0, it indicates negative spatial correlation. When I = 0, it means that the spatial distribution is random and there is no spatial autocorrelation. In the above formula, Yi and Yj represent the observed Level of Agricultural Industry Agglomeration (AIA) or Agricultural Green Development Efficiency (AGDE) in regions i and j, respectively. Wij is the spatial weight matrix.

Spatial Econometric Model

Considering the correlation of geographical space, spatial econometric model is introduced to reveal the influence of agricultural industrial agglomeration on agricultural green development efficiency more comprehensively. Spatial measurement models mainly include spatial error model (SEM), spatial lag model (SAR) and spatial Durbin model (SDM). Among them, the Durbin model between SDM models can take into account the spatial lag of both dependent and independent variables. At the same time, considering that the influence of agricultural industry agglomeration on the efficiency of agricultural green development may be non-linear, the square term of agricultural industry agglomeration is added to the model. The specific type of spatial measurement model should be determined based on the results of LR and Wald tests. Therefore, this paper constructs a general spatial metrology model as follows:

$$AGDE_{it} = \alpha_0 + \rho WAGDE_{it} + \beta AIA_{it} + \gamma C_{it,k} + \theta WAIA_{it} + \xi W\sum_{k=1}^{n} C_{it,k} + \mu_i + \upsilon_t + \varepsilon_{it} \tag{9}$$

In the above formula, $AGDE_{it}$ and AIA_{it} represent the explained variable and the core explanatory variable, respectively. ρ is the spatial correlation coefficient, and W is the spatial weight matrix. β, γ, θ and ξ are the parameters to be estimated, μ_i is the spatial effect, v_i is the time effect, and ε_{it} is the spatial error term.

Results and Discussion

Spatiotemporal Variation of Agricultural Green Development Efficiency

In order to further understand the spatiotemporal evolution differences of agricultural green development efficiency in different provinces and cities, the agricultural green development efficiency of 30 provinces and cities during 2011-2020 was first divided into different types of state Spaces. Considering that the observed amounts of each type of province and city were roughly the same, the quantile division method [36] was used to divide the agricultural green development

Table 2. Markov transition probability of agricultural green development efficiency from 2011 to 2020.

t/t+1	n	1	2	3	4
1	35	0.710	0.282	0	0.008
2	62	0.141	0.754	0.105	0
3	113	0	0.153	0.731	0.116
4	90	0	0	0.001	0.989

efficiency into 1/4, 1/2 and 3/4 quantiles. The value of agricultural green development efficiency was divided into four adjacent but non-intersecting complete intervals: (0.1621, 0.2910], (0.2910, 0.3654], (0.3654, 0.5057] and (0.5057, 1.8219], the complete interval of these four state types is expressed by k = 1, 2, 3, 4, respectively. The greater k is, the higher the efficiency of regional agricultural green development is. Therefore, the traditional first-order Markov transition probability matrix can be obtained (see Table 2). The diagonal elements in Table 3 represent the probability that the types of agricultural green development efficiency do not transfer, while the non-diagonal elements represent the probability that the types of agricultural green development efficiency transfer between different types. It can be seen that: (1) Agricultural green development efficiency has a significant trend of transferring to a high level on the whole. (2) The transfer of agricultural green development efficiency has the stability of maintaining the original state. From the perspective of diagonal elements, the probability values on the diagonal are greater than those on the non-diagonal elements, and the stability of low level and high level at both ends is the largest, which is 0.710 and 0.989 respectively, indicating that there is a "club convergence" effect of convergence to low level and high level of agricultural green development efficiency. (3) It is difficult to realize leapfrog transfer of agricultural green development efficiency. The non-diagonal probability values are all smaller than the diagonal probability values, and the non-adjacent diagonal elements are all less than 0.01, which means that the probability of leapfrog transfer of urban ecological efficiency between two consecutive years is very small, reflecting that the improvement of efficiency under the green development of agriculture is a stable and continuous process, and it is difficult to realize the development and evolution of leapfrog types in the short term.

The upward or downward transfer of agricultural green development efficiency is not isolated in geographical pattern. The improvement of agricultural green development efficiency not only depends on endogenous development, but is closely related to surrounding areas. On the basis of the traditional Markov chain, geographical background factors were introduced to construct the spatial Markov chain transfer probability matrix based on the spatial lag types of different regions, and the influence of geographical background on the transfer probability of agricultural green development efficiency was investigated (Table 3). The results of Table 2 and Table 3 show that: (1) Geospatial pattern plays an important role in the dynamic evolution of agricultural green development efficiency in China. Under different neighborhood background, the type transfer probability of agricultural green development efficiency in different provinces and cities is not the same, otherwise, the effect of spatial lag will not exist. For example, P12=0.282 without considering the geographical spatial pattern, and when a province and city is adjacent to a province and city of type 2, $P12_{|2}$=0.274. Considering the spatial background, it is necessary to analyze the evolution and transfer of agricultural green development efficiency. (2) Considering the geographical spatial pattern, the probability of the type transfer of agricultural green development efficiency in a province or city is not the same when it is adjacent to different types of provinces or cities. For example, $P23_{|2}$=0.035<P23 =0.105<$P23_{|3}$=0.120. Generally speaking, it is adjacent to provinces or cities with higher agricultural green development efficiency. The probability of its upward shift will increase. It can be seen that the provinces with low agricultural green efficiency have a negative effect on the surrounding provinces and cities, while the provinces with high agricultural green development efficiency have a positive spillover effect on the neighboring provinces and cities. In general, the state transfer of agricultural green development efficiency has a certain spatial correlation and is affected by the surrounding areas. Moreover, the influence effect of different agricultural green development efficiency in dynamic transfer has obvious heterogeneity. Regions with higher development level can drive the common development of surrounding areas, which increases the probability of agricultural green development transferring to higher clubs, but the probability of upward transfer is still low, showing obvious club convergence.

Spatial Autocorrelation Test

Global Moran's I index was calculated to better represent the spatial aggregation of agricultural industrial agglomeration and agricultural green development efficiency in China. The global Moreland index of agricultural industrial agglomeration

Table 3. Spatial Markov transition probability matrix of agricultural green development efficiency from 2011 to 2020.

t/t+1	n	1	2	3	4
1	6	0.716	0.284	0	0
2	27	0.142	0.748	0.11	0
3	24	0	0.009	0.884	0.107
4	6	0	0	0	1
1	20	0.826	0.274	0	0
2	28	0	0.964	0.035	0
3	48	0	0	0.808	0.192
4	0	0	0	0	0
1	6	0.932	0.067	0	0
2	17	0	0.887	0.120	0
3	32	0	0	0.931	0.068
4	11	0	0	0.075	0.924
1	3	0.851	0.149	0	0
2	20	0.015	0.823	0.162	0
3	9	0	0.011	0.861	0.128
4	73	0	0	0.008	0.991

and agricultural green development efficiency in China is shown in Fig. 1. According to the global Moran's I test of agricultural industrial agglomeration, the efficiency of agricultural industrial agglomeration and agricultural green development in each year from 2011 to 2020 is significantly positive, indicating that China's industrial agglomeration and agricultural green development efficiency have strong spatial positive correlation. H1 is assumed to be established. Therefore, it is reasonable to use the spatial econometric model to analyze the influence of agricultural industry agglomeration on green development efficiency in China.

Econometric Model Estimation Results

Before using the spatial model, it is necessary to determine which model is the most suitable according to the relevant test results. First, the residual of OLS estimation results was used for spatial correlation test, and the test results were shown in Table 4. LM-Error, Robust LM-Error, LM-Lag and Robust LM-Lag

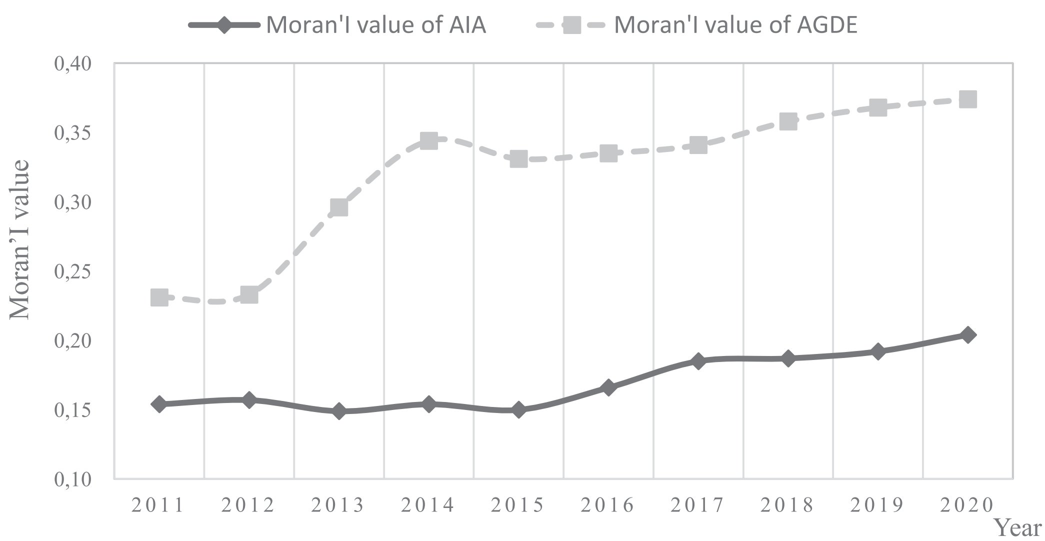

Fig. 1. Average Global Moran' I values of AIA and AGDE from 2011 to 2020.

Table 4. Test results.

Inspection method	coefficient	p
LM-Error	8.662	0.003
Robust LM-Error	10.231	0.001
LM-Lag	9.112	0.002
Robust LM-Lag	12.024	0.000
Wald inspect	60.08	0.000
Hausman inspect	165.23	0.000

are all significant. Therefore, both spatial error model (SEM) and spatial lag model (SAR) are applicable, indicating that there is a spatial correlation between agricultural industrial agglomeration and agricultural green development efficiency, and it is necessary to use spatial panel model to study the content of this paper. The LR test results show that the spatial lag and spatial error coefficients are both significant at the level of 1%, indicating that SDM will not degenerate into SAR and SEM models, and SDM is the optimal adaptation model. Further, Wald test is used to test, and it is found that the P-value rejects the null hypothesis, and SDM is also supported as the optimal model. Finally, combined with the Hausman test, the P value is 0, indicating that the null hypothesis is rejected and the time-space double fixed effect should be selected. Therefore, it is most appropriate to choose the spatial Durbin model which is bifixed in time and space.

Based on the analysis of the parameter estimation of the spatial Durbin model (Table 5), it can be found that the influence of agricultural industry integration on AGDE passes the hypothesis test at the significance level of 1%, and the coefficient is positive, and the agricultural industry agglomeration has a significant positive impact on the efficiency of agricultural green development. Among them, the agricultural industrial agglomeration increased by 1%, and the agricultural green development efficiency increased by 0.512. That is, the integrated development of agricultural industry has a strong environmental effect while promoting the development of rural economy. The integrated development of agricultural industry can improve agricultural production efficiency and reduce the input of polluting factors such as fertilizers and pesticides, thus enhancing the sustainable development ability of agricultural system and contributing to the realization of China's carbon peak and carbon neutrality goals. In addition, the spillover coefficient ρ passed the significance level test of 5%, indicating that AGDE has a significant spatial spillover effect, that is, the increase of AGDE in the local area has a certain radiation promotion effect on the AGDE in the neighboring area.

In terms of control variables, the effect of financial support to agriculture on AGDE is negative and significant at 5%, which indicates that the level of financial support to agriculture is an obstacle to the improvement of AGDE. The reason is that China's financial support for agriculture tends to subsidize petroleum agricultural elements such as fertilizers, pesticides and agricultural machinery to a large extent, which has a negative effect on the efficiency of agricultural green development. The industrialization (IND) coefficient is significantly negative, indicating that the level of industrialization has a inhibitory effect on the improvement of AGDE. The main reason is that at present, China's industry is ahead of agriculture, which has a certain squeezing effect on agriculture, attracting a large number of agricultural resources, thus hindering the process of green agricultural development. The urbanization coefficient is significantly positive, indicating that the improvement of urbanization level has a positive effect on the efficiency of agricultural green development. This is because the promotion of urbanization can stimulate the demand for agricultural products, and provide economic and technical support for green agricultural production, thereby promoting the improvement of green development efficiency.

Table 5. Estimation results of spatial Durbin model.

Variable	SDM Model	SARModel	SEM Model
lnATL	0.512** (4.249)	0.174* (2.305)	0.239*** (3.357)
LnAGDE	0.253** (3.364)	0.264** (3.211)	0.205** (2.623)
lnFSA	-0.145**(-2.164)	-0.173** (-3.175)	-0.245** (-3.346)
lnIND	0.031** (1.975)	0.029** (1.142)	0.047* (2.125)
lnHC	1.252* (3.201)	1.125 (1.184)	1.172 (0.959)
lnURB	0.181** (3.145)	0.086* (2.113)	0.142** (2.897)
ρ	0.344*** (3.903)	0.243*** (3.625)	0.273** (2.901)
turning point	39.2	36.4	40.5
Log L	400.124	360.237	287.039

Note: *, ** and ***represent the significance level of 10%, 5% and 1%, respectively, with T values shown in brackets.

Table 6. Decomposition results of spatial effect in different regions.

Variable	Direct effect	Indirect effect	Total effect
The eastern region	0.464**(2.894)	0.412**(3.105)	0.891**(2.787)
The central region	0.516** (2.950)	0.314**(3.213)	0.811** (3.112)
The western region	0.471** (3.279)	0.307**(2.587)	0.704**(2.741)

Note: **represents the significance level of 5% with T values shown in brackets.

The human capital level (HC) coefficient is positive and significant, indicating that the improvement of human capital level has a positive impact on the efficiency of agricultural green development, that is, the higher the human capital level (HC), the higher the possibility of mastering high-tech, and the more conducive to improving the efficiency of agricultural green development.

In view of the large differences in the development of agricultural industry in different regions of China, the whole research region is divided into the eastern, central and western regions to construct spatial Durbin model for research, to deeply explore the direct effects and spatial spillover effects of AIA on AGDE, and to analyze the differences of spillover effects between different regions. 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; The western region includes Chongqing, Sichuan, Guizhou, Guangxi, Yunnan, Shaanxi, Inner Mongolia, Gansu, Ningxia, Qinghai and Xinjiang. As can be seen from Table 7, 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. The direct effect of the integrated development of agricultural industries in the central region is more prominent on AGDE, which may be because the resource base of the integrated development of agricultural industries in the central region is better, while AGDE is not high, so the marginal effect of AIA on AGDE is more prominent. In terms of the total spatial spillover effect, the spillover effect of AIA on AGDE in the eastern region was 0.891, and $P<0.05$, which was larger than that in the central and western regions (0.811, 0.704). This is because the economic foundation and infrastructure conditions in the eastern region are better than those in the central and western regions, and the flow of talents, information and elements can interact conveniently and efficiently, so the spillover effect in the eastern region is more prominent.

Conclusions

In order to clarify the impact of China's agricultural industrial agglomeration on agricultural green development efficiency and its spillover effects, SBM-undesirable model was used to calculate the agricultural green development efficiency of 30 provinces (autonomous regions and municipalities) in China during 2011-2020 and analyze its spatiotemporal evolution trend, combined with the traditional Markov chain and spatial Markov chain transfer probability results. The convergent evolution law of agricultural green development efficiency among provinces was compared and analyzed. The spatial Dubin model was constructed to analyze the spatial spillover effect of agricultural industrial agglomeration on agricultural green development efficiency at the national and regional levels. The main conclusions of this paper are as follows: (1) According to the results of spatial Moran index, it is concluded that agricultural green development efficiency has spatial autocorrelation within the region, and agricultural industry agglomeration can significantly promote the growth of AGDE. Assuming H1 is established, this is consistent with the conclusions of existing studies that agricultural industry agglomeration can effectively improve labor productivity [37] and agricultural energy efficiency [38]. (2) The introduction of the spatial Markov chain transfer probability matrix shows that geographical location background has a significant influence on the spatio-temporal evolution and transfer of agricultural green development efficiency, and the spatial distribution has a volatile agglomeration phenomenon. The influence of agricultural green development efficiency between neighboring regions is mutual and presents a spatial agglomeration pattern. Cities with higher agricultural green development efficiency are more likely to drive the upward transfer of agricultural green development efficiency in neighboring areas, with a positive spillover effect, showing a club convergence phenomenon of "the high one is always high, the low one is still low, the high one is low, and the low one is high". (3) Through the test of spatial Durbin model, it is concluded that agricultural industrial agglomeration can improve the efficiency of agricultural green development, and this enhancement effect has spatial spillover. The development of regional AGDE is significantly influenced by the agglomeration of agricultural industry in the region and adjacent areas. In terms of control variables, financial support for agriculture (FSA) and industrialization (IND) have significant negative effects on agricultural green development efficiency, and human capital (HC) and urbanization (URB) have significant positive effects on agricultural green development efficiency. (4) The influence of agricultural industrial agglomeration on agricultural green development efficiency and its spatial spillover have regional heterogeneity, and hypothesis H3 is valid. The effect of agricultural industrial agglomeration on the efficiency of agricultural green development has strong heterogeneity, showing a gradient decline distribution in the eastern, central and western regions.

In view of the above conclusions, this paper puts forward the following policy recommendations: (1) Grasp the spatial correlation law of provincial agriculture and promote the improvement of agricultural green development efficiency. Agricultural production is highly dependent on the natural environment, and regional development is obvious. It is necessary to strengthen regional coordination and cooperation, give full play to the spatial spillover effect, strengthen inter-regional technical and management exchanges, promote inter-provincial agricultural cooperation, and realize the sustainable development of regional agriculture. (2) The government should issue corresponding policies to scientifically layout the development of agricultural industry, appropriately guide the agglomeration of agricultural industry within a reasonable range allowed by the regional resource and environmental carrying capacity, optimize the allocation of agricultural resources, strengthen agricultural technological innovation, and promote the improvement of the efficiency of agricultural green development. (3) Fully mobilize key influencing factors to promote high-quality agricultural development. We will rationally plan and utilize fiscal funds to support agriculture, increase support for the green transformation and development of agriculture, and increase the utilization rate of fiscal funds. We will promote the construction of a new type of urbanization and stimulate the consumption demand of urban residents for agricultural products. We should strengthen industry's efforts to feed agriculture, cultivate agricultural talents and improve agricultural technology. Create a good environment for the improvement of agricultural green development efficiency.

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Conflicts of Interest

The authors declare no conflict of interest.

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