

Article

The Effect of Industrial Agglomeration on Agricultural Green Production Efficiency: Evidence from China

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Abstract: Understanding how industrial agglomeration affects agricultural green production efficiency is essential for green agricultural development. This study uses the super-efficient Epsilon-Based Measure (EBM) model and Global Malmquist–Luenberger (GML) index to measure and analyze the spatial and temporal evolution characteristics and core sources of dynamics of agricultural green production efficiency in China by using panel data from 30 Chinese provinces from 2006 to 2020. It also empirically investigates the relationships between industrial agglomeration, land transfer, and agricultural production efficiency. By using fixed, intermediary, and threshold effect models, the internal links between industrial agglomeration, land transfer, and agricultural green production efficiency are examined. The findings indicate the following. (1) The green production efficiency of Chinese agriculture exhibits the regional characteristics of being “high in the west and low in the east, high in the south and low in the north” in terms of space; in terms of time, the overall trend is that green production technology efficiency is growing, with an average annual growth rate of 11.45%, and the growth primarily depends on the “single-track drive” of green technological progress. (2) Industrial agglomeration significantly affects agricultural green production efficiency, green technology efficiency, and green technology change; the corresponding coefficient values are 0.115, 0.093, and 0.022. (3) According to the mechanism-of-action results, land transfer mediates the effects of industrial agglomeration on agricultural green production efficiency, green technology efficiency, and green technology change. These effects have effect values of 28.48%, 27.91%, and 47.75%, respectively. (4) The threshold effect’s findings demonstrate a double threshold effect of industrial agglomeration on the green production efficiency of agriculture in terms of land transfer, with threshold values of 1.468 and 3.891, respectively. As a result, this study suggests adhering to the idea of synergistic development, promoting agricultural green development, strengthening the development of industrial agglomerations, promoting the quality and efficiency of industry, improving land-transfer mechanisms, and placing a focus on resource efficiency improvements, as well as other policy recommendations.

Keywords: industrial agglomeration; land transfer; agricultural green production efficiency; intermediary effect model; threshold effect model



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1. Introduction

The foundation of a country’s economic and social development is agriculture. Further, the green development of agriculture is a critical project in the current international effort to address climate change and environmental pollution. As a major agricultural producer, China makes such a significant contribution to world food security, which uses less than 9 percent of the world’s land to yield about one-quarter of the world’s food production and feed nearly one-fifth of the world’s population [1]. However, China’s agriculture has

long been in the conventional vast production mode, which has led to several ecological and environmental issues. China's agricultural development is at a bottleneck; the growth of the agricultural economy is excessively dependent on resources, the transformation of green development has put forward higher requirements for emission reduction and the efficiency of agricultural production, and the pressure of resource tightening and environmental protection is enormous [2]. People's demand for agricultural products has changed from "quantity" to "quality". While pursuing a high efficiency of agricultural production, it is also necessary to consider the ecological environment. Therefore, agricultural green production efficiency has become a vital path choice for agricultural green development [3]. It is challenging to accomplish agricultural green development solely by reducing agricultural input and increasing the use of contemporary agro-technology, even if agricultural green production efficiency has been highly regarded compared to traditional agriculture. The "No. 1 Central Document" in 2023 emphasizes the importance of the agricultural industry playing an essential part in advancing agricultural green development and setting higher standards for the agricultural industry [4].

In recent years, in order to solve the problem of "big but not strong" in China's agricultural industry, the "14th Five-Year Plan" national agricultural green development plan proposed to promote the agglomeration of agricultural industries by creating and supporting contemporary agro-industrial parks and towns, to fulfill and improve the efficiency of agricultural green production [5]. Industrial agglomeration reflects the degree of convergence of agriculture in a particular region; it is a crucial indicator of scale and a prerequisite for the intensive use of local resources, and it is more and more linked to the development of environmentally friendly agriculture [6]. Simultaneously, under the impetus of industrial agglomeration, orderly circulation of land management rights and moderate-scale agricultural management have become key points for improving production efficiency [7]. Consequently, there is a closer relationship between industrial agglomeration, land circulation, and agricultural green production efficiency. It is worth considering whether or not there is a relationship between land transfers, industrial agglomeration, and agricultural green production efficiency. Can land transfers via industrial agglomerations help increase agricultural green production efficiency? Does the promotive effect of an industrial agglomeration on agricultural green production efficiency change at different levels of land transfer? These are the primary issues that this study aims to address. Therefore, the scientific measurement of agricultural green production efficiency, analysis of the characteristics of its spatial and temporal evolution and core power sources of growth, exploration of the driving role of industrial agglomeration on agricultural green production efficiency, and clarification of its mechanism of action and the differential characteristics of the impacts' effects are of great theoretical and practical significance for promoting agricultural green development.

Agricultural green production efficiency, land circulation, and industrial agglomeration are currently the topics of hot academic discussion. (1) Existing research has three primary opposing viewpoints regarding how industrial agglomeration affects agricultural green production efficiency. First, industrial agglomeration promotes agricultural green production efficiency [8]; that is, industrial agglomerations have effects such as scale and knowledge spillover, which can continuously stimulate the endogenous momentum of agricultural green development by improving technological innovation, boosting regional competitiveness, optimizing resource allocation, and specializing the division of labor, among other things. Second, industrial agglomeration prevents increases in agricultural green production efficiency [9]. The congestion effect, which occurs when resource consumption exceeds the environment's capacity, is triggered by excessive industrial agglomeration. This effect impedes economic development, causes environmental pollution, and ultimately restrains the development of green agriculture. Areas with more developed industrial clusters frequently have more serious environmental damage. Third, a nonlinear relationship exists between industrial agglomeration and agricultural green production efficiency [10,11]. The impact of industrial agglomeration on agricultural green production

efficiency changes with the degree of agglomeration; i.e., at the early stage of industrial agglomeration, both the effect of capacity expansion, which aggravates resource use and environmental damage, and the possibility of the scale effect, which reduces pollution, exist. In contrast, at the later stage of industrial agglomeration, there is not only the effect of green technological innovation, which reduces resources, but also the effect of scale, which reduces pollution. The result may have a “U” shape [11] or an inverted “U” shape [10]. (2) In terms of land transfer and agricultural green production efficiency, some researchers reckoned that land transfer and agricultural green production efficiency are positively correlated, meaning that achieving large-scale operations through land transfer can directly optimize resource utilization, and indirectly promote green agricultural development by supporting inclusive digital finance and digital village development [12]. Some scholars have also argued that inflows and outflows in land transfer have the opposite effects on agricultural green production efficiency [13]. (3) Regarding industrial agglomeration and land transfer, most scholars believe that industrial agglomeration is an essential driving force of land transfer [14,15]. By developing contemporary agricultural industrial parks and industrial solid towns, industrial agglomeration can revitalize farmers’ idle land and realize large-scale agricultural land management, influencing the behavior of rural land transfer. Additionally, other researchers have discovered that elements such as the degree of financial support for agriculture [16], environmental regulation [17], and the degree of marketization [18], all have varying degrees of substantial effects on agricultural green production efficiency.

There are abundant studies on industrial agglomeration and agricultural green production efficiency. However, it is still controversial, and only a few studies have included land transfer to explore the intrinsic correlation among the three [10,19,20]. As a result, this study elaborates on the following principal aspects. First, the study’s focus is widened, and Chinese provincial panel data from the years 2006–2020 were used as the research sample to measure and analyze the current traits of geographical and temporal evolution, as well as the primary driving forces behind agricultural green production efficiency in China. Second, industrial agglomeration and agricultural green production efficiency were measured scientifically using the location entropy method and the super-efficiency EBM-GML index model, which guaranteed the correctness of the estimation results. The third aim was to sort out the relationship between industrial agglomeration, land transfer, and agricultural green production efficiency using the fixed effect model and the intermediary effect model, test the direct impact of industrial agglomeration on agricultural green production efficiency, and investigate the intermediary effect of land transfer in this process. Fourth, the threshold effect model was employed to investigate whether or not industrial agglomeration affects agricultural green production efficiency differently depending on the level of land transfer. This study aims to establish a scientific foundation for the green development of Chinese agriculture by expanding on the aspects mentioned above and then suggesting corresponding countermeasures.

2. Theoretical Analysis and Research Hypothesis

2.1. Direct Influence of Industrial Agglomeration on Agricultural Green Production Efficiency

There may be both positive and negative impacts of agro-industrial agglomeration on agricultural green production efficiency. Its positive impact is mainly realized through the following effects. First comes the competition effect [21]. Under the influence of the agglomeration economy, the same or similar agricultural production operators are more concentrated, which inevitably exacerbates the competition between the operators in this region. This behavior forces agricultural production operators to innovate green production technology and improve application efficiency of green technology, to save energy and reduce emission so as to enhance the competitiveness of the market, to reduce the production of inputs and environmental pollution, and ultimately enhance the efficiency of green production. Second is the effect of economies of scale [11]. In the process of industrial agglomeration, the scale of the industry is continuously upgraded. Various

sectors promote the optimal allocation of resources through a specialized division of labor and collaboration, etc., i.e., industrial agglomeration can also reduce the factor inputs of agricultural production while guaranteeing the agricultural output, which further alleviates environmental pollution and thus promotes the enhancement of agriculture green production efficiency. Additionally, industrial agglomeration is helpful for the government's unified supervision of formulating and implementing agricultural green development policies. By creating green production standards to limit production behavior or providing subsidies to promote green production, these policies effectively reduce pollution emissions and increase agriculture green production efficiency [22,23].

However, agro-industrial agglomeration may also generate negative externalities. On the one hand, the effect of economies of scale is not absolutely favorable due to the limited agricultural resources of a particular region; when the scale of industrial agglomeration continues to expand, resulting in excessive concentration of industry, the formation of the impact on the industrial structure and the production of various aspects of the production are challenging to coordinate, which may result in a waste of resources and even environmental pollution, thus apparently increasing the cost of production and distribution, and ultimately inhibiting agriculture green production efficiency [24]. On the other hand, industrial agglomeration also has a confinement effect. During the pre-production phase of agricultural production, each factor input is larger, forcing some of the agricultural production operators with lower production efficiency unable to withdraw quickly. Thus, they barely continue to consume agricultural resources inefficiently to maintain agricultural production [25]. However, agricultural industry agglomeration significantly affects agricultural green production efficiency regardless of the positive and negative effects. Hence, the following hypothesis is put forth:

H1. *Industrial agglomeration has a direct impact on agricultural green production efficiency.*

2.2. Indirect Effects of Industrial Agglomeration on Agricultural Green Production Efficiency: Land Transfer's Mediating Role

In the area of industrial agglomeration and land transfer, following the theory of external economies of scale, the expansion of scale results in an incremental return to scale for regional production operators, meaning that a region with a larger agricultural industrial scale is more productive than a region with a smaller scale. This result further encourages the continuous extension of the regional industrial chain and the formation of industrial agglomerations [26]. On the one hand, due to the optimal allocation of land resources serving as the foundation and key component of industrial agglomeration, land transfer is necessary for its formation and growth. At the same time, by encouraging land transfer, production operators revitalize underutilized and abandoned land, raise the scale and standardization of agricultural production, and increase the scale of production, thereby realizing economic benefits. Additionally, as a result of the collaboration of many participants, different scales of operating modes are developed during the extension of the industrial chain, which further develops the level of industrial agglomeration [27]. On the other hand, the modes of land transfer have improved due to industrial agglomeration. Differences in resource endowment, environmental regulation, and on the market level have resulted in obvious regional distinctions in the kinds of land transfer supported by industrial agglomeration, and these have been used to promote agricultural industrialization and modest-scale operation in each region [28]. The primary methods of land transfer currently in use include subcontracting, renting, transferring, swapping, borrowing, and so on. Accordingly, each region also encourages a range of novel methods of land transfer, such as "farmers' cooperatives & farmers" or "enterprises & farmers", based on the characteristics of resource endowment, which is crucial for the growth of regional agriculture [29]. Land transfer will be facilitated by industrial agglomeration.

In the area of land transfer and agriculture green production efficiency, land transfer refers to the transfer of land contracted by farmers to a third party under the principle of equal, paid, and voluntary ownership. Land transfer provides a way to revitalize land

resources and break the longstanding smallholder production method [30]. On the one hand, the resource allocation theory contends that, in the event of a fully developed market, the scarcity of land resources will result in a logical flow of resources into every aspect of agricultural production, to achieve the best possible allocation of land resources. In other words, production operators with higher green production efficiency typically acquire more land resources to increase their scale of production, in order to produce more output. In contrast, production operators with lower green production efficiency prefer to reduce land use to free up agricultural labor resources and engage in off-farm work to seek out more off-farm income [31]. On the other hand, for a long time, due to the uncertainty of the policy, some farmers have been worried about the loss of land rights and interests after the expiration of their land contracts. Thus, they have adopted such methods as abandonment or sloppy management to protect their land rights and interests [32]. According to the land property rights theory, land transfer is a behavior based on the premise of clear land tenure. Land transfer indirectly improves the stability of farmers' land rights and interests by determining land tenure, which makes farmers increase the production input and fine-manage agriculture, fundamentally changing farmers' crude production and management mode to increase agricultural green production efficiency [33]. Accordingly, the following hypothesis is proposed:

H2. *Industrial agglomeration can indirectly affect agricultural green production efficiency by promoting land transfer.*

2.3. Nonlinear Relationship between Industrial Agglomeration, Land Transfer, and Agricultural Green Production Efficiency

The degree of industrial agglomeration is a crucial indicator of agricultural modernization because it may effectively encourage the green development of agriculture and, to a certain extent, reflect the size of arable land operations and the current activity of the land-transfer market. However, since land transfer in China still primarily occurs among friends with little difference in their land-use efficiency, it is challenging for land to flow into production operators with higher green production efficiency; this cannot play the role of optimizing resource allocation, and even further causes the fragmentation of land resources, thereby reducing green production efficiency [11]. At the same time, land transfer may simultaneously affect the original, refined production model while increasing the scale of operation due to the disparities in resource endowment between each location. Frequent land transfers are ineffective in stabilizing agricultural output considering the long-cycle characteristics of agricultural production, which ultimately prevents an increase in agricultural green production efficiency [32]. Therefore, industrial agglomeration may have varied effects on agricultural green production efficiency due to the rising amount of land transfer. In general, the boosting effect of industrial agglomeration on agricultural green production efficiency often diminishes over time while land-transfer frequency increases. Consequently, the following hypothesis is put forth:

H3. *Under various levels of land transfer, industrial agglomeration has a diverse impact on agricultural green production efficiency.*

3. Materials and Methods

3.1. Study Design

3.1.1. Super-Efficient Epsilon-Based Measure (EBM) Model

Agricultural green production efficiency is a crucial benchmark for determining green agricultural development because it incorporates pollution emissions into a measurement framework to fully assess the state of agricultural development while achieving the maximum output under the assumption of established resource factor inputs. This approach assesses the degree of economic development and highlights the value of resource utilization and environmental protection [34]. The super-efficient EBM model suggested is

a viable option for assessing agricultural green production efficiency because it considers the coexistence of radial and non-radial relationships, resource inputs, and both desired and unintended outcomes [35]. This study constructs a non-oriented global super-efficient EBM model with non-desired outputs as follows [36]:

$$P^* = \min_{\theta, \eta, \lambda, s^-, s^+} \frac{\theta + \varepsilon_x \sum_{i=1}^m \frac{\omega_i^- s_i^-}{x_{io}}}{\eta - \varepsilon_y \sum_{r=1}^s \frac{\omega_r^+ s_r^+}{y_{ro}} - \varepsilon_h \sum_{p=1}^q \frac{\omega_q^{h-} s_q^{h-}}{h_{qo}}} \quad (1)$$

$$s.t. \begin{cases} \sum_{t=1}^T \sum_{j=1, j \neq 0}^n x_{ij}^t \lambda_j^t - s_i^- \leq \theta x_{io}, i = 1, \dots, m \\ \sum_{t=1}^T \sum_{j=1, j \neq 0}^n y_{rj}^t \lambda_j^t + s_r^+ \geq \eta y_{ro}, r = 1, \dots, s \\ \sum_{t=1}^T \sum_{j=1, j \neq 0}^n b_{qj}^t \lambda_j^t - s_q^{b-} \leq \eta b_{qo}, q = 1, \dots, p \\ \sum_{t=1}^T \sum_{j=1, j \neq 0}^n \lambda_j^t = 1 \\ \lambda \geq 0, s_i^- \geq 0, s_r^+ \geq 0, s_q^{b-} \geq 0 \end{cases}$$

In Equation (1), the letters ω_i^- , ω_r^+ , and ω_q^{h-} stand for the weights of the input factors, the desired outcomes, and the undesirable outcomes, respectively. Input redundancy variables are denoted by s_i^- , while s_r^+ and s_q^{b-} , respectively, denote the desired output deficiency variables and undesirable output redundancy variables. ε represents the radial and non-radial slack combination degree and accepts values between 0 and 1. Weights were applied to the data in this research by using the MaxDEA ULTRA 9 software, which can more accurately reflect the weights of each input element and outcome, thus avoiding subjectivity when defining weights in the model.

3.1.2. Global Malmquist–Luenberger (GML) Index

The GML index was utilized to examine the number of changes in agricultural green production efficiency across the reporting periods to better understand the dynamics of agricultural green production efficiency. Because the GML index has greater transferability and continuity than the ML index, thus allowing the potential issue of the ML index's lack of a workable solution to be overcome and permitting technological regression, it is frequently used to quantify green production efficiency [37,38]. The GML index was constructed as follows [39]:

$$GML^{t,t+1}(x^t, y^t, b^t, y^{t+1}, b^{t+1}) = \frac{1 + D_G^T(x^t, y^t, b^t)}{1 + D_G^T(x^{t+1}, y^{t+1}, b^{t+1})} \quad (2)$$

In Equation (2), $D_G^T(x, y, b) = \max\{\beta | (y + \beta y, b - \beta b) \in P_G(x)\}$ is derived from the global benchmark production possibility set. If $GML^{t,t+1} > 1$, this indicates that agricultural green production efficiency increased; otherwise, it indicates that agricultural green production efficiency decreased. Equation (3) illustrates how the GML index is divided into two parts—the green technical efficiency index (GEC) and the green technical change index (GTC)—in order to investigate the fundamental driving force behind agricultural green production efficiency.

$$GML^{t,t+1} = GTC^{t,t+1} \times GEC^{t,t+1} \quad (3)$$

3.2. Model Setting

3.2.1. Base Regression Model

Before building the baseline regression model, deciding whether to employ mixed effects, fixed effects, or random effects models is essential. According to the Hausman test results, the fixed effect model (FE) is preferable for variables with significant individual effects, but further investigation into variable multicollinearity is still required. The follow-

ing fixed effect model was constructed to verify the direct effect of industrial agglomeration on agricultural green production efficiency:

$$AGPE_{it} = \alpha + cAGG_{it} + \delta \sum Control_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

In Equation (4), AGPE represents agricultural green production efficiency; *i* is the region; *t* is the year; α is the intercept term; AGG represents industrial agglomeration, and *c* is its coefficient that is to be estimated; Control represents the control variable, and δ is its coefficient vector; μ is an individual effect; ε is a random error term. Furthermore, because the model configuration for Equation (4) and the investigation of the impacts of industrial agglomeration on green technical efficiency (GEC) and green technical change (GTC) are essentially the same, they are not reproduced here.

3.2.2. Mediation Models

This research employed a panel mediating effect model to investigate the mediating effect of land transfer in order to determine if industrial agglomeration can improve agricultural green production efficiency through the promotion of land transfer. Based on Equation (4) and relevant studies [40], the mediating effect model was created as follows.

$$LT_{it} = \alpha + aAGG_{it} + \delta \sum Control_{it} + \mu_i + \varepsilon_{it} \quad (5)$$

$$AGPE_{it} = \alpha + c'AGG_{it} + bLT_{it} + \delta \sum Control_{it} + \mu_i + \varepsilon_{it} \quad (6)$$

In Equations (5) and (6), LT is the mediating variable for land transfer; *a* and *c'* are the coefficients for industrial agglomeration that are required to be estimated; *b* is the coefficient for land transfer that needs be estimated; the remaining variables all have definitions that are compatible with those in Equation (4). The coefficient *c* in Equation (4) represents the total effect of industrial agglomeration on agricultural green production efficiency; coefficient *a* in Equation (5) represents the impact of industrial agglomeration on land transfer; coefficient *c'* in Equation (6) represents the direct impact of industrial agglomeration on agricultural green production efficiency. The indirect impact is significant when the coefficients α and *b* are significant. Additionally, if the coefficient *c'* is significant and *a* and *b* has the same sign as *c'*, a partial mediating effect with an effect value of $a \times b/c$ is recognized.

3.2.3. Threshold Effect Model

Based on the aforementioned theoretical study, it is necessary to determine if industrial agglomeration has a variable impact on agricultural green production efficiency. Following the pertinent study [41], the threshold effect of land transfer was tested by using land transfer as a threshold variable to create a segmental function of industrial agglomeration with respect to agricultural green production efficiency. Equation (4) and the panel threshold effect model were configured as follows:

$$AGPE_{it} = \alpha + \beta_1 AGG_{it} \times I(LT_{it} \leq \gamma) + \beta_2 AGG_{it} \times I(LT_{it} > \gamma) + \delta \sum Control_{it} + \mu_i + \varepsilon_{it} \quad (7)$$

In Equation (7), β_1 and β_2 are the coefficients to be estimated for the corresponding threshold intervals; $I(\cdot)$ is the indicative function, taking the value of 1 if the expression in parentheses is true and 0 otherwise; γ is the threshold value to be determined. The remaining variables have meanings consistent with those in Equation (4).

3.3. Variable Setting

3.3.1. Dependent Variable

This study's explanatory variable is agricultural green production efficiency, which is the global index calculated with the super-effective EBM–GML model. The following are some of the illustrations of the input and output indicators utilized for the measurement.

Regarding related studies [3,18,42], in this study, the total sown area of agricultural works (thousand hectares), agricultural employment (ten thousand people), agricultural fertilizer application (converted) (tons), pesticide use (tons), agricultural plastic film use (tons), the total power of agricultural machinery (ten thousand kilowatts), agricultural diesel fuel use (tons), rural electricity consumption (billion-kilowatt hours), and effective irrigation area (thousand hectares) were used as input indicators. Because the number of individuals in agricultural employment is not directly published in the statistical yearbooks, we used the number of individuals employed in the primary sector multiplied by the ratio of total agricultural output value to total agricultural, forestry, animal husbandry, and fishery output value in order to derive this value [1]. The total agricultural output value (billion yuan) was used as the desired output indicator, and the base period of 2006 was used as a deflator to eliminate the effect of the price level; agricultural carbon emission (tons) and agricultural surface pollution were utilized as non-desired output indicators. The total agricultural carbon emissions were computed using $E = \sum E_i = \sum T_i \xi_i$, where E_i represents each carbon source's carbon emissions, T_i represents each source's carbon usage, and ξ_i represents each source's carbon emission coefficient. The main agricultural carbon sources and coefficients were the following: agricultural tillage (3.126 kg/hm²), according to a study conducted by the Institute of Biology and Technology, China Agricultural University; agricultural fertilizer (0.8956 kg/kg) and pesticide (4.9341 kg/kg), according to a study conducted by Oak Ridge National Laboratory; agricultural plastic film (5.18 kg/kg), according to a study conducted by Institute of Agricultural Resources and Ecological Environment, Nanjing Agricultural University, China; agricultural diesel (0.5927 kg/kg), according to a relevant study by the IPCC UN Intergovernmental Panel on Climate Change; agricultural irrigation (20.476 kg/hm²) [43]. Pesticide loss or residue, agricultural plastic film, and fertilizer use are the main causes of agricultural surface source pollution. Each source's pollution output is a function of its usage amount and pollution coefficient. According to the First National Pollution Source Census's Handbook of Pollution Coefficients for Agricultural Surface Source Pollution Sources, the coefficient of pesticide loss was determined to be 50%, that of agricultural plastic films was determined to be 10%, and that of fertilizer residues was determined to be 75% [44]. However, because the pollutants from each source differ and cannot simply be statistically added up, the amount of pollution from each pollutant was standardized by using the entropy value method before being finally integrated into a comprehensive index through objective assignment, thus avoiding the measurement error caused by inconsistency in the measurement scale [45].

3.3.2. Core Independent Variables

The main explanatory factor in this study was industrial agglomeration, which was calculated by using locational entropy [46,47], and this eliminated the effects of regional-scale differences and other effects and allowed the level of agricultural agglomeration to be calculated more precisely; the specific measurement formula is as follows:

$$AGG_{it} = \frac{A_{it}/G_{it}}{A_t/G_t} \quad (8)$$

In Equation (8), AGG_{it} stands for region i 's industrial agglomeration in year t , and its industrial agglomeration is proportional to the value; A_{it} and G_{it} stand for region i 's total agricultural output value and regional GDP in year t , respectively; A_t and G_t stand for the country's total agricultural output value and GDP in year t , respectively.

3.3.3. Intermediate Variable

Land transfer served as the mediating variable in this study. It was represented by the ratio of the total area of farmland under a family contract that had been transferred to the entire area of farmland under a family contract in the area [48,49]. The total area of transfer included the areas of leasing (subcontracting), shareholding, and other forms, as well as

the areas transferred to farmers, family farms, professional cooperatives, enterprises, and other subjects.

3.3.4. Control Variables

Because of the vulnerability of agricultural green production efficiency to many factors, the following variables were considered control variables to improve the findings' external validity [13,36,50,51]:

- The level of financial support for agriculture (Sup), which was characterized by the ratio of the local financial expenditure on agriculture, forestry, and water affairs to the regional GDP.
- Environmental regulation (Reg), which was characterized by the ratio of completed investments in industrial pollution control to the added value of the industry.
- R&D intensity, which was characterized by using the ratio of internal expenditure on R&D funding to the regional GDP.
- Foreign direct investment (For), which was characterized by using the total foreign direct investment multiplied by the current USD/CNH exchange rate and then divided by the regional GDP.
- The level of transportation infrastructure (Tra), which was characterized by using the number of road miles.
- The proportion of affected area (Dis), which was characterized by using the ratio of the affected area to total crop-sowing area.
- The level of marketization (Mar), which was characterized by the Fan Gang marketization index [52].
- The technology market development (Tmd) level, which was characterized by using the technology market turnover with respect to the regional GDP.

3.4. Data Source and Description

The sample period for this article was chosen as 2006–2020 in consideration of each indicator's availability, and the panel data of 30 Chinese provinces (excluding Tibet, Hong Kong, Macau, and Taiwan) were the subject of the examination. The China Rural Statistical Yearbook, China Statistical Yearbook, EPS database, and the statistical yearbooks and bulletins of each province and city in the corresponding years were the primary sources of data on agricultural green production efficiency and industrial agglomeration. The data on land transfer were obtained from the China Rural Management Statistical Annual Report and China Agricultural Statistics; for some missing values, linear interpolation was used to fill in the gaps. Because this study depended more on weight and other percentage data, logarithmic processing of the data and descriptive statistics of variables were used, as stated in Table 1, to lessen the impacts of heteroskedasticity and extreme values.

Table 1. Variables' descriptive statistics.

Indicator	Mean	Std. Dev	Min	Max
lnAGPE	0.508	0.334	−0.130	1.597
lnGTC	0.581	0.359	−0.078	1.631
lnGEC	−0.072	0.159	−0.890	0.325
lnAGG	−0.069	0.847	−3.161	1.443
lnLT	2.863	0.949	0.304	4.512
lnSup	0.831	0.664	−0.759	2.400
lnReg	−1.235	0.848	−4.763	1.131
lnR&d	0.224	0.628	−1.602	1.863
lnFor	0.363	1.088	−4.576	2.103
lnTra	11.609	0.856	9.249	12.885
lnDis	2.643	0.876	−0.525	4.242
lnMar	2.003	0.256	1.212	2.479
lnTmd	−0.672	1.350	−4.006	2.866

4. Results and Discussion

4.1. Analysis of the Agricultural Green Production Efficiency Measurement Results

4.1.1. Time-Series Evolutionary Feature Analysis

First, agricultural green production efficiency (AGPE) was measured while taking non-desired outputs into account and agricultural production efficiency (APE) was measured without taking non-desired outputs into account by using the super-efficient EBM model. Second, the average production efficiency values were obtained by adding the efficiency values of each province by year and taking the mean values (Figure 1). The results demonstrated an overall increase in green production efficiency in Chinese agriculture, which was generally in agreement with the conclusions of some scholars [53]. Specifically, agricultural green production efficiency rose from 0.312 in 2006 to 0.848 in 2020 with an average annual growth rate of 11.45%, while agricultural production efficiency rose from 0.335 to 0.868 with an average annual growth rate of 10.60%. However, when non-desired outputs were taken into consideration, the value of agricultural green production efficiency decreased noticeably compared to when they were not considered during the same period. Using the agricultural green production efficiency index to gauge the state of agricultural development is more logical. China's agricultural green growth has produced impressive results as green development has become more popular, agricultural surface pollution is avoided, and low-carbon production systems are continuously improved.

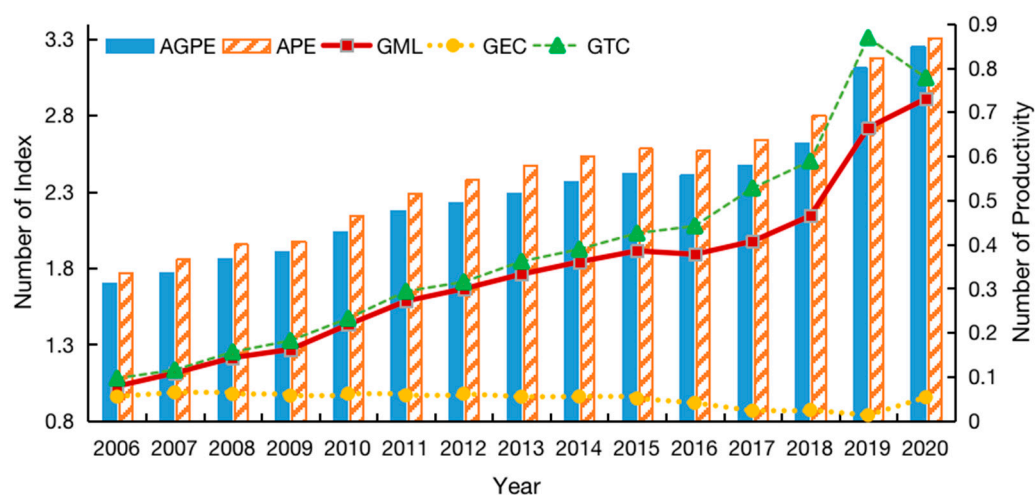


Figure 1. Time-series characteristics of indicators related to agricultural green production efficiency.

Equations (2) and (3) were used to measure the agricultural green production efficiency index and its decomposition term index. Since the measured values of agricultural green production efficiency were chain growth indices, to more intuitively portray the time-series evolutionary characteristics of agricultural green production efficiency and its core sources of dynamics, the indices were treated as cumulative change indices with 2006 as the base period, i.e., each index was a continuous-chain product index from the base period to the reporting period (see Figure 1) [18]. The findings demonstrated a strong correlation between the GTC and agricultural green production efficiency indexes. However, the GEC index showed fewer significant changes and even declined in some years. This indicated that the GTC's "single-core drive" was an essential factor contributing to the green production efficiency of Chinese agriculture throughout the study period. China has been innovating and introducing advanced green technologies in recent years, which has been driven by the idea of "green development". The expansion of the scale of agricultural green technologies has resulted in a continuous rise in agricultural modernization, a continuous transformation and upgrading of the agricultural production model towards sustainable development, and a steady increase in the efficiency of agricultural green production.

4.1.2. Analysis of the Spatial Variation Characteristics

Clarifying the spatial differences in agricultural green production efficiency helps in grasping the regional evolution pattern of China's agricultural green development. This study created a spatial trend surface fit of green production efficiency in Chinese agriculture from 2006 to 2020 by using the ArcGIS 10.2 software (Figure 2). As observed in Figure 2, generally, the regional distribution of green production efficiency in Chinese agriculture varied greatly. Still, all levels rose throughout the study period. Specifically, in the north–south direction, in 2006, agricultural green production efficiency displayed a “U”-shaped distribution pattern with the characteristics of being low in the middle and high on both sides; by 2020, the efficiency level of the central region had significantly improved and was essentially the same as that of the northern region, while the agricultural green production efficiency of the southern region was lower. Due to its superior natural resources (land, water, and climate) compared to those of other regions, the southern region still had a high degree of green production efficiency. The efficiency levels of the various regions differed less in the east–west direction. Still, during the sample period, the western region's efficiency levels improved more quickly than did those of the central and eastern regions. The result was primarily because the western region had many biological species, a wide distribution, and a high economic utilization value, which are a crucial foundation and material guarantee for the development of a green agricultural economy [54]. These findings show that the spatial evolution of agricultural green production efficiency, an important measure of the regional green development level, is closely related to the spatial differences in the characteristics of regional agricultural resource factor endowment, the green technology development level, and economic development level.

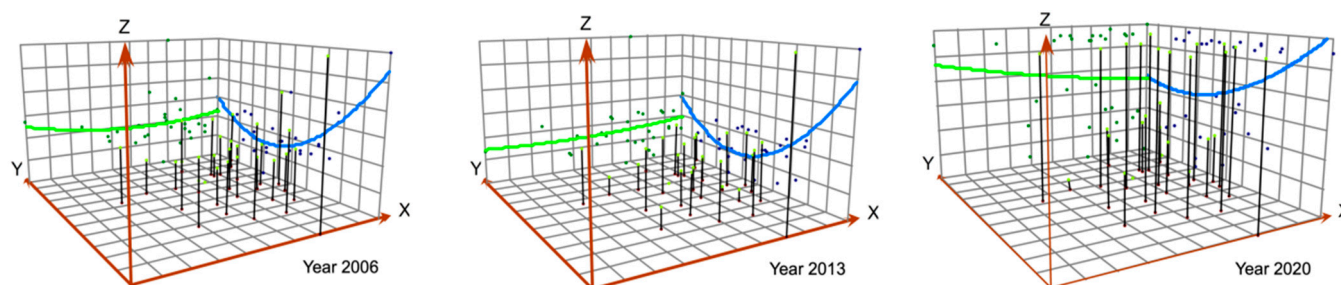


Figure 2. Spatial trend surface fit of Chinese agricultural green production efficiency in 2006–2020. Note: The green line indicates the east–west direction, and the blue line indicates the north–south direction.

4.2. Analysis of the Baseline Model's Regression Results

The “variance inflation factor” method was used to test for multicollinearity to avoid distorted model estimates due to excessive inter-variable correlation. According to the results of multicollinearity, the Mean-VIF was 3.16 and the Max-VIF was 5.74, which were both below the crucial number of 10; this indicates that there was no multicollinearity and the relevant requirements of the fixed effects model were met. As a result, Equation (4) was used in this study to examine the impact of industrial agglomeration on the index of agricultural green production efficiency (Table 2).

As shown in Table 2, industrial agglomeration passed the positive significance test at the 5% level for the agricultural green production efficiency index, indicating that industrial agglomeration could significantly promote agricultural green production efficiency. These results are consistent with those of previous studies showing that agricultural industrial agglomeration can improve agricultural income [55], reduce agricultural surface pollution [10], and optimize industrial processes [11]. The effects of industrial agglomeration on the GEC and GTC were further investigated, and the findings demonstrated that industrial agglomeration continued to significantly contribute to green technical efficiency and change. The findings demonstrated that, on the one hand, as agricultural industry agglomeration rose, the industrial chain was enhanced. The gradual development of the agglomeration economy intensified healthy competition and cooperation among business organizations in

the regions, forcing business organizations to continuously innovate in green production technology or improve the efficiency of green technology applications, prompting them to engage in energy-saving activities and, thus, achieve optimal resource allocation and reductions in environmental pollution, which promoted agricultural green production efficiency. The implementation of centralized government oversight and environmental regulation policies, on the other hand, was facilitated by industrial agglomeration, which also encouraged the spread of green production technologies, increased their coverage and radiation, significantly lowered the mismatch between resource factors and pollution emissions, and enhanced agricultural green production efficiency.

Table 2. Baseline regression results.

Indicator	lnAGPE	lnGEC	lnGTC
lnAGG	0.115 ** (0.056)	0.093 ** (0.041)	0.022 * (0.014)
lnSup	0.191 *** (0.037)	−0.044 (0.027)	0.236 *** (0.037)
lnReg	−0.033 ** (0.013)	0.005 (0.010)	−0.038 *** (0.013)
lnR&d	0.333 *** (0.056)	0.025 (0.041)	0.307 *** (0.056)
lnFor	−0.042 ** (0.016)	0.021 * (0.012)	−0.064 *** (0.016)
lnTra	0.391 *** (0.111)	−0.102 (0.082)	0.493 *** (0.112)
lnDis	−0.036 *** (0.013)	−0.004 (0.010)	−0.032 *** (0.013)
lnMar	0.539 *** (0.098)	−0.070 (0.072)	0.609 *** (0.098)
lnTmd	0.061 *** (0.014)	−0.017 (0.010)	0.078 *** (0.014)
R-squared	0.744	0.115	0.791

Note: Robust standard errors are in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

Additionally, among the control factors, Sup, R&d, Tra, Mar, and Tmd all significantly improved agricultural green production efficiency for the following reasons:

- Sup: With the scale of financial support for agriculture steadily growing, the method of providing that support evolved from straightforward direct subsidies to the use of financial policies to direct and leverage financial and social capital to invest in the development of modern agriculture, thereby promoting agricultural green production efficiency [56].
- R&d: Agricultural green production efficiency could be increased by increasing R&D investments in green technology for agriculture and improving resource utilization efficiency, which played a vital role in raising crop yields and lowering production costs [57].
- Tra: Transport infrastructure not only made it easier for investors to invest in rural areas and improved the conditions for rural transportation, but it also helped modernize these areas and disseminate information, which increased agricultural green production efficiency [45].
- Mar and Tmd: One way in which the development of the technology market advanced was by encouraging the growth of low-carbon and green industries. On the other hand, the level of marketization advanced the market-based system for allocating resources and the environment. It hastened the adoption of advanced energy conservation and carbon reduction technologies, thereby enhancing agricultural green production efficiency [52].

In contrast, Reg, For, and Dis all significantly inhibited agricultural green production efficiency for the following reasons:

- Reg: With the development of the economy, the increase in environmental regulations directly led to an increase in the internal costs of investing in enterprises, which, to some extent, reduced the incentive to invest and hindered the further development of technology, thus inhibiting agricultural green production efficiency [53].
- For: The inflow of foreign capital had a constraining effect on China's economic development, leading to an increasingly pronounced low-performance ecological contradiction in the Chinese market in terms of the distortion of factor resources

and resource depletion, which ultimately inhibited agricultural green production efficiency [50].

- Dis: The expansion of the impacted area resulted in not only a reduction in the desired output, but also increases in pesticides, fertilizers, and other inputs for resilience operations, resulting in a rise in undesirable output, which prevented the increase in agricultural green production efficiency [1].

4.3. Robustness Tests

In order to verify the robustness of the findings, robustness results were obtained and are presented in Table 3. (1) Using the variable replacement method, replacing the dependent variable, the super-efficient Slacks-Based Measure (SBM) model was used to re-measure agricultural green production efficiency by defining a new variable as “AGPE#”. The regression results are shown in column (1). Compared to the EBM model, the SBM model also overcomes the non-radial problem when dealing with the presence of non-desired outputs; thus it can be widely used for the early measurement of green production efficiency.

Table 3. Robustness test results.

Indicator	(1) lnAGPE#	(2) lnAGPE	(3) lnAGPE
lnAGG	0.219 ** (0.091)		0.139 ** (0.057)
lnAGG#		0.139 ** (0.063)	
Controls	Yes	Yes	Yes
N	450	450	420
R-squared	0.725	0.724	0.728

Note: ** $p < 0.05$.

(2) Using the variable substitution method, involving the substitution of core independent variables, we replaced the narrowly defined gross value of agricultural output in Equation (8) with the broadly defined gross value of agriculture, forestry, animal husbandry, and fisheries to remeasure the agricultural industry agglomeration. The new variable is defined as “AGG#”, and the regression results are shown in column (2).

(3) We performed an adjustment of the sample period, involving a reduction in the sample period. The sample period was adjusted to cover 2006 through 2019. Because the COVID-19 pandemic, which affected agricultural production in 2020, would have had a significant impact, only samples taken before 2020 were kept for analysis to exclude the effects of this significant environmental change. The regression results are shown in column (3).

All of the above robustness tests passed requirements such as multicollinearity and will not be repeated here.

The findings on the impact of industrial agglomeration on agricultural green production efficiency were robust, as can be seen from the results in Table 3. This is because the direction and significance of the coefficients of the industrial agglomeration variables for each test did not significantly change when compared to those of the results of the benchmark regression in Table 2. Accordingly, H1 was tested.

4.4. Endogeneity Test

Although this paper controls for as many critical variables as possible, there are more factors affecting agricultural green production efficiency, and it is not possible to control for them in a way that completely prevents, for example, the creation of omitted variables and bidirectional causality, which can lead to bias in the estimation results, because there is the possibility that agricultural green production efficiency may in turn affect industrial agglomeration. For example, green technological advances increase agricultural green production efficiency, which may lead to the specialization of production in modified areas, thus promoting industrial agglomeration. Therefore, this study attempts to mitigate the endogeneity problem in two ways.

4.4.1. Lagged One-Period Core Explanatory Variables

The results from when the industrial agglomeration variable was lagged by one period to examine its impact on agricultural green production efficiency are shown in column (1) of Table 4; this is mainly to consider that the industrial agglomeration in the lagging period is closely related to the industrial agglomeration in the current period, but will not be affected by agricultural green production efficiency in the current period, reducing the reverse causality between current industrial agglomeration and agricultural green production efficiency. The results indicate that, after a one-period lag, industrial agglomeration passed the positive significance test at the 10% level for agricultural green production efficiency. After a one-period lag, the results showed that industrial agglomeration still significantly improved agricultural green production efficiency.

Table 4. Endogeneity test results.

Indicator	(1) lnAGPE	(2) lnAGPE	(3) lnAGG	(4) lnAGPE
			Phase I	Phase II
L. lnAGG	0.112 * (0.062)			
lnAGG				0.272 *** (0.054)
lnDen		0.101 (0.280)	−0.133 ** (0.064)	
L2. lnAGG		0.156 (0.153)	0.874 *** (0.033)	
Controls	Yes	Yes	Yes	Yes
F Statistic				F = 391.173
Over-identification test				P = 0.280
N	420	390	390	390
R-squared	0.711	0.670	0.994	0.878

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

4.4.2. Instrumental Variable Method for Panel Data

In this study, industrial clustering was chosen as a dependent variable, and the lagged second-stage industrial agglomeration and employment density (Den) were selected as instrumental variables [58]. A two-stage least squares (2SLS) analysis was conducted to test for endogenous variables. The considerations for selecting lagged second-stage industrial agglomeration as an instrumental variable are as follows. Firstly, one common approach when determining instrumental variables is to use the lagged variable of an endogenous variable as an instrument variable, using lagged second-stage industrial agglomeration as an instrument variable. Because the earlier-stage industrial agglomeration lays the foundation for the later-stage industrial agglomeration and is supported by the results from Table 4, Column (3), it demonstrates that the industrial agglomeration lagged in the second stage is closely related to the current industrial agglomeration. Secondly, the impact of the industrial agglomeration lagged in the second stage on the current industrial agglomeration primarily affects the current industrial agglomeration through the indirect influence of lagged industrial agglomeration in the first stage. Thus, there is almost no significant impact on agricultural green production efficiency in the current period, which is supported by the results of Column (2) in Table 4. This instrumental variable not only fulfills the requirement of “correlation” with the core independent variable but also meets the requirement of “exogeneity” with the dependent variable and “exclusion restriction” concerning the control variable. It is a reasonable exogenous indicator. In addition, the considerations for choosing employment density as an instrumental variable are as follows. Employment density is measured by the ratio of the number of persons employed in the agriculture sector to the area of the administrative division of the region. This treatment hypothesizes that the employment density of a region reflects the degree of dependence of the industry on labor; then, under the competitive effect of industrial agglomeration, agricultural production operators tend to adopt modern equipment, etc., to reduce the input of labor, so employment density is negatively correlated with industrial agglomeration, which is corroborated by the results of Column (3) in Table 4. However, employment density

is highly correlated with the size of the administrative division. It thus has almost no effect on agricultural green production efficiency, as supported by the results of Column (2) in Table 4. Thus, employment intensity also satisfies the requirements of the instrumental variable's "correlation", "exogeneity", and "exclusion restriction".

Specifically, the results of column (3) in Table 5 show the correlation between industrial agglomeration lag two and employment density on industrial agglomeration. The results in column (4) show that after applying the two-stage least squares method to alleviate the endogeneity problem, the effect of industrial agglomeration on agricultural green production efficiency still passed the positive significance test at the 1% level. Additionally, the test results for weak instrumental variables revealed that the F-statistic was 391.173, which is significantly higher than the critical value, indicating that there was no problem with weak Instrumental variables. Similarly, the test results for over-identification revealed that the *p*-value was 0.280, so the original hypothesis of exogenous instrumental variables was accepted, indicating that there was no problem with over-identification. As a result, this demonstrated that industrial agglomeration did increase agricultural green production efficiency.

Table 5. Results of regional the heterogeneity test.

Indicator	Western	Central	Eastern
lnAGG	0.438 *** (0.144)	0.535 *** (0.101)	−0.261 *** (0.094)
lnSup	0.146 ** (0.065)	−0.005 (0.065)	0.150 ** (0.070)
lnReg	−0.044 * (0.024)	−0.048 * (0.027)	−0.006 (0.020)
lnR&d	0.086 (0.086)	0.442 *** (0.097)	0.406 *** (0.119)
lnFor	0.027 (0.018)	−0.042 (0.044)	−0.167 *** (0.032)
lnTra	0.999 *** (0.163)	0.448 ** (0.220)	−0.253 (0.221)
lnDis	−0.053 ** (0.025)	−0.039 (0.030)	−0.014 (0.018)
lnMar	0.218 ** (0.105)	1.315 *** (0.266)	0.309 (0.282)
lnTmd	0.012 (0.019)	−0.020 (0.032)	0.128 *** (0.027)
lnSup	0.146 ** (0.065)	−0.005 (0.065)	0.150 ** (0.070)
N	135	135	180
R-squared	0.860	0.784	0.758

Note: *** *p* < 0.01, ** *p* < 0.05, and * *p* < 0.1.

5. Regional Heterogeneity Analysis

China is a vast country with different levels of agricultural green development in different provinces influenced by natural resources, cultural practices, and industrial structure. It can be preliminarily judged that apparent regional heterogeneity exists in industrial agglomeration and agricultural green production efficiency in each region; however, whether or not the effects of industrial agglomeration on agricultural green production efficiency in different regions are also regionally heterogeneous needs to be analyzed. To this end, this study divided China into three parts according to topographical and other characteristics—western (Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang), central (Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan), and eastern (Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan) China—to further investigate the inter-regional heterogeneity, and the regression results are shown in Table 5.

Table 5 demonstrates that the central and western regions both passed the positive significance test at the 1% level for industrial agglomeration in terms of agricultural green production efficiency, whereas the eastern region passed the negative significance test at the 1% level. The possible reason is that, compared with the central and western regions, the eastern region has a higher level of economic development based on its coastal location. Under the influence of foreign direct investment, the expansion of its production scale has increased the inputs of pesticides, chemical fertilizers, and other factors, spiking up the pressure on the agroecological environment, which has inhibited the enhancement of the efficiency of green production in agriculture. On the other hand, due to the constraints of environmental regulations, the improvement of transportation infrastructure,

and market-oriented regulation, the central and western regions have promoted agricultural green production efficiency. Therefore, the central and western regions should continue to play an innovative role in industrial agglomeration. In contrast, the eastern regions should concentrate on improving the efficiency of and technological changes in agricultural green technology in industrial agglomeration and avoid heedlessly expanding the scale of industrial agglomeration.

6. Mediation Models Test

According to theory, industrial agglomeration could promote land transfer in boosting agricultural green production efficiency. The mediating effect of land transfer was tested by using Equations (4) to (6). The same fixed-effects model was utilized in the regression analysis in order to assure the comparability of the test results, and the results are displayed in Table 6.

Table 6. Test results for the mechanism of action.

Indicator	(1)lnLT	(2)lnAGPE		(3)lnGEC		(4)lnGTC	
lnAGG	0.309 ** (0.139)		0.148 *** (0.055)		0.028 * (0.014)		0.064 * (0.034)
lnLT		0.101 *** (0.019)	0.106 *** (0.019)	0.032 ** (0.015)	0.084 ** (0.041)	0.032 *** (0.008)	0.034 *** (0.008)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	450	450	450	450	450	450	450
R-squared	0.758	0.762	0.758	0.123	0.114	0.814	0.813

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

Table 6 demonstrates that the effect of industrial agglomeration on land transfer in column (1) passed the positive significance test at the 5% level. This showed that industrial agglomeration could encourage the intensive input of production factors, large-scale operation, and stimulation of the land-transfer market's activity. With a mediating effect value of 28.48%, land transfer played a mediating role in the influence of industrial agglomeration on agricultural green production efficiency, as shown in Table 6, where both industrial agglomeration and land transfer passed the positive significance test at the 1% level for agricultural green production efficiency. Industrial agglomeration encouraged the growth of the land transfer market, which optimized the allocation of resources and factors, increased the utilization rate of resources and factors, and, thus, encouraged the improvement of agricultural green production efficiency. The mediating effect values for the impact of industrial agglomeration on GEC and GTC were 27.91% and 47.75%, respectively, as shown in Table 6. On the one hand, land transfer boosted green technical efficiency by maximizing the distribution of production resource components, such as land, labor, and capital, and raising the utilization rate of resource factors under the same level of resource factor inputs. On the other hand, land transfer sped up the industrialization and scale of agricultural production by transferring farmers' land into new agricultural business entities with more advanced technology. This increased the competitiveness of the agricultural market, improved agricultural innovation, and, ultimately, fostered the advancement of green technology. Accordingly, H2 was verified.

7. Threshold Effect Models Test

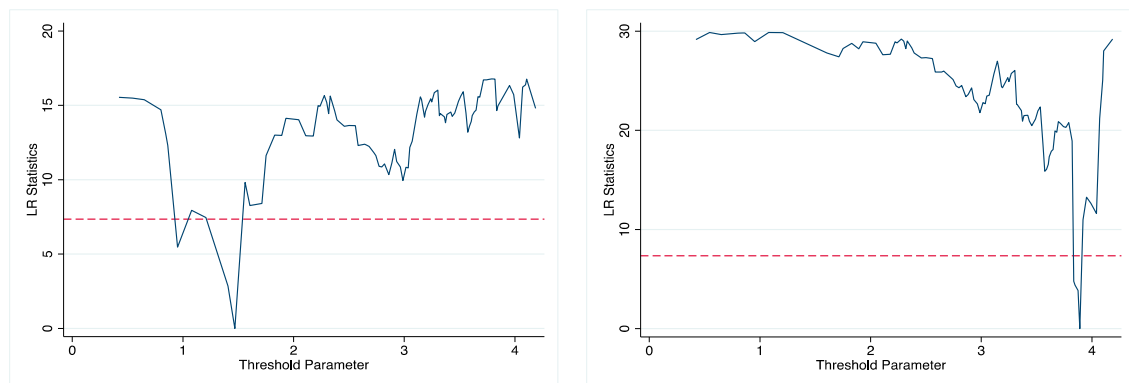
According to theory, industrial agglomeration could promote land transfer in boosting the efficiency of agricultural green production. However, with increasing levels of land transfer, it is necessary to examine whether or not there are differences in the promotive effect of industrial agglomeration on agricultural green production efficiency. Therefore, the threshold effect test was performed by using Equation (7), and the results are shown in Table 7.

Table 7. Results of the threshold effect test.

Indicator	Threshold Type	F Value	p Value	Threshold Value	95% Confidence Interval
lnLT	Single Threshold	34.36 **	0.014	3.891	(3.847, 3.918)
	Double threshold	17.26 *	0.068	1.468	(1.307, 1.561)
	Triple Threshold	3.71	0.788	2.987	(2.964, 3.015)

Note: *p*-values are the results of 500 replicate samplings using the bootstrap method. Note: ** *p* < 0.05 and * *p* < 0.1.

With land transfer serving as the threshold variable, the results in Table 7 demonstrate that both the single and double thresholds passed significant positive tests, thus proving the existence of a double-threshold effect with threshold values of 1.468 and 3.891, respectively. There was a significant nonlinear relationship between industrial agglomeration and agricultural green production efficiency, as shown by the likelihood ratio function plot in Figure 3, which corresponded to the threshold values, showing that both thresholds' corresponding LR values were less than the critical values at the 5% significance level.

**Figure 3.** Likelihood ratio function plots for the first and second thresholds.

The threshold effect of land transfer was tested next by using the double-threshold model, and the outcomes are displayed in Table 8.

Table 8. Results of the threshold effect test.

Indicator	Coefficient	Std. Dev	t-Value
$\ln LT \leq 1.468$	0.611 ***	0.124	4.92
$1.468 < \ln LT \leq 3.891$	0.361 ***	0.101	3.58
$\ln LT \geq 3.891$	0.218 **	0.086	2.53
Controls		Yes	
N		450	
R-squared		0.788	

Note: *** *p* < 0.01, ** *p* < 0.05.

Table 8 demonstrates that when the logarithm of land transfer increased, the coefficient value of industrial agglomeration for agricultural green production efficiency declined from 0.611 to 0.218, and the *t*-value was reduced from 4.92 to 2.53, which indicated that there was a characteristic of a diminishing marginal effect of industrial agglomeration on the promotion of agricultural green production efficiency. A possible reason is that, on the one hand, the development of industrial agglomeration required continuous adjustment of the industrial structure to meet the market competition, and smooth land transfer is a necessary condition for bringing into play the effect of industrial agglomeration; however, frequent land transfer leads to an excessive adjustment of the planting structure, and production operators, out of the pursuit of profit maximization, turn from food crops to cash-crop planting, which relies more on chemical fertilizers, pesticides, and other chemicals, thus

changing the original intensive production method and leading to a weakening of the effect of industrial agglomeration on the enhancement of agricultural green production efficiency through land transfer [59]. On the other hand, with the deepening of land transfer, land resources and production may be controlled by capital. Even the phenomenon of “land enclosure movement” will lead to the distortion of the land-transfer market. The price of land transfer will rise sharply, driven by the profit-seeking nature of capital, which will influence the price and supply of agricultural products, thus causing a mismatch of resources such as land and, ultimately, inhibiting the development of green agriculture. This will lead to a distortion in the land-transfer market, leading to a sharp increase in the land transfer price driven by capital profit and influencing the price and supply of agricultural products. Accordingly, hypothesis H3 was verified.

8. Conclusions

This study used panel data from 30 provinces in China from 2006 to 2020 as research samples and used the super-efficient EBM model combined with the GML index to measure and explore the green production efficiency of Chinese agriculture, the characteristics of its spatial and temporal evolution, and its core power sources. A fixed-effect model was used to test the influence of industrial agglomeration on the green production efficiency of agriculture, and the influence of regional heterogeneity was analyzed. A model of mediating effects was constructed to clarify the transmission mechanism of land transfer in industrial agglomeration with respect to agricultural green production efficiency; a model of threshold effects was constructed to explore the heterogeneous effects of industrial agglomeration on agricultural green production efficiency with different levels of land transfer. The results showed the following:

(1) China’s agricultural green production efficiency showed stable growth over time. Its growth mainly relied on the “single-track drive” of green technological change, with an average annual growth rate of 11.45% from 2006 to 2020; the green development of agriculture was steadily promoted, and the construction of an ecological civilization achieved remarkable results.

(2) Industrial agglomeration had a significant positive effect on agricultural green production efficiency, and the findings still held after testing the robustness of the sample. In addition, among the control variables, the level of financial support for agriculture (Sup), the intensity of R&D (R&D), the level of transport infrastructure (Tra), the level of marketization (Mar), and the development of the technology market (Tmd) promote agricultural green production efficiency. In contrast, the opposite is true for environmental regulation (Reg), foreign direct investment (For), and the proportion of affected area (Dis). Furthermore, there was regional heterogeneity in the effect of industrial agglomeration on agricultural green production efficiency, with the western and central regions having a facilitating effect. In contrast, the eastern region showed an inhibiting effect.

(3) Industrial agglomeration could enhance agricultural green production efficiency by promoting land transfer and still had a significant contribution to the enhancement of green technological efficiency and green technological change, with mediating effect values of 28.48%, 27.91%, and 47.75%, respectively. This was driven by industrial agglomeration, the revitalization of land and other resources, the release of agricultural capacity, and the acceleration of green production technology promotion and transformation, thus promoting the green development of agriculture.

(4) Land transfer had a double-threshold effect on the effect of industrial agglomeration on agricultural green production efficiency. With different levels of land transfer, the influence of industrial agglomeration on agricultural green production efficiency was heterogeneous. When the land-transfer level crossed the threshold value, the intensity of the effect of industrial agglomeration on agricultural green production efficiency was weakened; the land transfer mode should be innovated to carry out moderate-scale operation in order to maximize the role of industrial agglomeration in promoting agricultural green development.

9. Policy Recommendations

The following policy recommendations are offered in light of the findings mentioned above:

(1) One should adhere to the idea of synergistic development and push for sustainable agricultural growth. There are differences in agricultural green development among regions in China due to differences in resource endowment, geographical location, and policy implementation. The specific manifestation is that at this stage, China's agricultural green development relies more on the "single-track drive" of green technological change, and green technological efficiency is not obvious. On the one hand, building on existing green technology policies, we should continue to guarantee investment in agricultural green technology research and development and expand the coverage and radiation of green technology by improving the green technology promotion system. The government can encourage different production operators to introduce foreign high-tech or independent inventions by enacting several laws, such as agricultural green production technology subsidies. On the other hand, in response to the weak efficiency drive of green technology, it is necessary to pay more attention to the enhancement of the effectiveness of green technology and to increase the training in green technology; for example, the local government can regularly organize farmers to watch open lectures related to green technology, in order to enhance the literacy of green technology, to optimize the allocation of resources, and to improve the efficiency of resource utilization, to realize the double benefits of economic and ecological benefits. Additionally, policies must be developed to meet local conditions due to the temporal and spatial variations in agricultural green production efficiency to encourage the coordinated growth of agricultural green. In order to address the issue of insufficient interregional cooperation, it is necessary to speed up the pace of transformation and upgrade of agricultural green development in the less efficient eastern and northern regions, encourage the reasonable flow of interregional resources such as technology, capital, and labor to high-efficiency regions, encourage the formation of a synergistic mechanism for the agricultural economy and ecology, and continue to close the gap.

(2) The development of industrial clusters should be bolstered and the standards and effectiveness of industries should be advanced. Industrial clustering has a significant role in the enhancement of the green development of agriculture, and the government should strengthen its supervision and leadership in this process. On the one hand, finance should enhance the economic support for industrial agglomeration and tilt financial expenditures moderately towards green agricultural production; increase the degree of market-oriented development, inviting upstream and downstream production operators to agglomerate and develop; and thoroughly enhance infrastructure building, opening up major production channels, and lowering production costs. At the same time, it is also necessary to strengthen the science and technology innovation drive, implement significant innovation projects in areas with regional characteristics and advantages, increase R&D investment and the construction of science and technology innovation talents, encourage fieldwork at the grass-roots level by university students, postgraduates and agricultural technicians specializing in agriculture, improve the transformation and industrialization of scientific and technological achievements, and activate new momentum for industrial agglomeration. On the other hand, a production safety responsibility system should be strictly implemented, risk prevention capabilities should be enhanced, risk supervision should be strengthened, and safe and orderly agricultural production should be guaranteed; at the same time, a good development environment should be created, the focus should be on building a market-oriented system, the rule of law, and the international business environment, improve financial literacy, avoid blindly attracting foreign investment, and focus on agricultural-scale operation. We will focus on the transformation of agricultural-scale operation from "quantity" to "quality", enhance the quality and efficiency of industrial development with multiple channels and initiatives, and gradually form a green and sustainable regional agricultural development pattern.

(3) The land transfer system should be enhanced, and there should be a focus on increasing resource efficiency. This study's results prove that land transfer plays a mediating role in the process of industrial agglomeration with respect to the efficiency of green production in agriculture. Thus, each region should follow the overall spatial development strategy requirements based on the current reality of industrial agglomeration development and the scientific planning for industrial agglomerations, and the layout should be optimized. The land transfer system should be enhanced, and there should be a focus on increasing resource efficiency. This study's results prove that land transfer plays a mediating role in the process of industrial agglomeration with respect to the efficiency of green production in agriculture. Each region should adopt a development strategy relevant to the local circumstances in response to the current issue that land transfer in China is still relatively low. In particular, it is essential to aggressively explore a range of land transfer methods, such as the collaboration model of the government, scientific research units, enterprises, farmers' cooperatives, and other multi-principal organizations. The potential of rural production resources should be fully stimulated by promoting a variety of moderate-scale enterprises in conformity with local conditions. However, since the role of industrial agglomeration in improving agricultural green production efficiency has weakened with the increase in the level of land transfer, it is necessary to stop the one-sided pursuit of scale when transferring land, effectively implement and improve the system of the "separation of three rights" of agricultural land, build a platform for rural property rights trading, regulate land transfer and mortgages, etc. At the same time, we should avoid the phenomena of non-agriculturalization and the lack of grain on agricultural land, strictly adhere to the "red line of arable land", ensure food security, improve the supervision system for rural land transfer, restrain rent-seeking behavior on land through laws and regulations, improve the management and service mechanisms for land transfer, enhance agricultural green production efficiency, and realize green agricultural development.

The study aims to investigate the relationship between industrial agglomeration and agricultural green production efficiency using empirical approaches. However, there are still areas that can be improved and explored because of the data's limitations and the author's inexperience. Firstly, although the study tests the superiority of the fixed-effects model over the random-effects model and the mixed regression model, it does not eliminate the dynamic panel bias, especially the potential bias of the fixed effects due to time-varying confounders, which may bias the model estimates. Secondly, although this study utilizes a variety of empirical methods to ensure the rigor and scientific of the findings, the empirical methods are still partially insufficient in that the study still has some limitations in terms of causality, especially the limitations related to instrumental variables, such as overcoming endogeneity. Two instrumental variables are introduced to mitigate the endogeneity; however, it is still impossible to completely prevent the generation of all endogeneity.

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