agriculture

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Impact of Farmers' Participation in the Transformation of the Farmland Transfer Market on the Adoption of Agricultural Green Production Technologies

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Abstract: Exploring the adoption of green production technologies by farmers (GTA) is of great significance, given the context of global climate change and sustainable agricultural development. This article starts from the perspective of the transformation of the farmland transfer market, based on research data from 2076 farmers, and uses the endogenous disposal effect model to examine its impact on GTA. The results indicate that the transformation of China's farmland transfer market has a significant "greening" effect on agriculture. Specifically, the paid transfer of farmland, written leases, and clear lease forms promote GTA, while acquaintance transactions are not conducive to it. Participation in the farmland transfer market has increased the likelihood of GTA by 18.7% and is statistically significant at the 1% level. However, the adoption level of green production technology by ordinary farmers remains low, and achieving green development in agriculture is a long and arduous task. Mechanism analysis shows that the transformation of the farmland transfer market can effectively enhance GTA by increasing the scale of operations, farmers' income, and mechanization levels. When the transfer targets new business entities, such as family farms, professional cooperatives, and enterprises, it significantly promotes GTA. The findings suggest that deepening the reform of the farmland transfer market, promoting large-scale agricultural operations, strengthening the application of green production technologies, improving the level of agricultural mechanization, and accelerating the process of sustainable agricultural development are all essential steps toward enhancing GTA and, ultimately, achieving sustainable agricultural development.

Keywords: transformation of farmland transfer market; the adoption of green production technology by farmers (GTA); economic incentives; scaled operation; mechanization

Citation: Quan, T.; Jia, W.; Quan, T.; Xu, Y. Impact of Farmers' Participation in the Transformation of the Farmland Transfer Market on the Adoption of Agricultural Green Production Technologies. *Agriculture* **2024**, *14*, 1677. https://doi.org/10.3390/agriculture14101677

Academic Editor: Anlu Zhang

Received: 18 August 2024
Revised: 13 September 2024
Accepted: 23 September 2024
Published: 25 September 2024

1. Introduction

Against the backdrop of the severe challenges of global climate change and the urgent need for sustainable agricultural development, the adoption and promotion of green production technologies have become key to achieving sustainable agricultural development and environmental protection [1]. The adoption of green production technology by farmers (GTA, hereinafter referred to as GTA) is directly related to the effectiveness of agricultural green development [2–4]. GTA refers to collecting various agricultural skills, tools, and rule systems adopted in the farm production process to produce high-quality agricultural products while reducing pollution, such as precision fertilization, water-saving irrigation, straw-returning technology, etc. [5,6]. GTA is regarded as an important strategy to address agricultural environmental pollution, ensure the quality and safety of agricultural products, and achieve sustainable agricultural development [7].

However, as the main body of agricultural production, farmers' technology adoption behavior is often constrained by various factors, among which the status of farmland transfer and the degree of market development are vital for farmers' decision making. With the continuous improvement of the rural land system and the deepening development of the market economy, the agricultural land transfer market is transforming from disorder to order, from standardization to normalization, from informal to formal, and from low efficiency to high efficiency [8,9]. The convenience of agricultural land transfer, the reduction of transfer costs, the standardization of transfer contracts, and the clarification of transfer periods all provide favorable conditions for farmers to adopt green production technologies.

Based on this, this article uses rich data from the China Rural Revitalization Comprehensive Survey Project. It employs endogenous disposal effect models and other methods to quantitatively evaluate the "greening" effect of the transformation of the agricultural land transfer market. By systematically analyzing the current situation and characteristics of the transformation of the farmland transfer market, focusing on the impact mechanism and path of the transformation of the agricultural land transfer market on GTA, and analyzing, in detail, the core elements of compensation, contract regularization, and lease term clarity in the process of agrarian land transfer, this study reveals how market transformation promotes the widespread application of green production technology through intermediate channels such as affecting the agricultural operation scale, farmers' income structure, and mechanization level. It also revealed the differential impact of different circulation objects (such as family farms, professional cooperatives, enterprises, and other new business entities) on the adoption level of green production technology. Based on this, policy recommendations are proposed to promote green development and the modernization of agriculture. Through this study, we hope to further enrich and improve the theoretical system of land transfer market transformation and green agriculture development and contribute wisdom and strength to promoting the green transformation and sustainable development of agriculture in developing countries.

2. Literature Review

Although the importance of GTA has been widely recognized, the adoption and promotion of green technology still face multiple challenges in many developing countries, especially those with a large proportion of agriculture and increasingly tight resource and environmental constraints. Specifically, on one hand, GTA often comes with high initial input costs, which pose an unbearable economic burden for small-scale farmers; economic benefits, social benefits, and risk perception are the main factors affecting GTA [10–12]. On the other hand, farmers have insufficient awareness of green production technologies and lack the necessary skills and knowledge to effectively apply these technologies [5]; At the same time, individual and family attributes such as gender, age, education level, political identity, family income, and family business scale also have an impact on GTA [3,13–15]. In addition, the imperfect external environment, such as market mechanisms, infrastructure, government behavior, and social capital, further restricts the widespread application of agricultural green production technologies [10,16,17]. Related studies have also found that the orderly transfer of land management rights and market transfer have immeasurable value in optimizing resource allocation, improving agricultural production efficiency, promoting farmers' environmental protection behavior, and promoting green agricultural development [18,19]. The behavior of farmers' land transfer is gradually showing a trend towards marketization and standardization. The land transfer market is undergoing a transformation from an informal "acquaintance market" to a formal trading market, which not only profoundly affects the pattern of rural economy but also provides new opportunities and motivation for GTA [20].

Against the backdrop of rural revitalization, promoting the marketization of agricultural land is an important rural reform undertaken by the Chinese government following the implementation of the household contract responsibility system. Existing studies typically use the proportion of farmland transfer [8] and the transfer of farmland kinship relationships [21] as indicators to characterize the informal features of rural land transfer. Other indicators, such as the paid transfer rate of rural land [9] and the signing of land transfer contracts [22], have also been used to capture these informal characteristics. Especially as an important means to achieve market functions, price has been widely recognized by the academic community [23]. Meanwhile, research suggests that the transformation of the farmland transfer market has a significant impact on the stability of land rights [24], market flow [25], rental forms and prices [26], cultivation efficiency [27], accelerated differentiation of farmers, and farmers' life satisfaction [28]. The transformation of the farmland transfer market is widely regarded as one of the most important means to reduce the fragmentation of agricultural land, increase land scale management, improve agricultural management performance, and optimize the allocation of agricultural land factors, thereby achieving increased agricultural production and farmer incomes [29]. However, there are also opposing views that the transformation of the land transfer market has entered a "declining growth rate" channel and has not changed the decentralized agricultural management model. The decentralized agricultural model often makes it difficult to achieve large-scale operation, resulting in increased production costs per unit area and low production efficiency. From an environmental perspective, it may also lead to inefficient use of land resources, exacerbating the risks of soil erosion and degradation. Moreover, due to the scattered distribution of farmers and uneven technological levels, it is difficult to popularize new technologies and varieties. This not only affects the improvement in agricultural production efficiency but also restricts the process of agricultural modernization.

There are two shortcomings in the existing research. Firstly, using a single indicator, such as kinship transfer, to characterize the market development level of farmland transfer may not fully reflect the complexity and multidimensional characteristics of the farmland transfer market; secondly, few have discussed the impact of the transformation of the farmland transfer market on GTA. It should be noted that although the existing research has discussed the impact of land transfer on environmental effects, it mainly focuses on the effects of land transfer on agricultural non-point source pollution and fertilizer use. For example, scholars such as Li (2023) and Wu (2018) believe that farmland transfer allows farmers to expand their agricultural output by inputting material factors such as land and capital, incentivizing farmers to make long-term production investments and improve soil quality [20,30]. Ranjan et al. (2019) argue that farmland transfer leads farmers to adopt more capital-intensive agricultural input strategies while utilizing environmental externalities to reduce production costs as an alternative strategy to compensate for labor shortages [31]. However, how the transformation of the farmland transfer market affects GTA has not been fully discussed, and its channels of action also need to be further studied. In addition, in terms of research methods for land transfer, scholars tend to use static panel data and traditional econometric methods such as ordinary least squares (OLS), two-way fixed effects, and random effects models [32], while there are relatively few studies using the treatment effect model (TEM) for analysis. Traditional regression models face limitations when dealing with self-selection bias and endogeneity issues. Farmers' participation in the transformation of the agricultural land transfer market is often influenced by multiple complex factors, encompassing both observable and unobservable variables, which may simultaneously impact farmers' decisions and the environmental effects of land transfer. As a more advanced tool, the TEM can more effectively tackle such endogeneity issues. Therefore, selecting appropriate estimation methods to overcome the estimation bias stemming from selective bias can facilitate a better understanding of the impact of farmers' participation in the transformation of the agricultural land transfer market on GTA.

A further question to consider is whether the transformation of the farmland transfer market can promote GTA. If possible, what is its underlying mechanism of action? And is there a difference in its effectiveness under different land transfer objects? The answers to the above questions undoubtedly have important enlightening significance for exploring the endogenous institutional reasons for green agricultural development, as well as for guiding farmers to achieve transformation and upgrades and promoting sustainable agricultural development.

3. Theoretical Analysis

3.1. Direct Effect of Market-Oriented Transformation of Farmland Transfer on GTA

The transformation of the farmland transfer market is an important way to alleviate the problem of fragmented farmland, promote the realization of large-scale agricultural management, and ensure food security. This transformation means that both parties have the autonomy and freedom to decide whether to transfer or not, and the standardized land transfer is completely determined by the market supply and demand relationship, market utility, and market mechanism of agricultural land [28,33]. Firstly, the market efficiency hypothesis in the field of finance suggests that market efficiency is a prerequisite for capital markets to achieve the optimal allocation of resources. The elements of the transfer object, transfer period, transfer price, and contract form in farmland transfer provide a solid foundation and strong guarantee for agricultural land economic exchange activities [34].

With the gradual transformation of the farmland transfer market from the traditional model of informal, free verbal agreements between acquaintances to a new model that targets a wider range of non-familiar groups, implements paid transactions, and relies on formal contractual legal protection, the establishment and improvement of a series of related systems have enhanced the enthusiasm of farmers to participate in land transfers [35]. At the same time, safe and clear property rights can increase the market value of land and promote the achievement of transactions, stabilize farmers' expectations for the future, reduce uncertainty risks in the land transfer process [36], reduce transaction costs for GTA, enhance the signaling function of factor prices [37], and stimulate farmers' willingness to improve production, thereby encouraging farmers to invest in long-term land planning and actively adopt and apply modern agricultural technologies [38].

Secondly, the deepening of the farmland transfer market has created conditions for GTA and generating economic value, which is essentially a Pareto improvement process for resource reallocation. As rational economic entities pursuing maximum benefits, farmers will achieve maximum economic benefits through reasonable technological choices under limited resource conditions [39]. Especially for transfer households, using green production technologies that increase crop yield, optimize crop quality, and enhance risk resistance not only helps them achieve their own economic goals but also effectively recovers land leasing costs. In the long run, the continuous improvement of the farmland transfer market has not only promoted environmental protection and improved crop yields and quality but has also achieved the internalization of externalities. This is beneficial not only for the sustainable development of agricultural production but also for enhancing the economic benefits and market competitiveness of farmers. In summary, the deepening of the farmland transfer market can reduce transaction costs, provide incentive mechanisms, generate economic value, and internalize externalities for farmers when adopting green production technologies.

Based on this, Hypothesis 1 is proposed:

Hypothesis 1. *The transformation of the farmland transfer market can help promote GTA.*

3.2. Indirect Effect of Market-Oriented Transformation of Farmland Transfer on GTA

3.2.1. Scaled Operation

The transformation of the farmland transfer market also indirectly affects GTA through the formation of large-scale operations [40]. With the continuous deepening of the transformation of the farmland transfer market, the vitality and potential of the farmland transfer market have been greatly stimulated. This transformation not only changed the originally scattered and narrow production mode but also reduced the degree of fragmentation of arable land, achieving the concentration and scale management of land. Scaled operation usually refers to the expansion of the agricultural production scale and the improvement in production efficiency through the concentration of production factors such as land, capital, technology, and labor in agricultural production or agricultural business activities. Especially for new agricultural operators, they generally adopt a scaled operation model to meet the urgent demand for specialization and large-scale production and operation. These entities actively create conditions to maximize economies of scale and play an important demonstrative and leading role in agricultural development.

The expansion of scaled operations and the concentration of land have reduced factor input costs, thereby promoting GTA [41]. Specifically, it has improved the diseconomies of scale caused by the inseparable fixed costs in agricultural production. Previous research has shown that the marketization of farmland transfer transfers land resources from inefficient users to efficient users through market mechanisms, achieving the optimized allocation of land resources and creating conditions for the adoption of ecological agricultural technologies, allowing their efficiency to be fully utilized [42]. The second is the factor price advantage formed by the large-scale purchase of production materials and the large-scale sale of agricultural products, which greatly reduces the fixed costs of GTA [43]. The third is the factor substitution effect formed by agricultural mechanization and agricultural investment. The deepening of the farmland transfer market has promoted the specialization and standardization of agricultural production, improved production efficiency, reduced factor input costs, and, thus, created favorable conditions for GTA, promoting the green transformation and sustainable development of agricultural production [8]. In addition, large-scale operations have a higher demand for agricultural technology, and farmers and agricultural enterprises will actively seek and obtain advanced and green production technology information to meet production needs [44]. Obviously, a scaled operation can fundamentally change the traditional small-scale farming method of "involution" and promote the development of agricultural production towards a more efficient and sustainable direction.

3.2.2. Farmers' Incomes

The deepening transformation of the farmland transfer market fundamentally optimizes the allocation of rural land and labor resources, significantly improves farmers' income levels, and greatly enhances the economic driving force for GTA [45]. On the one hand, the transformation of the farmland transfer market has built a solid property rights protection barrier, improved the stability of property rights, reduced transaction costs, and enabled property rights holders to achieve optimal resource allocation within the scope of property rights constraints. This also helps to improve the agricultural production efficiency and farmers' incomes, thereby stimulating farmers' confidence and long-term planning for long-term investment, naturally promoting the widespread application of ecological agriculture technology.

On the other hand, the deepening transformation of the farmland transfer market has prompted farmers with different resource endowments to leverage their comparative advantages, reducing the relative probability of farmers falling into poverty [46,47]. With the formation of large-scale land management and the increase in farmers' economic income expectations, farmers have a stronger willingness and more funds to learn and adopt ecological agricultural technologies to improve their agricultural production efficiency and product quality in order to occupy a more advantageous position in the market and maximize the value of green agricultural products. In addition, an increase in farmers' incomes usually increases their risk tolerance, making them more willing to try new agricultural green production technologies and methods.

3.2.3. Mechanization Level

The level of agricultural mechanization refers to the degree of mechanization in agricultural production, which is a product of the combination of industrial technology and agricultural technology. The transformation of the farmland transfer market promotes the shift of agricultural production from labor intensive to capital intensive and plays a driving role in improving the level of agricultural mechanization. On the one hand, the concentrated land scale is beneficial for farmers to carry out projects such as soil layer adjustment, land consolidation, and strip construction, which increases the demand for agricultural machinery and equipment and, thus, improves the level of agricultural mechanization. At the same time, the investment and usage costs of agricultural machinery and equipment can be better shared through large-scale production, thereby promoting the promotion and popularization of agricultural mechanization and further promoting the specialization and standardization of agricultural production [48].

On the other hand, an improvement in the mechanization level can increase the land use efficiency, reduce waste and losses in agricultural production, and decrease the use of fertilizers and pesticides [49]. With the improvement in the production efficiency and cost reduction brought by agricultural mechanization, farmers are more likely to accept and apply new agricultural green production technologies and scientific management methods and pay more attention to the sustainability and environmental protection of agricultural production. At the same time, the role of agricultural mechanization is increasingly focused on combining with green production technologies, which helps reduce carbon emissions and non-point source pollution and is an important way to achieve the development of green agricultural production. In addition, farmers have received relevant technical training during the popularization of agricultural mechanization, which enhances their awareness and understanding of modern and green agricultural technologies and helps promote GTA [50].

Based on this, this article proposes the following hypotheses:

Hypothesis 2. *The transformation of the farmland transfer market has promoted GTA by promoting large-scale agricultural operations*.

Hypothesis 3. *Participating in the transformation of the farmland transfer market has an economic incentive effect, which promotes GTA by increasing the farmers' incomes*.

Hypothesis 4. *The transformation of the farmland transfer market promotes GTA by increasing the level of mechanization*.

4. Materials and Methods

4.1. Model Construction

4.1.1. Farmers' Participation and Decision Making

Whether farmers participate in the transformation of the farmland transfer market is not a result of random allocation but rather a choice made by farmers based on various factors, which is a self-selection behavior. Economists believe that farmers make certain choices in order to maximize individual utility. According to Mises' theory of human behavior, individuals are actors seeking satisfaction, and the purpose of farmers participating in the transformation of the farmland transfer market is to reduce discomfort and increase satisfaction in various aspects such as the economy. Under the assumption that farmers are actors seeking utility or maximizing satisfaction, they will only choose to participate in land transfer when the transformation of the land transfer market can bring increased utility or more satisfaction to farmers. Due to the subjective nature of the expected benefits of farmers' participation or non-participation in reality, the difference in benefits ($MAT_i{}^*$) cannot be observed. Therefore, we use latent variable models such as:

$$\begin{aligned} \mathrm{MAT}^* &= \beta\omega_i + \mu_i \\ \mathrm{MAT_i} &= \begin{cases} 1, \text{if } \beta\omega_i + \mu_i > 0 \\ 0, \text{if } \beta\omega_i + \mu_i \le 0 \end{cases} \end{aligned} \tag{1}$$

Among them, $\mathrm{MAT_i}$ is an unobservable latent variable. ω_i is the influencing factor of whether participating in the transformation of the farmland transfer market can bring a utility increase or more satisfaction to farmers, and β represents the coefficient to be estimated. μ_i is a random error term. When participating in the transformation of the farmland transfer market can bring more benefits to farmers, that is, when $\beta\omega_i + \mu_i > 0$, farmers will choose to participate ($\mathrm{MAT_i} = 1$); when farmers believe that participating in the transformation of the farmland transfer market cannot bring them more benefits, i.e., $\beta\omega_i + \mu_i \leq 0$, they will not choose to participate in the transformation of the farmland transfer market ($MAT_i = 0$).

The error term w in Equation (1) follows a binary normal distribution with the variance $\sigma^2 = 1$ and a mean equal to 0, i.e., $\mu_i \sim N(0,1)$. The probability of farmers choosing to participate can be expressed as follows:

$$P(MAT_i = 1|\omega_i) = P(MAT_i^* > 0) = P(\mu_i < -\beta\omega_i) = F_\mu(\beta\omega_i) \quad (2)$$

In Equation (2), $F_\mu(\cdot)$ is the cumulative distribution function of μ_i.

4.1.2. Multiple Linear Regression Model and Selection Bias

In order to estimate the impact of the market-oriented transformation of farmland transfer on GTA, a multivariate regression model was initially developed. The benchmark model is displayed as:

$$GTA_i = \alpha_0 + \delta_1 MAT_i + \delta_2 X^* + \varepsilon_i \quad (3)$$

Among them, subscript i represents the i-th farmer, GTA_i represents the adoption of agricultural green production technologies by *i* farmers, MAT_i represents whether they participate in the transformation of the land transfer market, and X_i is the set of control variables; ε_i is a random perturbation term. α_0, δ_1, and δ_2 represent the coefficients to be estimated; the least squares method can estimate Equation (3). However, the unobservable information contained in the error term μ_i in Equation (1) and the error term ε_i in Equation (3) may simultaneously affect farmers' willingness to participate and the adoption of agricultural green production technologies, resulting in a correlation between the two error terms, namely $Corr(\mu_i, \varepsilon_i) \neq 0$. In the context of self-selection bias and endogeneity, if OLS is used to estimate Equation (3), the estimated coefficients obtained are biased. Therefore, choosing appropriate estimation methods to overcome the estimation bias caused by selective bias can help us better understand the impact of farmers' participation in the transformation of the farmland transfer market on GTA.

4.1.3. Measurement Method

Several methods have been developed to address self-selection bias and endogeneity issues in the survey data obtained through non-experimental studies. For example, the propensity score matching (PSM) method is widely used to solve biased estimation problems caused by selection bias. However, the PSM method only considers the impact of observable factors on the explained variable when eliminating selection bias and handling endogeneity issues while ignoring the role of unobservable factors. At this point, using the PSM method for analysis will result in biased estimation coefficients. Therefore, this article uses the treatment effect model (TEM) proposed by Cong and Drukker (2000) to analyze the impact of participating in the transformation of farmland transfer markets on GTA [51]. The treatment effect model uses the treatment equation to estimate the likelihood of each individual falling into the treatment group and then incorporates the estimated likelihood as an independent variable into the outcome equation to explain the self-selection bias caused by observable and unobservable factors. It is widely used in the literature to address the shortcomings of propensity score matching.

The TEM consists of two stages. The first stage selects Equation (1) to examine the determining factors of whether farmers are willing to participate in the transformation of the farmland transfer market; the second stage is the resulting Equation (3), which measures the impact of the market-oriented transformation of farmland transfer on GTA. When constructing the TEM, in order to identify the model, the selection of equations requires at least one effective instrumental variable. The instrumental variable should satisfy

Equation (4) and affect whether farmers are willing to participate in the transformation of the farmland transfer market without affecting GTA.

$$\mathrm{Corr}(Z_i, MAT_i) \neq 0,\ \mathrm{Corr}(Z_i, \varepsilon_i) = 0 \quad (4)$$

In TEM estimation, the marginal effect of the processing variable on the explained variable can be directly estimated. In addition, $\rho_{u\varepsilon}$ is the correlation coefficient between the selected equation's error term (μ_i) and the resulting equation's error term (ε_i). $\rho_{u\varepsilon} \neq 0$ is an endogenous source. If $\rho_{u\varepsilon}$ is statistically significant, indicating the existence of estimation bias caused by unobservable factors, then the TEM is superior to the PSM method in estimating the impact of participating in the transformation of the farmland transfer market on GTA. In addition, $\rho_{u\varepsilon} > 0$ indicates a positive selectivity bias, while $\rho_{u\varepsilon} < 0$ indicates a negative selectivity bias.

4.1.4. Mechanism Model

In order to further investigate how farmers' participation in the transformation of the farmland transfer market indirectly affects the adoption of green production technologies by increasing the scale of agricultural land management, farmers' incomes, and the level of agricultural mechanization, we constructed Model (5):

$$M_i = \alpha_0 + \delta_1 MAT_i + \delta_2 X' + \varepsilon_i \quad (5)$$

Among them, M_i represents intermediary variables, including the land management scale, farmer income, and agricultural mechanization. If significant, it indicates that the mediating variable is valid.

4.2. Variable Setting

4.2.1. Handling Variables

Whether the transfer of farmers' land reflects market transformation is the variable to be treated in this article (MAT). MAT involves the introduction of market mechanisms and the improvement of standardization in the process of land transfer. In order to comprehensively and specifically measure the market-oriented characteristics of land transfer, this study constructs an indicator system for MAT based on four dimensions: acquaintance transaction object (NTA), paid land transfer (PC), written lease form (WLA), and clear lease term (CLA). These four dimensions cover multiple important aspects of the farmland transfer market, from the nature of the transaction object (acquaintances or non-acquaintances), the transfer method (paid or unpaid), and the form of the contract (written or oral) to the clarity of the lease term, which can comprehensively reflect the transformation status of the farmland transfer market. The questionnaire measures MAT by asking whether one knew the other party before transferring the land (yes 0; no 1), whether rent was collected (yes 1; no 0), whether a written agreement was signed (yes 1; no 0), and whether a clear lease term was agreed upon (yes 1; no 0). If farmers meet the above two or more indicators, the value of the transformation of the farmland transfer market is 1; otherwise, it is 0. Setting the standard as "meeting two or more indicators" can, to some extent, ensure that the identified market transformation cases have higher representativeness and credibility. This helps to reduce the possibility of misjudgment due to the satisfaction of a single indicator, thereby improving the accuracy and reliability of research. Among all samples, 59.68% of farmers did not know each other before transferring their land, 38.83% of farmers collected rent during land transfer, but only 23.56% and 23.36% of farmers signed written agreements and agreed on clear lease terms. The overall participation level of farmers in the transformation of the farmland transfer market is 28.6%. The problems of information asymmetry, uneven rent collection, and lack of written agreements and lease terms in the process of land transfer cannot be ignored. There is still great room for development in the efficiency and standardization of land transfer.

4.2.2. Explained Variables

Based on the survey questionnaire, this article selects the number of green agricultural technologies adopted by farmers, including green farming technology, green pesticide prevention and control technology, green fertilization technology, green irrigation technology, and green waste treatment technology, to comprehensively reflect GTA [5,6,52]. The more green agricultural technologies are adopted, the higher the degree of adoption of green production technologies, with values of 0, 1, 2, 3, 4, and 5 adopted. Among them, green farming techniques mainly include deep tillage technology, low tillage or no-till sowing technology, crop rotation and intercropping technology, etc.; the green pesticide prevention and control technology mainly includes reducing the use of pesticides, using biological pesticides, etc.; green fertilization techniques mainly include reducing the use of chemical fertilizers and applying organic fertilizers; green irrigation technology mainly refers to water-saving irrigation technology (sprinkler irrigation, drip irrigation, etc.); green waste treatment technologies mainly include returning straw to the field and recycling pesticides.

Among all samples, less than 2% of farmers adopted five or zero green agricultural technologies, with the highest number of farmers adopting two and three green agricultural technologies, reaching 40.94% and 23.55%, respectively. These indicate that GTA exhibits a significant polarization trend, and this extreme distribution may reflect the different attitudes and limitations of farmers in technology application. Although a considerable number of farmers have adopted green agricultural technologies, there is still a large number of farmers who have only adopted a small amount of technology. This indicates that there is still great potential and space for the promotion and application of green agricultural technology. The number of various green agricultural technologies adopted is shown in Figure 1.

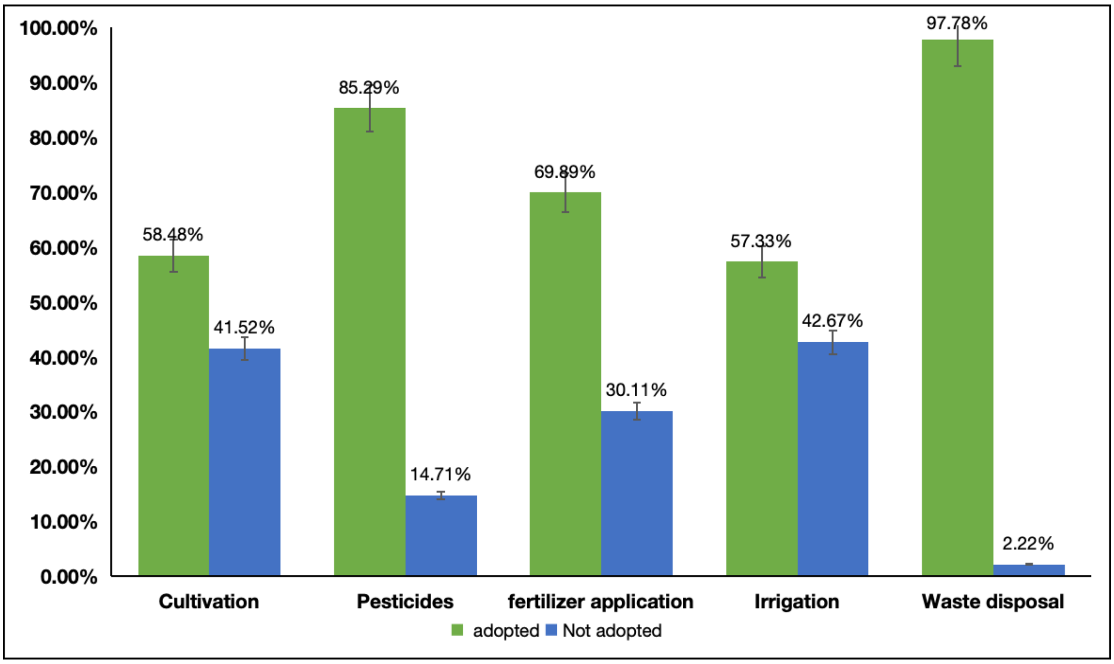

Figure 1. The adoption of various green agricultural technologies.

Further statistics (Table 1) show that farmers who participate in the transformation of the farmland transfer market are more likely to implement green pesticide prevention and control technology, green irrigation technology, and green waste treatment technology than those who do not participate. However, in terms of green farming and fertilization techniques, the average of participating members is lower than that of non-participating members. At the same time, this study used an independent sample *t*-test to investigate the differences in GTA between participating and non-participating members. The results showed that there were significant differences in the adoption of green pesticide control technology between participating and non-participating members, and there was a trend of differences in the adoption of green irrigation technology.

Table 1. Comparison of average adoption of green production technologies by farmers.

Green Production Behavior	Total Sample Mean	Participating Members	Non-Participating Members	Pr(∣T∣ > ∣t∣)
Green farming techniques	0.4155	0.3912	0.4253	0.1557
Green pesticide prevention and control technology	0.1467	0.1560	0.1427	0.0021
Green fertilization technology	0.2983	0.2495	0.3179	0.2904
Green irrigation technology	0.4251	0.4422	0.4177	0.0699
Green waste treatment technology	0.9777	0.9831	0.9755	0.4828

4.2.3. Mediating Variables

The mediating variables are as follows: the scale of land management (SCALE): this is measured by the area of land management of farmers, specifically using their own contracted land minus the area of land already transferred out, plus the area of land already transferred in and the land being cleared; farmer income (INCOME): this is represented by the net income from agricultural operations; and mechanization level (MECHANIZATION): this is characterized by the presence or absence of large-scale machinery at home.

4.2.4. Tool Variables

In order to address potential endogeneity issues in the model, considering the possibility of omitted variable bias, reverse causality, and other endogeneity issues between participation in agricultural land marketization and GTA, this paper uses the mean values of farmers from villages other than our own who participate in agricultural land marketization as instrumental variables (IVMAT). The same group effect indicates that whether farmers participate in the market-oriented transfer of agricultural land is influenced by the participation of other farmers in the village, meeting the requirements of instrumental variable correlation. However, whether other farmers participate in the market-oriented transfer of agricultural land generally does not affect the GTA of individual farmers, meeting the exogenous requirements of instrumental variables. In theory, the above instrumental variables are effective.

4.2.5. Control Variables

In order to ensure the robustness of the results, referring to relevant research and considering data availability, this paper selects control variables from individual characteristics of farmers, family endowments, external environments of villages, and other aspects; introduces the gender, age, education level, marriage status, health status, and political affiliation of the interviewed household heads at the individual characteristics level of farmers; introduces organizational forms at the level of family endowment and the acceptance of online training by family members; and introduces village incomes, distance from the town's government office, and village terrain at the level of village environment. In order to avoid bias in the analysis results caused by regional factors, regional dummy variables were also introduced in the empirical analysis. The variable definitions and descriptive statistical data are shown in Table 2.

Table 2. Descriptive statistics of variables.

Variable	Variable Declaration	Mean	Std. Dev.
GTA	Green production technology adoption: yes = 1; no = 0	2.107	0.935
MAT	Market transformation of agricultural land transfer: yes = 1; no = 0	0.286	0.452
NTA	Did you know each other before transferring the land: yes = 0; no = 1	0.597	0.491
PC	Rent collection: yes = 1; no = 0	0.388	0.487
WLA	Signed a written agreement: yes = 1; no = 0	0.236	0.424
CLA	Agreed on clear lease term: yes = 1; no = 0	0.234	0.423
GENDER	Gender: male = 1; female = 0	0.954	0.209
AGE	Actual age (years)	59.421	10.618
EDU	1 = did not attend school; 2 = primary school; 3 = junior high school; 4 = high school; 5 = technical secondary school; 6 = vocational and technical schools; 7 = college diploma; 8 = bachelor's degree; 9 = graduate student	2.112	1.666
MARRY	Marriage: 1 = married; 2 = unmarried	1.146	0.608
HEALTH	Health self-assessment: very poor = 1; poor = 2; fair = 3; good = 4; very good = 5	3.539	1.021
CPC	Member of the Communist Party of China: yes = 1; no = 0	0.212	0.409
COOPERATIVE	Whether to join the cooperative: Yes = 1; No = 0	0.236	0.425
TRAIN	Have you received computer or mobile internet training? Yes = 1; no = 0	0.073	0.26
RENJUNKEZHIPEI	Per capita disposable income of rural households in their villages/CNY 10,000	1.364	1.974
TOWNDIS	Distance from village committee to county government (in kilometers)	5.866	5.678
TERRAIN	Is the terrain of the village where the farmer's family is located flat? No = 0; yes = 1	1.496	1.173
IVMAT	The average participation of other farmers in the market-oriented transformation of agricultural land in villages other than your own	0.285	0.259
INCOME	Statistics of net income from planting operations: annual income: CNY 10,000	1.226	2.961
SCALE	Farmer's land management area (mu): total management area = self-contracted land − transferred land area + transferred land area + reclaimed land	22.1947	76.645
MECHANIZATION	Do you have large machinery at home? Yes = 1; no = 0	0.458	0.498

4.3. Data Sources

This study conducted empirical research using data from the "China Rural Revitalization Comprehensive Survey" (CRRS) project in 2020. The sampling process was as follows: Firstly, the project team divided the national townships into 300 administrative villages based on their level of economic development, regional location, and agricultural development. The CRRS employed a multi-stage stratified random sampling principle, selecting one-third of the provinces and regions in each region to obtain 10 provinces (regions). Secondly, the four regions of eastern, central, western, and northeastern China were divided into five groups according to their level of economic development: high, medium high, medium, medium low, and low. Subsequently, one county was randomly selected from each group, resulting in a total of 50 counties. Furthermore, among the 50 counties obtained, they were grouped into five categories based on their relative ranking to all counties (cities, districts): high, medium high, medium, medium low, and low. From each group, one township was selected, yielding a total of 150 townships. Then, from each township, one village with good economic conditions and one with poor economic conditions were randomly chosen, resulting in 300 villages. Finally, within these 300 villages, 12–14 households were selected using equidistant random sampling, yielding more than 3800 farmer survey questionnaires. The CRRS encompassed multiple modules, including the rural population and labor force, agricultural production, input–output, agricultural planting structure, and farmers' incomes and expenditures. In the analysis of this article, after eliminating the missing values of relevant variables such as individual characteristics of farmers, family endowments, and the external environment of villages required for this study, a sample of 2076 farmers was ultimately utilized.

5. Results and Discussion

5.1. The Impact of the Transformation of the Farmland Transfer Market on GTA

This article first tested the multicollinearity between various control variables. The results in Table 3 show that the VIF values of all independent variables are very close to 1 and far below 10, indicating that there is almost no multicollinearity problem between the independent variables. Columns (1)–(2) of Table 4 present the estimated results of the GTA impact on the transformation of the farmland transfer market using the TEM. The likelihood ratio test indicates that we can reject the null hypothesis that there is no correlation between the treatment allocation error and outcome error. The residual correlation coefficient is significantly negative at the 1% level, where $\alpha \tanh\rho = \frac{1}{2}\ln\left(\frac{1+\rho}{1-\rho}\right)$, indicating that the estimated correlation between the treatment allocation error and outcome error is significantly negative at the 1% level.

Table 3. Multicollinearity test.

Variable	VIF	1/VIF
TERRAIN	1.04	0.959345
RENJUNKEZHIPEI	1.03	0.969593
CPC	1.03	0.970615
COOPERATIVE	1.03	0.971191
TRAIN	1.03	0.971649
FANMAR	1.01	0.98752
TOWNDIS	1.01	0.988361
GENDER	1.01	0.989615
HEALTH	1.01	0.992065
Mean VIF	1.02	

Table 4. Benchmark estimation results.

Variable	(1)	(2)	(3)	(4)
	Selection Equation	Outcome Equation	OLS	OLS
MAT		1.639 *** (0.196)	0.173 ** (0.071)	0.178 ** (0.071)
GENDER	0.071 (0.243)	0.028 (0.128)		0.042 (0.112)
AGE	−0.004 (0.004)	−0.005 ** (0.002)		−0.005 ** (0.002)
EDU	0.054 ** (0.026)	0.006 (0.016)		−0.006 (0.014)
MARRY	−0.031 (0.070)	0.007 (0.038)		0.000 (0.038)
HEALTH	−0.008 (0.041)	0.013 (0.023)		0.017 (0.021)
CPC	0.103 (0.106)	0.039 (0.059)		0.047 (0.054)
COOPERATIVE	0.168 * (0.097)	0.111 ** (0.056)		0.069 (0.051)
TRAIN	−0.053 (0.158)	0.180 * (0.100)		0.200 ** (0.083)
RENJUNKEZHIPEI	−0.021 (0.025)	0.014 * (0.008)		0.011 (0.011)
TOWNDIS	−0.001 (0.007)	−0.009 ** (0.004)		−0.011 *** (0.004)
TERRAIN	0.033 (0.038)	0.028 (0.022)		0.056 *** (0.019)
IVMAT	1.541 *** (0.347)			
_cons		2.093 *** (0.224)	2.088 *** (0.022)	2.221*** (0.201)
Residual correlation coefficient ath(ρ)	−1.046 *** (0.170)			
Wald test for equation independence	37.75 ***			
Log likelihood	−2887.3354			
LR test	21.08 ***			

Note: *, **, and *** indicate significance at the statistical levels of 10%, 5%, and 1%, respectively; the robust standard error is in parentheses; the same applies below.

The negative correlation indicates that unobservable factors that improve the adoption level of observed agricultural technologies often occur simultaneously with unobservable factors that reduce the transformation of farmland transfer markets. Therefore, it is appropriate to use the TEM to correct the selectivity bias. The estimated ATE involved in the transformation of the farmland transfer market is 1.639. In this case, ATET is the same as ATE because the treatment indicator variable did not interact with any outcome covariates, and the correlation and variance parameters were the same for the control and treatment groups.

The estimation results of the selection equation for participation behavior in the transformation of the farmland transfer market indicate that several factors significantly influence participation behavior. In addition to the instrumental variable representing the average participation of other farmers in the same village, education and organizational forms also play a role. Farmers with higher education levels and greater participation in cooperatives exhibit a greater inclination to engage in the circulation market. This may be attributed to the fact that farmers with higher levels of education often possess stronger abilities to obtain, process, and analyze information. This enables them to better understand and evaluate circulation policies, market trends, and contract terms, ensuring that their own rights and interests are protected. As a result, they are able to make more rational and favorable decisions, ultimately increasing their willingness to participate in the circulation market. Cooperatives, as an organizational form, have the ability to organize dispersed farmers and create economies of scale. They typically provide a wide range of services and support, including information sharing, technical guidance, market integration, and financial services. These services and support mechanisms serve to reduce transaction risks and enhance market bargaining power. Ultimately, these benefits increase farmers' willingness and satisfaction to participate in the circulation market.

According to the outcome equation, it can be seen that the participation behavior in the transformation of the farmland transfer market has passed the significance test at the 1% level, and the direction of influence is positive. This indicates that compared to non-participating farmers, those who participate in the transformation of the farmland transfer market have a positive effect on GTA. Therefore, Hypothesis 1 has been verified. The transformation of the farmland transfer market has promoted the green production mode of scale, intensification, and specialization, ultimately achieving the optimal allocation of land resources. Farmers who participate in this transformation often pay more attention to the introduction and application of modern agricultural technology and management methods. This enhances their own green production capacity and generates demonstration effects for others. In addition, a series of economic incentive policies and measures, such as land transfer subsidies and green production incentives, have encouraged these participating farmers to adopt green production technologies and management methods more actively.

From the estimation results of the control variables, it is evident that the age of the household head, social relationships, family members' acceptance of online training, per capita disposable income, and distance from the town government all exert a significant impact on GTA. Specifically, older farmers, influenced by traditional planting habits, exhibit less interest and motivation in adopting green production technologies compared to their younger counterparts. The estimated coefficient of joining a cooperative is positively significant at the 5% statistical level, indicating that cooperative membership can drive green production among farmers through technical training, premium incentives, and other means. The acceptance of online training by farmers has a significant positive impact on GTA, highlighting the importance of farmers' open attitude towards new knowledge and technologies for GTA. Online training, as a convenient and efficient learning method, can swiftly enhance farmers' technical skills and environmental awareness, thereby promoting the implementation of green production behaviors. The significant positive coefficient of per capita disposable income suggests that farmers with higher incomes have more funds to invest in the purchase of new technologies and equipment and are also better equipped to bear the short-term risks and costs associated with adopting new technologies. Lastly, there is a significant negative relationship between the distance to the town government and green production adoption, which may be attributed to the fact that this distance reflects, to some extent, the convenience of farmers in obtaining agricultural materials and services. The farther away from the town government, the less convenient it is for farmers to access the machinery, agricultural materials, information, etc., required for green production technology, resulting in a hindrance to their adoption efforts.

To test the robustness of the estimation results, the method of replacing the econometric model is adopted. Columns (3)–(4) in Table 4 are estimated using OLS, and the results are consistent with those estimated using the TEM. This indicates that the empirical analysis results mentioned above are robust.

5.2. The Impacts of the Four Dimensions of Participating in the Transformation of the Farmland Transfer Market on GTA

Table 5 reports the estimated impacts of the four dimensions of the transformation of the farmland transfer market on GTA. Columns (1) and (2) of Table 5 show the estimation results of non-acquaintance transactions on GTA using the TEM. The results indicate that non-acquaintance transactions involved in the transformation of the farmland transfer market are beneficial for GTA. This suggests that acquaintance transactions may not be equally beneficial for GTA. This may be because transactions between acquaintances are often based on personal relationships and trust, lacking guidance from market price mechanisms. As a result, land transfer prices may deviate from the market value. In this situation, farmers may not have sufficient economic incentives to adopt green production technologies, which typically require higher initial investment. In addition, the inefficiency of land resource allocation, the fragility of informal contracts, and the lack of supervision and incentive mechanisms all limit the dissemination and acquisition of technological information. This, in turn, hinders the promotion and application of green production technologies.

Table 5. The impacts of four dimensions of participating in the transformation of the farmland transfer market on GTA.

Variable	(1)	(2)	(3)	(4)
	NTA	**Outcome Equation**	**PC**	**Outcome Equation**
MAT		0.511 *** (0.142)		0.542 *** (0.123)
IVMAT	1.262 *** (0.130)		1.705 *** (0.121)	
CONTROL	CONTROL	CONTROL	CONTROL	CONTROL
Residual correlation coefficient ath(ρ)	−0.295 *** (0.096)		−0.353 *** (0.087)	
Wald test for equation independence	9.55 ***		16.32 ***	
Log likelihood	−3585.6494		−3529.3839	
LR test	6.33 **		15.71 ***	
Variable	**(5)**	**(6)**	**(7)**	**(8)**
	WLA	**Outcome Equation**	**CLA**	**Outcome Equation**
MAT		0.294 ** (0.116)		0.510 *** (0.114)
IVMAT	1.810 *** (0.144)		1.787 *** (0.145)	
CONTROL	CONTROL	CONTROL	CONTROL	CONTROL
Residual correlation coefficient ath(ρ)	−0.201 *** (0.074)		−1.046 *** (0.170)	
Wald test for equation independence	7.35 ***		18.49 ***	
Log likelihood	−3367.1804		−3374.2298	
LR test	5.17 **		12.51 ***	

Note: **, and *** indicate significance at the statistical levels of 5%, and 1%, respectively; the robust standard error is in parentheses; the same applies below.

The results in columns (3) and (4) of Table 5 show that compensated land transfer promotes GTA. The paid transfer of agricultural land helps to achieve large-scale land management. In addition, farmers may produce green agricultural products to obtain price premiums. Columns (5) and (6) of Table 5 indicate that written leases promote GTA, while columns (7) and (8) of Table 5 indicate that explicit leases promote GTA. Compared to oral contracts, written contracts usually specify the names, addresses, transfer periods, start and end dates of both parties, their rights and obligations, transfer prices, and payment methods. Clarifying the lease agreement can form a stable expectation of land management rights for land transfer to households, which is conducive to increasing long-term investment in land transfer to households. On the one hand, it can suppress opportunistic behaviors of land transfer-out households, such as reclaiming land at any time or arbitrarily increasing land rent, and improve the stability expectations of land transfer-in farmers. On the other hand, signing formal contracts is conducive to attracting new types of business entities, such as professional large-scale farmers, family farms, and cooperatives, to participate in agricultural production and operation. Due to the higher transaction risks faced by new business entities, the signing of written contracts is conducive to attracting new business entities to engage in land transfer behavior, as well as forming long-term and stable transfer relationships between land transfer-in and transfer-out households, which can achieve economies of scale and promote GTA.

5.3. Robust Testing

In order to test the robustness of the impact of farmers' participation in the transformation of the farmland transfer market on the adoption of GTA, this paper employs the substitution estimation method and an alternative dependent variable to conduct robustness testing on the benchmark regression results. Firstly, considering that the transformation of the farmland transfer market is a discrete endogenous variable, an extended regression model (ERM) utilizing multivariate normal distribution and maximum likelihood estimation is used to solve the endogenous problem. The participation behavior in the transformation of the farmland transfer market is a 0 or 1 variable. This article uses the extended Probit regression (ERP) to estimate both Equations (1) and (3) simultaneously. Furthermore, using "whether to use organic fertilizers" instead of "GTA adoption", the intervention group average treatment effect (ATT) of farmland transfer market transformation was estimated through EPR to examine the magnitude of the effect of farmland transfer market transformation on GTA. ATT states that the focus of this article is on the extent to which joining the farmland transfer market transformation can affect GTA compared to not participating in it. The calculation equation for ATT is as follows:

$$\mathrm{ATT} = \mathrm{E}(\mathrm{GTA}_{1i} - \mathrm{GTA}_{0i} | \mathrm{MAR}_i = 1) \tag{6}$$

Among them,GTA_{1i} and GTA_{0i} are the results when the i-th farmer participates and does not participate, respectively. Table 6 presents the estimated GTA impact of the EPR model on the transformation of the farmland transfer market. The correlation coefficient is −0.500, which is significantly different from zero at the 1% statistical level, indicating that using EPR to control endogeneity for analysis is reasonable. According to column (1) of Table 6, in addition to the significant impact of IV on whether farmers participate in the transformation of the farmland transfer market, factors such as their gender, age, education level, participation in cooperatives, and terrain can also change farmers' choices regarding participation. From columns (2) and (3), it can be seen that some control variables have the same effect direction on the GTA of the two types of farmers. For example, the age of the respondents suppressed GTA, but plain areas had a positive impact on the GTA behaviors of both types of farmers, although EPR directly calculated the coefficient of the transformation of the farmland transfer market on GTA.

Table 6. Robust test.

Variable	(1)	(2)		(3)
	Selection Equation	Participating Farmers	Non-Participating Farmers	Ordered Logit
MAT		0.395 (0.547)	−0.691 (0.457)	0.340 ** (0.164)
GENDER	−0.356 * (0.193)	0.121 (0.332)	0.212 (0.214)	0.104 (0.219)
AGE	0.011 *** (0.003)	−0.014 ** (0.007)	−0.021 *** (0.005)	−0.009 ** (0.004)
EDU	0.047 ** (0.022)	−0.021 (0.040)	−0.073 ** (0.029)	−0.021 (0.028)
MARRY	0.097 (0.065)	−0.195 (0.164)	−0.087 (0.073)	0.019 (0.072)
HEALTH	0.040 (0.033)	−0.068 (0.056)	0.019 (0.044)	0.029 (0.042)
CPC	0.116 (0.084)	−0.180 (0.160)	−0.067 (0.108)	0.078 (0.108)
COOPERATIVE	−0.320 *** (0.077)	−0.117 (0.149)	−0.017 (0.111)	0.147 (0.102)
TRAIN	−0.231 * (0.126)	0.040 (0.212)	0.441 ** (0.172)	0.252 (0.164)
RENJUNKEZHIPEI	0.010 (0.016)	0.008 (0.025)	0.026 (0.022)	0.021 (0.019)
TOWNDIS	−0.002 (0.006)	0.003 (0.008)	−0.028 ** (0.011)	−0.024 *** (0.008)
TERRAIN	0.135 *** (0.033)	0.234 ** (0.099)	0.176 ** (0.087)	0.103 *** (0.039)
IVMAT	1.194 *** (0.141)			
_cons	−1.241 *** (0.328)			
ρ		−0.500 *** (0.1628)		
Log likelihood		−1719.1694		
Prob > chi2				0.000

Note: *, **, and *** indicate significance at the statistical levels of 10%, 5%, and 1%, respectively; the robust standard error is in parentheses; the same applies below.

The coefficient for non-participating members is −0.691 and is statistically significant at the 1% level; the coefficient for participating farmers is 0.395. The negative impact of joining the market-oriented transfer of agricultural land is decreasing, and the coefficient changes from negative to positive, indirectly indicating that participating in the transformation of the farmland transfer market has a positive effect on GTA.

The above results can only reflect the direction of the impact of the transformation of the farmland transfer market on GTA. To obtain the magnitude of the impact of the transformation of the farmland transfer market, it is necessary to further calculate ATT based on the estimation in Table 6. According to the ATT estimation results shown in Table 7, it can be seen that compared to not participating in the transformation of the farmland transfer market, the likelihood of participating in GTA for land transfer has increased by 18.7% and is statistically significant at the 1% level. This indicates that participating in the marketization of farmland transfer has significantly promoted GTA behavior. In addition, in column (3) of Table 6, we also used an ordered logic model to measure the impact of farmers' participation in the transformation of the agricultural land transfer market on GTA. The participation behavior in the transformation of the agricultural land transfer market passed a significance test at the 5% level, and the direction of influence was positive, indicating that participation in the marketization of agricultural land transfer significantly promoted GTA behavior. Hypothesis 1 was validated.

Table 7. ATT of the impact of the transformation of the farmland transfer market on GTA.

Variable	ATT	Standard Error	z	95% Confidence Interval
MAT	0.18700	0.058 ***	3.22	(0.073, 0.301)

Note: *** indicate significance at the statistical levels of 1%.

5.4. Impact Mechanism Testing

According to the theoretical analysis in the previous text, farmers' participation in the transformation of the farmland transfer market can affect their adoption of green agricultural technology (GTA) through three paths: scale of operation, farmer's income, and mechanization. Based on this, the article uses the mediation effect model to test the above three pathways of action (Table 8). From the results in column (1) of Table 8, it can be seen that the coefficient of the impact of the transformation of the farmland transfer market on farmers' scale of operation is significantly positive, indicating that the transformation promotes the adoption of GTA through the scale effect. Scaled operation brings advantages such as expanding and consolidating land area, saving funds, and saving labor, which makes farmers willing to increase their investment in agricultural green production technology. The estimated results in column (2) of Table 8 show that farmers participating in the transformation of the farmland transfer market experience an increase in agricultural income, indicating that participating in the transformation has economic incentives. As mentioned earlier, farmers who participate face lower agricultural production costs and are more likely to achieve income growth. With the increase in farmers' incomes, they have more funds to purchase the production materials, such as equipment, seeds, fertilizers, etc., required for GTA; pay for technical training and other expenses; and usually have stronger risk tolerance. This lowers the economic threshold for GTA and increases their willingness and ability to adopt new technologies. This result confirms Hypothesis 3. The third column of Table 8 indicates that farmers participating in the transformation of the farmland transfer market are significantly more likely to invest in agricultural machinery production. Mechanized operations enable farmers to allocate more labor resources to other economic activities or higher value agricultural production processes, thereby providing farmers with more time and economic space to adopt GTA. Mechanized agricultural equipment is often equipped with advanced intelligent technologies such as sensors and control systems, which can reduce resource waste and environmental pollution. This precise method of operation is in line with the concept of green production technology and helps promote GTA. Hypothesis 4 is proven.

Table 8. Mechanism inspection.

Variable	(1)	(2)	(3)
	Scale	Income	Mechanization
MAT	14.951 ** (6.768)	2.883 *** (1.040)	0.319 *** (0.095)
CONTROL	CONTROL	CONTROL	CONTROL
Residual correlation coefficient ath(ρ)	−0.065 *** (0.012)	−0.548 ** (0.236)	−0.317 ** (0.126)
Wald test for equation independence	28.17 ***	5.42 **	6.35 **

Note: **, and *** indicate significance at the statistical levels of 5%, and 1%, respectively; the robust standard error is in parentheses; the same applies below.

5.5. Heterogeneity Test of Different Land Transfer Objects

At present, the entities involved in land transfer now include ordinary farmers as well as new types of business entities such as family farms, professional cooperatives, and enterprises. Different transfer objects are associated with different levels of productivity. To examine the differences in the impact of different land transfer destinations (to ordinary farmers or to new business entities) on farmers' GTA, this study divided the sample into two groups—new business entities and small-scale ordinary farmers—and further analyzed whether the participating farmers' GTA would have differentiated effects due to different land sizes. Table 9 shows that transferring land to new business entities, such as family farms, professional cooperatives, and enterprises, significantly promotes GTA adoption at the 1% level, while transferring land to ordinary farmers has not been significantly validated for GTA adoption. This is because the land transfer between farmers is mainly the transfer of land cultivation rights between small farmers, which has not fundamentally changed the fragmented and decentralized land management pattern, nor has it brought about significant changes in production and the operation methods; therefore, it is difficult to have a substantial driving effect on the adoption of GTA.

Table 9. Heterogeneity test of different land transfer objects.

Variable	(1)	(2)	(3)	(4)
	Selection Equation	**Outcome Equation: Ordinary Farmers**	**Selection Equation**	**Outcome Equation: New Type of Business Entity**
MAT		0.028 (0.125)		1.849 *** (0.291)
IVMAT	2.139 *** (0.404)		1.704 *** (0.555)	
CONTROL	CONTROL	CONTROL	CONTROL	CONTROL
Residual correlation coefficient ath(ρ)	0.014 (0.150)		−1.244 *** (0.267)	
Wald test for equation independence	0.02		21.74 ***	
Log likelihood	−870.46284		−747.97364	
LR test	0.01		10.85 ***	

Note: *** indicate significance at the statistical levels of 1%; the robust standard error is in parentheses; the same applies below.

6. Conclusions

6.1. Research Conclusion

In the dual context of intensified global climate change and the urgent demand for sustainable agricultural development, adopting a new perspective on the transformation of the farmland transfer market for deeply analyzing GTA is not only a positive exploration of the path of agricultural green development but also a key link in promoting the modernization of agriculture. This article constructs an evaluation framework that encompasses well-known transaction objects, mechanisms for compensated land transfer, the standardization of written lease agreements, and clear lease terms, thoroughly and comprehensively measuring the current situation and effectiveness of the transformation of China's land transfer market. Based on detailed data from 2076 households covered by the "Comprehensive Survey of Rural Revitalization in China" project, the advanced endogenous disposal effect model (TEM) was used to accurately reveal the profound impact and internal mechanism of participating in the transformation of the farmland transfer market on farmers' adoption of green production technology.

Previous research has found that the current transformation practice of China's farmland transfer market has shown a significant "green effect". Specifically, the paid transfer of agricultural land, written leases, and clear lease forms have promoted the adoption of green production technologies by farmers, while the transformation of the informal farmland transfer market is not conducive to the adoption of agricultural green production technologies. Using multiple statistical methods and estimating the ATT, the results showed that compared to farmers who did not participate in the transfer market, farmers who actively participated in the transformation of the farmland transfer market were significantly more likely to adopt green production technologies, with a 18.7% increase. This positive impact reached an extremely significant level statistically ($p < 0.01$). However, it is worth noting that despite the initial results, the overall level of adoption of green production technologies by ordinary farmers is still at a relatively low level, indicating that the road to achieving comprehensive agricultural green development is still long and full of challenges.

A further mechanism analysis uncovers multiple positive effects of the transformation of the farmland transfer market: promoting large-scale agricultural operations to improve production efficiency, stimulating farmers' enthusiasm through economic incentive mechanisms, accelerating the process of agricultural mechanization to reduce production costs, and, ultimately, significantly promoting the adoption of green production technologies by farmers. Notably, when the recipients of a land transfer are new types of business entities, such as family farms, professional cooperatives, and agricultural enterprises, their catalytic effect on the adoption of green production technologies by farmers is even more significant, demonstrating the leading role of these new business entities in promoting green agricultural development.

6.2. Limitations

The limitations of this study primarily encompass two aspects: Firstly, despite our efforts to broaden the analysis by considering various factors at the individual, family, and village levels, there may still exist unobserved variables or omitted variable biases that could potentially influence our results. Future research could delve deeper and incorporate additional pertinent control variables to enhance the precision of our causal inference. Secondly, this article adopts an economic perspective to dissect the impact of the transformation of the agricultural land transfer market on farmers' environmental decision making. However, it may not fully capture the diverse influences, such as psychological factors. Furthermore, while this study lays out the essential groundwork for accelerating the modernization of agriculture and rural areas and fostering the revitalization of rural industries, it fails to delve into the environmental externalities and exacerbating social inequality stemming from marketization and agricultural modernization, nor does it discuss how to harmonize environmental, social, and economic development. Future research should underscore the importance of sustainable practices and policies to mitigate these risks, encompassing the improvement of infrastructure, education, and healthcare to alleviate potential social disparities. Additionally, future research ought to concentrate more on formulating comprehensive strategies to balance these repercussions, including reinforcing environmental protection measures, enacting socially inclusive policies, and advocating sustainable economic development, to maximize the positive repercussions of agricultural modernization. At the same time, we also recognize the limitations of current research in evaluating the transformation of the agricultural land transfer market and agricultural modernization, such as the lack of comprehensive data support and systematic evaluation methods. Therefore, we encourage future research to further explore these fields and provide strong support for formulating more scientific and reasonable agricultural modernization policies. Finally, the research area of this article is mainly based on the Chinese region, and policy recommendations may be limited by other specific conditions such as the region.

6.3. Policy Suggestions

Based on this, this article proposes a series of strategic recommendations:

Firstly, we need to deepen the reform of the farmland transfer market, optimize the efficiency of resource allocation, and leverage the scale effect to promote green production technology. The government should gradually improve the three-level agricultural land transfer service system within the county by building a rural agricultural land transfer platform, accelerating the integration and application of national agricultural land information, and promoting the reform of the agricultural land transfer market. Secondly, the agricultural sector should attach great importance to and strengthen the level of agricultural mechanization, enhance farmers' ability to acquire and apply technology, and increase research and application promotion of green production. At the same time, government department should carry out mechanization transformation of agricultural land, improve the construction of agricultural machinery adaptation system, comprehensively enhance the effectiveness of agricultural land market supply, and provide solid support for green production. Thirdly, the government, agricultural entities, technology enterprises, farmers, and other parties should jointly participate and strive to build a comprehensive and efficient green agricultural product market system, smooth the sales channels of green agricultural products, and enhance the economic motivation of farmers to adopt green production technologies. Fourthly, the government should vigorously support new types of business entities and guides ordinary farmers to establish professional farmer cooperatives and regularly provide training to new agricultural management entities to effectively enhance their ability to obtain information. The implementation of this series of comprehensive measures is expected to significantly improve the adoption level of green production technologies by farmers, injecting strong impetus into accelerating the sustainable development of agriculture in China.

Author Contributions: Conceptualization, T.Q. (Tianshu Quan), W.J., T.Q. (Tianli Quan) and Y.X.; methodology, T.Q. (Tianshu Quan), W.J., T.Q. (Tianli Quan) and Y.X.; software, T.Q. (Tianshu Quan) and Y.X.; validation, T.Q. (Tianshu Quan) and T.Q. (Tianli Quan); formal analysis, T.Q. (Tianshu Quan), T.Q. (Tianli Quan) and Y.X.; investigation, T.Q. (Tianshu Quan), W.J. and Y.X.; resources, T.Q. (Tianshu Quan) and T.Q. (Tianli Quan); data curation, T.Q. (Tianshu Quan) and T.Q. (Tianli Quan); writing—original draft preparation, T.Q. (Tianshu Quan), W.J., T.Q. (Tianli Quan) and Y.X.; writing—review and editing, T.Q. (Tianshu Quan), T.Q. (Tianli Quan) and Y.X.; visualization, W.J., T.Q. (Tianli Quan) and Y.X.; supervision, W.J. and Y.X.; project administration, T.Q. (Tianshu Quan) and Y.X.; funding acquisition, T.Q. (Tianshu Quan) and Y.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Major Program of the National Fund of Philosophy and Social Science of China, grant number [23&ZD109].

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are available from the China Rural Revitalization Survey at [http://rdi.cssn.cn/] accessed on 20 January 2024.

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

References

1. Jiang, X.L.; Sun, Y.; Shen, M.; Tang, L.X. How Does Developing Green Agriculture Affect Poverty? Evidence from China's Prefecture-Level Cities. *Agriculture* **2024**, *14*, 402. [CrossRef]
2. Wang, X.; Drabik, D.; Zhang, J.B. How channels of knowledge acquisition affect farmers' adoption of green agricultural technologies: Evidence from Hubei province, China. *Int. J. Agric. Sustain.* **2023**, *21*, 2270254. [CrossRef]
3. Mao, H.; Zhou, L.; Ying, R.Y.; Pan, D. Time Preferences and green agricultural technology adoption: Field evidence from rice farmers in China. *Land Use Policy* **2021**, *109*, 105627. [CrossRef]
4. Eanes, F.R.; Singh, A.S.; Bulla, B.R.; Ranjan, P.; Fales, M.; Wickerham, B.; Doran, P.J.; Prokopy, L.S. Crop advisers as conservation intermediaries: Perceptions and policy implications for relying on nontraditional partners to increase US farmers' adoption of soil and water conservation practices. *Land Use Policy* **2019**, *81*, 360–370. [CrossRef]

5. Yang, C.F.; Ji, X.; Cheng, C.M.; Liao, S.; Bright, O.; Zhang, Y.F. Digital economy empowers sustainable agriculture: Implications for farmers' adoption of ecological agricultural technologies. *Ecol. Indic.* **2024**, *159*, 111723. [CrossRef]
6. Li, X.K.; Guo, H.D.; Jin, S.Q.; Ma, W.L.; Zeng, Y.W. Do farmers gain internet dividends from E-commerce adoption? Evidence from China. *Food Policy* **2021**, *101*, 102024. [CrossRef]
7. Donkor, E.; Onakuse, S.; Bogue, J.; De Los Rios-Carmenado, I. Fertiliser adoption and sustainable rural livelihood improvement in Nigeria Chock. *Land Use Policy* **2019**, *88*, 104193. [CrossRef]
8. Bai, Z.M.; Zhang, X.C.; Xu, J.B.; Li, C.X. Can Farmland Transfer Reduce Fertilizer Nonpoint Source Pollution? Evidence from China. *Land* **2024**, *13*, 798. [CrossRef]
9. Qiu, T.W.; He, Q.Y.; Choy, S.T.B.; Li, Y.F.; Luo, B.L. The impact of land renting-in on farm productivity: Evidence from maize production in China. *China Agric. Econ. Rev.* **2021**, *13*, 22–39. [CrossRef]
10. Visser, M.; Jumare, H.; Brick, K. Risk preferences and poverty traps in the uptake of credit and insurance amongst small-scale farmers in South Africa. *J. Econ. Behav. Organ.* **2020**, *180*, 826–836. [CrossRef]
11. Omotilewa, O.J.; Ricker-Gilbert, J.; Ainembabazi, J.H. Subsidies for Agricultural Technology Adoption: Evidence from a Randomized Experiment with Improved Grain Storage Bags in Uganda. *Am. J. Agric. Econ.* **2019**, *101*, 753–772. [CrossRef] [PubMed]
12. Liu, M.Z.Y.; Liu, H. Farmers' adoption of agriculture green production technologies: Perceived value or policy-driven? *Heliyon* **2024**, *10*, e23925. [CrossRef]
13. Ndiritu, S.W.; Kassie, M.; Shiferaw, B. Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy* **2014**, *49*, 117–127. [CrossRef]
14. Dar, M.H.; Waza, S.A.; Nayak, S.; Chakravorty, R.; Zaidi, N.W.; Hossain, M. Gender focused training and knowledge enhances the adoption of climate resilient seeds. *Technol. Soc.* **2020**, *63*, 101388. [CrossRef] [PubMed]
15. Huang, X.H.; Lu, Q.; Wang, L.L.; Cui, M.S.; Yang, F. Does aging and off-farm employment hinder farmers' adoption behavior of soil and water conservation technology in the Loess Plateau? *Int. J. Clim. Change Strateg. Manag.* **2020**, *12*, 92–107. [CrossRef]
16. Bambio, Y.; Agha, S.B. Land tenure security and investment: Does strength of land right really matter in rural Burkina Faso? *World Dev.* **2018**, *111*, 130–147. [CrossRef]
17. Kurkalova, L.; Kling, C.; Zhao, J.H. Green subsidies in agriculture: Estimating the adoption costs of conservation tillage from observed behavior. *Can. J. Agric. Econ.-Rev. Can. D Agroecon.* **2006**, *54*, 247–267. [CrossRef]
18. Zang, D.G.; Yang, S.; Li, F.H. The Relationship between Land Transfer and Agricultural Green Production: A Collaborative Test Based on Theory and Data. *Agriculture* **2022**, *12*, 1824. [CrossRef]
19. Ren, J.; Chen, X.; Shi, L.; Liu, P.; Tan, Z. Digital Village Construction: A Multi-Level Governance Approach to Enhance Agroecological Efficiency. *Agriculture* **2024**, *14*, 478. [CrossRef]
20. Li, X.H.; Qiao, S.Y.; Jiang, Y.J. The causal mechanism of farmers' chemical fertilizer reduction: An empirical perspective from farmland transfer-in and digital extension. *Front. Sustain. Food Syst.* **2023**, *7*, 1231574. [CrossRef]
21. Qiu, T.W.; Luo, B.L.; Tang, L.; He, Q.Y. Does land tenure security increase the marketization of land rentals between acquaintances? *Appl. Econ. Lett.* **2022**, *29*, 790–793. [CrossRef]
22. Zhou, L.Y.; Lu, H.; Wu, B.Y. Identifying the effects of the stability of farmland transfer management rights on the use of organic fertilizer with different farmland scales and crop types. *Front. Environ. Sci.* **2022**, *10*, 1006405. [CrossRef]
23. Kreps, D.M. *Microeconomic Foundations I: Choice and Competitive Markets*; Economics Books; Princeton University Press: Princeton, NJ, USA, 2013.
24. Lu, H.; Zhang, P.W.; Hu, H.; Xie, H.L.; Yu, Z.N.; Chen, S. Effect of the grain-growing purpose and farm size on the ability of stable land property rights to encourage farmers to apply organic fertilizers. *J. Environ. Manag.* **2019**, *251*, 109621. [CrossRef] [PubMed]
25. Huang, J.; Gao, L.; Rozelle, S. The effect of off-farm employment on the decisions of households to rent out and rent in cultivated land in China. *China Agric. Econ. Rev.* **2012**, *4*, 5–17. [CrossRef]
26. Chen, J.; Xu, J.W.; Zhang, H.X. Explanation of the Phenomenon "Different Prices on the Same Land" in the Farmland Transfer Market-Evidence from China's Farmland Transfer Market. *Agriculture* **2022**, *12*, 2087. [CrossRef]
27. Pei, S.Y.; Zhao, S.D.; Li, X.; Li, J.H. Impacts of Rural-Urban Labour Transfer and Land Transfer on Land Efficiency in China: A Analysis of Mediating Effects. *Land* **2024**, *13*, 702. [CrossRef]
28. Li, Y.C.; He, J.; Zheng, J.X.; Xu, D.D. How can continuous land transfers guarantee food security? A study from the perspectives of plot size. *Appl. Econ.* **2024**. [CrossRef]
29. Cao, Y.; Zou, J.; Fang, X.; Wang, J.; Cao, Y.; Li, G. Effect of land tenure fragmentation on the decision-making and scale of agricultural land transfer in China. *Land Use Policy* **2020**, *99*, 104996. [CrossRef]
30. Wu, Y.Y.; Xi, X.C.; Tang, X.; Luo, D.M.; Gu, B.J.; Lam, S.K.; Vitousek, P.M.; Chen, D.L. Policy distortions, farm size, and the overuse of agricultural chemicals in China. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 7010–7015. [CrossRef]
31. Ranjan, P.; Wardropper, C.B.; Eanes, F.R.; Reddy, S.M.W.; Harden, S.C.; Masuda, Y.J.; Prokopy, L.S. Understanding barriers and opportunities for adoption of conservation practices on rented farmland in the US. *Land Use Policy* **2019**, *80*, 214–223. [CrossRef]
32. Wang, H.; Riedinger, J.; Jin, S. Land documents, tenure security and land rental development: Panel evidence from China. *China Econ. Rev.* **2015**, *36*, 220–235. [CrossRef]
33. Qiu, T.W.; Ma, X.L.; Luo, B.L.; Choy, S.T.B.; He, Q.Y. Land defragmentation in China: Does rental transaction inside acquaintance networks matter? *J. Appl. Econ.* **2022**, *25*, 259–278. [CrossRef]

34. Qiu, T.W.; Shi, X.J.; Luo, B.L. Formalizing agricultural rentals in China: Does local public action help? *Dev. Policy Rev.* **2022**, *40*, e12592. [CrossRef]
35. Qiu, T.W.; Zhang, D.R.; Zhu, M.D. Do land transfers reduce the effects of labour costs on agricultural land abandonment? *Appl. Econ.* **2024**. [CrossRef]
36. Slaev, A.D. The relationship between planning and the market from the perspective of property rights theory: A transaction cost analysis. *Plan. Theory* **2017**, *16*, 404–424. [CrossRef]
37. Kan, K. Creating land markets for rural revitalization: Land transfer, property rights and gentrification in China. *J. Rural Stud.* **2021**, *81*, 68–77. [CrossRef]
38. Li, R.S.; Huang, B.; Liu, S.Q.; Xu, D.D. Land Transfer Contract and Farmers' Straw-Returning Behavior: Evidence from Rural China. *Land* **2024**, *13*, 905. [CrossRef]
39. Adnan, N.; Nordin, S.M.; Rahman, I.; Noor, A. Adoption of green fertilizer technology among paddy farmers: A possible solution for Malaysian food security. *Land Use Policy* **2017**, *63*, 38–52. [CrossRef]
40. He, J.; Zhou, W.; Guo, S.; Deng, X.; Song, J.; Xu, D. Effect of land transfer on farmers' willingness to pay for straw return in Southwest China. *J. Clean. Prod.* **2022**, *369*, 133397. [CrossRef]
41. Gao, Y.; Zhao, D.Y.; Yu, L.L.; Yang, H.R. Influence of a new agricultural technology extension mode on farmers' technology adoption behavior in China. *J. Rural Stud.* **2020**, *76*, 173–183. [CrossRef]
42. Cao, H.; Zhu, X.Q.; Heijman, W.; Zhao, K. The impact of land transfer and farmers' knowledge of farmland protection policy on pro-environmental agricultural practices: The case of straw return to fields in Ningxia, China. *J. Clean. Prod.* **2020**, *277*, 123701. [CrossRef]
43. Helfand, S.M.; Taylor, M.P.H. The inverse relationship between farm size and productivity: Refocusing the debate. *Food Policy* **2021**, *99*, 101977. [CrossRef]
44. Yang, X.; Zhou, X.H.; Deng, X.Z. Modeling farmers' adoption of low-carbon agricultural technology in Jianghan Plain, China: An examination of the theory of planned behavior. *Technol. Forecast. Soc. Change* **2022**, *180*, 121726. [CrossRef]
45. Liu, S.; Xu, H.; Deng, L.L. Does land transfer help alleviate relative poverty in China? An analysis based on income and capability perspective. *Appl. Econ.* **2024**. [CrossRef]
46. Chang, X.; Chen, J.; Ye, L.X. Trend prediction of farmers' spontaneous land transfer behavior: Evidence from China. *Appl. Econ.* **2024**. [CrossRef]
47. Cheng, Y.F.; Yu, J.Y.; Min, S.; Wang, X.B. The effects of land titling on intergenerational transfers in rural China. *J. Econ. Behav. Organ.* **2024**, *225*, 228–251. [CrossRef]
48. Qian, L.; Lu, H.; Gao, Q.; Lu, H.L. Household-owned farm machinery vs. outsourced machinery services: The impact of agricultural mechanization on the land leasing behavior of relatively large-scale farmers in China. *Land Use Policy* **2022**, *115*, 106008. [CrossRef]
49. Arslan, A.; Belotti, F.; Lipper, L. Smallholder productivity and weather shocks: Adoption and impact of widely promoted agricultural practices in Tanzania. *Food Policy* **2017**, *69*, 68–81. [CrossRef]
50. Mgendi, B.G.; Mao, S.P.; Qiao, F.B. Does agricultural training and demonstration matter in technology adoption? The empirical evidence from small rice farmers in Tanzania. *Technol. Soc.* **2022**, *70*, 102024. [CrossRef]
51. Cong, R.; Drukker, D.M. Treatment effects model. *Stata Tech. Bull.* **2001**, *10*, 55.
52. Li, W.J.; Ruiz-Menjivar, J.; Zhang, L.; Zhang, J.B. Climate change perceptions and the adoption of low-carbon agricultural technologies: Evidence from rice production systems in the Yangtze River Basin. *Sci. Total Environ.* **2021**, *759*, 143554. [CrossRef] [PubMed]