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Leveraging agricultural production trusteeship to enhance agricultural production efficiency, promote sustainable agricultural practices, and optimize resources: empirical evidence from China

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Agricultural production trusteeship, through a "service-driven large-scale operation," provides a new pathway for improving agricultural production efficiency and reducing resource waste. Based on micro-survey data from farmers in Shandong Province, and employing a research approach that combines theoretical and empirical analysis, this study reveals the mechanism by which agricultural production trusteeship impacts agricultural production efficiency. The research finds that agricultural production trusteeship has a significant positive effect on agricultural production efficiency, and this conclusion remains robust even after accounting for endogeneity issues. Agricultural production trusteeship enhances agricultural production efficiency by strengthening economies of scale, with indirect effects from economies of scale accounting for 45.63% of the total effect on agricultural production efficiency. Under full trusteeship, economies of scale become more pronounced, with the indirect effects reaching 51.23%. This study also demonstrates that the pathway of "land transfer → large-scale operation → economies of scale → agricultural production efficiency" is not the only route. The "service-driven large-scale operation" model under agricultural production trusteeship has significant potential to improve efficiency, reduce resource waste, and better fit the context of China's smallholder economy. The paper provides policy recommendations for promoting agricultural trusteeship services, including developing context-specific trusteeship models, strengthening the role of village collectives, and increasing subsidies for agricultural machinery and equipment to trusteeship service organizations, in order to promote sustainable agricultural development and enhance resource use efficiency.

KEYWORDS

agricultural production efficiency, economies of scale, sustainable development, policy recommendations, agricultural production trusteeship

1 Introduction

In China, small-scale peasant family farming constitutes the vast majority of agricultural business entities (Wu et al., 2018). The efficiency dilemma inherent in smallholder family farming hinders the development of modern agriculture (Luo, 2020; Isaga, 2018; Kamara et al., 2019; Hoang, 2023). Among the challenges, land fragmentation presents the greatest obstacle to improving agricultural production efficiency under the basic national conditions of "a large country with small farmers" (Han et al., 2020; Gąsiorowski and Bielecka, 2014). Land fragmentation deeply impacts agricultural production efficiency, mainly by reducing the circulation rate of agricultural production factors (Wen et al., 2020) and hindering the promotion of mechanization and agricultural technologies (Zhang and Yang, 2012; Austin et al., 2012; Tan et al., 2010). At present, exploring effective ways to improve agricultural production efficiency under long-term smallholder family farming is an important issue faced by mainstream policymakers, academic theorists, and grassroots practitioners.

Regarding the improvement of agricultural production efficiency, existing research suggests that relying on land transfer to achieve large-scale land management and thereby increase agricultural production efficiency is the current main approach (Yan et al., 2018). Land transfer can optimize the allocation of land resources (Shi et al., 2020; Mao, 2023; Kuang et al., 2022), alleviate land resource misallocation, and improve farmers' technology choices through large-scale farming, which in turn affects agricultural production efficiency (Gai et al., 2023; Mao, 2023). As land consolidation and large-scale operations are achieved, the allocation of production factors such as labor, capital, and land becomes more reasonable, and the economies of scale brought about by large-scale farming gradually increase (Yu et al., 2022), significantly improving agricultural production efficiency (Han et al., 2020). However, land transfer has evidently entered a deep reform phase, with the growth rate slowing down and the characteristics of small-scale transfers in and out becoming more prominent, weakening its contribution to large-scale farming and, thus, limiting its impact on improving agricultural production efficiency. According to data released by the Ministry of Agriculture and Rural Affairs, the growth rate of China's land transfer area had decreased to 4.71% by 2019, down by 17.95% compared to 2013 (He and Yi, 2024). Moreover, by the end of 2020, the proportion of transferred farmland in the country exceeded one-third, but even in this situation, there were still 200 million smallholder households with less than 10 mu of land (Liu et al., 2022). This indicates that the traditional land transfer model is facing deep-seated obstacles. On one hand, it is constrained by the transaction costs and risk aversion in land property rights transfer; on the other hand, it is confined by the historical inertia of the small - scale peasant economy. As a result, the agglomeration speed of land factors has significantly slowed down, making it difficult to achieve the economies of scale effect. Against this realistic background, "service-based large-scale farming" achieved through agricultural production trusteeship has emerged as a new paradigm to break through the physical space constraints of land and improve agricultural production efficiency.

Looking at existing studies, most have focused on demonstrating the impact of land transfer on agricultural production efficiency, with the main analytical framework being "land transfer → large-scale land management → economies of scale in land → agricultural production efficiency." However, the practical results so far have been less than ideal. In response, this study constructs a path to enhance agricultural production efficiency guided by agricultural production trusteeship, aiming to mitigate land fragmentation through agricultural production trusteeship, achieve economies of scale, and thus improve agricultural production efficiency. The specific research questions are as follows: First, does agricultural production trusteeship have a significant positive effect on agricultural production efficiency? Second, can agricultural production trusteeship achieve economies of scale through "service-based large-scale farming" and thereby enhance agricultural production efficiency? Finally, this study proposes the efficiency-enhancing path of "agricultural production trusteeship → service-based large-scale farming → economies of scale in services → agricultural production efficiency".

2 Theoretical analysis and research hypotheses

2.1 Agricultural production trusteeship and agricultural production efficiency

Agricultural production trusteeship inherently reflects farmers' pursuit of agricultural production efficiency. From the definitions of "trusteeship" and "efficiency" in authoritative dictionaries such as The Chinese Dictionary, The Xinhua Dictionary, and Cihai, it can be observed that "trusteeship" and "efficiency" are naturally closely related. "Trusteeship" can be understood as delegated management or proxy management, while "efficiency" refers to whether the inputs or consumption are maximized to achieve their value. Under such circumstances, the inherent characteristic of trusteeship, the professional handling of affairs, is naturally aligned with the 'efficiency' that pursues value maximization. Extending this to agricultural production trusteeship and agricultural production efficiency, agricultural production trusteeship involves farmers delegating agricultural tasks they cannot perform or perform well to service organizations. Agricultural production efficiency refers to the effectiveness of resource utilization, representing the degree to which agricultural resources are allocated and utilized under various production goals. Under agricultural production trusteeship, farmers rely on service organizations to solve issues they cannot handle themselves or that are not economically rational, thereby promoting the effective use of agricultural resources and improving production efficiency (Jiang, 2020).

The specific impacts of agricultural production trusteeship include the improvement of agricultural production efficiency through factor substitution and technological nesting, brought about by the differences between service providers and smallholders in production processes. For example, large and intelligent agricultural machinery replaces household labor and small-scale machinery. Beyond the mechanization improvements, agricultural production trusteeship also promotes more scientific field management, including soil testing and fertilizer recommendations, rational pesticide mixing, and responses to weather disasters and pest prevention.

Based on the above, the following hypothesis is proposed:

> *H1*: Agricultural production trusteeship significantly promotes the improvement of agricultural production efficiency.

In addition to efficiency improvements arising from differences in production operations, agricultural production trusteeship also objectively promotes large-scale operations, providing a key approach to mitigating the efficiency losses caused by land fragmentation. Land fragmentation is a critical factor inhibiting the enhancement of agricultural production efficiency. Further analysis of whether agricultural production trusteeship can mitigate the efficiency losses due to land fragmentation and achieve productivity gains through economies of scale has significant theoretical implications, which will be discussed in the following section.

2.2 Economies of scale and agricultural production efficiency

Land fragmentation is a key factor that inhibits the improvement of agricultural production efficiency. The current state of agricultural production is characterized by "one person managing just over one mu of land, with each household managing no more than ten mu". In the process of household contract farming, village collectives must balance factors such as the location, quality, and area of farmland among farmers, often resulting in households owning multiple plots of farmland that are dispersed and vary in size. According to the third national agricultural census conducted in 2016, the average farmland size per household in China was 8.8 mu, with only 3.98 million households engaged in large-scale farming, leaving the vast majority of farmers without large-scale operations. This highlights the basic national and agricultural condition of "a large country with small farmers".

Land fragmentation affects agricultural production by limiting mechanized operations and significantly increasing production costs. Land fragmentation hinders agricultural mechanization (Popov, 2017; Tomić et al., 2018), and as fragmentation intensifies, the likelihood of choosing mechanized operations decreases (Wen and Yang, 2019). Additionally, the spatial division and separation of plots increase labor inefficiencies as workers move between different plots (Sui et al., 2022), while also raising the transport-related losses of pesticides and fertilizers (Wang et al., 2019). Accelerating the realization of large-scale agricultural operations is therefore a priority in the agricultural sector.

Land transfer is not the only path to large-scale farming. In recent years, land transfer has become increasingly difficult due to rising risks from market, social, and natural factors (Zhou et al., 2022). According to China's Rural Business Management Statistics Yearbook, during the 12th Five-Year Plan period, the annual growth rate of land transfer nationwide averaged 24.01%, increasing from 228 million mu in 2011 to 447 million mu in 2015. However, during the 13th Five-Year Plan, this growth rate slowed significantly, with an average annual growth rate of only 4.35% (Zhong et al., 2020). Consequently, the neoclassical economic theory of "clear land ownership → land transfer → large-scale land management → agricultural modernization" cannot effectively guide China's agricultural production practices (Yang, 2015). However, land transfer is not the only path to large-scale farming, and the service-based large-scale farming achieved through agricultural production trusteeship provides a solution for Chinese-style large-scale agricultural operations.

Agricultural production trusteeship, in a novel model, achieves unified farming while maintaining unchanged household contract systems, land use rights, farming entities, and beneficiaries (Jiang, 2020). As a result, agricultural production trusteeship is increasingly viewed as an effective form of achieving economies of scale, a model that the academic and practical communities refer to as "service-based large-scale farming" (Ji and Li, 2020). In terms of both connection mechanisms and operational models, agricultural production trusteeship and land transfer represent two different approaches. From the perspective of connection mechanisms, the benefit linkages between land transfer participants (transferors and transferees) are mainly based on "transfer fees" (Zeng et al., 2019). In contrast, the benefit linkage mechanism between service organizations and farmers in agricultural production trusteeship involves "trusteeship fees" instead of transfer fees, with service fees connecting farmers and service organizations. From the operational model perspective, land transfer is based on expanding the area of land managed, while agricultural production trusteeship is based on a division of labor and service-based large-scale farming (Zhou, 2017).

2.3 Agricultural production trusteeship, economies of scale, and agricultural production efficiency

Agricultural production trusteeship relies on service-based large-scale farming to alleviate land fragmentation, achieve economies of scale, and effectively enhance agricultural production efficiency. By entrusting farming tasks such as plowing, sowing, field protection, and harvesting to agricultural production trusteeship service organizations, farmers can achieve the same benefits as large-scale farming through land transfer, without the need for land transfers, thus lowering operational risks. Agricultural production trusteeship allows smallholder farmers to realize service-based large-scale farming through professional management of farming activities. Agricultural production trusteeship helps reduce the input costs of fertilizers, pesticides, and other agricultural materials. After participating in agricultural production trusteeship, inputs such as fertilizers and pesticides can be reduced by 7–8% (Wang et al., 2017). Agricultural production trusteeship can be divided into full trusteeship and partial trusteeship. Compared to partial trusteeship, full trusteeship covers all aspects of agricultural production, providing a comprehensive service from sowing to harvesting for farmers who are unable or unwilling to farm themselves (Huang, 2016), achieving more significant economies of scale and better supporting large-scale agricultural operations.

Based on the above, the following research hypotheses are proposed:

> *H2*: Economies of scale play a significant mediating role in the mechanism by which agricultural production trusteeship affects agricultural production efficiency.
>
> *H3*: The degree of agricultural production trusteeship has a significant impact on economies of scale, with households adopting full trusteeship achieving more pronounced economies of scale.

3 Data sources, variable selection, and model design

3.1 Data sources

The data used in this study were derived from a series of surveys on "agricultural production trusteeship" conducted in Shandong Province

in 2022. In recent years, the Shandong Provincial Party Committee and the provincial government, in line with President Xi Jinping's instructions, have focused on building a "Qilu model" for rural revitalization, exploring and developing many effective and distinctive practices. The agricultural production trusteeship model is one such practice, with efforts to establish a "Qilu model" for agricultural production trusteeship. According to data from the Shandong Provincial Party Committee and the provincial government, by July 2022, the total service area for agricultural production trusteeship in the province exceeded 200 million mu, and the agricultural production trusteeship model was being promoted nationwide. Therefore, selecting Shandong Province as the research area holds representative significance.

The survey covered six cities, including Weihai, Yantai, Qingdao, Linyi, Liaocheng, and Dezhou, which represent different geographical conditions, levels of economic development, and natural resource conditions. To facilitate comparison, in addition to households participating in agricultural production trusteeship, the survey also collected data from households not participating in agricultural production trusteeship. A total of 336 questionnaires were collected, and after excluding invalid questionnaires (those with errors, omissions, or logical inconsistencies), 306 valid questionnaires remained, of which 183 households participated in agricultural production trusteeship, and 123 did not.

3.2 Variable selection

3.2.1 Dependent variable

The dependent variable is agricultural production efficiency, which was measured using the Data Envelopment Analysis (DEA) method. Compared to parametric methods, DEA has broader applicability, as it avoids estimation bias caused by unmet assumptions. In this setup, input factors include agricultural labor, fertilizer and pesticide inputs, and agricultural machinery inputs, while output factors are measured by crop output value.

3.2.2 Core independent variable

The core independent variable is agricultural production trusteeship, where households that adopted agricultural production trusteeship are coded as 1, and those that did not are coded as 0.

3.2.3 Mediating variable

The mediating variable is economies of scale. Drawing on existing research, scale efficiency is used to measure farmers' economies of scale. Scale efficiency reflects the degree to which economies of scale are realized (Li et al., 2023); the higher the value, the better the realization of economies of scale (Chen and Lai, 2022). Scale efficiency is commonly used to analyze the degree of agricultural scale management (Wu et al., 2022) and to represent the effects of economies of scale (Gan et al., 2022; Zhu and Li, 2021). Scale efficiency is measured using the VRS-DEA model (BCC model), which incorporates the factor of returns to scale into the DEA model, allowing for the calculation of scale efficiency under different input–output conditions.

3.2.4 Instrumental variable

Based on existing research (Yu et al., 2022; Li and Mao, 2021), "the agricultural production trusteeship adoption rate among other households in the village" is selected as the instrumental variable. This variable was chosen because there is a certain "peer effect" in farmers' production decisions—individual behaviors are influenced not only by personal factors but also by other individuals in the same group. Specifically, this manifests through reduced information search costs due to information dissemination mechanisms and improved production behaviors through the "role model" effect (Shi and Zhang, 2022). Under this "peer effect," the level of agricultural production trusteeship in the village influences individual households' decisions regarding agricultural production trusteeship, thus satisfying the relevance condition for an instrumental variable. In terms of exogeneity, this variable can satisfy the exogeneity assumption. For example, if farmer A is considered, whether other farmers adopt agricultural production entrustment will not directly affect the agricultural production efficiency of farmer A. Specifically, the adoption of agricultural production entrustment by other farmers will not have a direct impact on farmer A's inputs and outputs. It will not change farmer A's input in processes such as land cultivation, sowing, field protection, and harvesting, nor will it affect the final output.

3.2.5 Control variables

Existing studies on econometric models related to farmers' agricultural production efficiency typically adopt a common set of control variables, focused on household management characteristics, individual characteristics of decision-makers, and village-level environmental characteristics (Gao and Zhang, 2017). The household management characteristics and individual characteristics of decision-makers are the most direct factors influencing agricultural production efficiency. These include factors such as crop structure, farm size, participation in cooperatives, and disaster exposure. Individual characteristics include age, education level, health status, and gender. Additionally, the village environment, such as the village's economic development level, infrastructure, and topography, is also an important factor affecting agricultural production efficiency. Accordingly, this study selects 11 control variables covering household management characteristics, individual characteristics of decision-makers, and village-level environmental characteristics, based on the three main aspects focused on by existing research (see Table 1 for details).

3.3 Model selection

3.3.1 Baseline regression model

To verify the impact of agricultural production trusteeship on agricultural production efficiency, we construct a model to analyze this relationship. The specific form of the model is as follows:

$$Efficient = \beta_0 + \beta_1 Production\text{-}services + \beta_2 Z + \varepsilon \quad (1)$$

Where *Efficient* is the agricultural production efficiency concerned in this study, *Production-services* is the core explanatory variable, which refers to the situation of agricultural production trusteeship, Z represents control variables, ε is the random disturbance term, β_0 is the constant, and β_1, β_2 are the coefficients. The control variables Z include household

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TABLE 1 Variable definitions, abbreviations, and descriptive statistics.

Variable category	Variable name	Abbreviation	Variable description	Mean	SD	Sample size
Input factors	Agricultural labor input	AgriLabor	Labor input in agricultural production (days/mu)	26.458	36.215	306
	Agricultural chemical input	AgriChem	Fertilizer and pesticide input (CNY/mu)	241.806	81.611	306
	Agricultural machinery input	AgriMach	Diesel consumption of agricultural machinery (liters/mu)	7.010	5.856	306
Output factors	Crop output value	CropValue	Crop output value (CNY/mu)	1325.964	309.989	306
Dependent variable	Agricultural Production Efficiency	AgriEff	Calculated using Data Envelopment Analysis (DEA)	0.348	0.194	306
Key independent variable	Agricultural Production Trusteeship	AgriTrusteeship	Whether participated in agricultural production trusteeship 1 = Yes, 0 = No	0.598	0.491	306
Mediating variable	Economies of Scale	ScaleEff	Measured by scale efficiency, calculated using the VRS-DEA model	0.713	0.256	306
Household operation characteristics	Agricultural crop structure	CropStruct	Proportion of grain crop sown area to total household sown area	0.824	0.378	306
	Grain crop sown area	GrainArea	Grain crop sown area (mu)	27.023	108.420	306
	Whether joined a cooperative	CoopMember	1 = Yes, 0 = No	0.542	0.499	306
	Natural disaster experience	DisastExp	Whether affected by a natural disaster; 1 = Yes, 0 = No	0.471	0.500	306
Decision maker's characteristics	Decision maker's age	DecAge	Actual age of the household head (years)	57.232	8.736	306
	Decision maker's education level	DecEdu	Whether the household head has reached high school (9 years) education or above; 1 = Yes, 0 = No	0.320	0.467	306
	Decision maker's health status	DecHealth	1 = Poor; 2 = Average; 3 = Good	2.742	0.474	306
	Decision maker's gender	DecGender	1 = Male; 0 = Female	0.961	0.194	306
Village characteristics	Village economic development level	VillageEcon	Per capita annual income of the village (ten thousand CNY)	1.310	0.822	306
	Village infrastructure	VillageInfra	Road mileage in the village (km)	3.685	2.495	306
	Village terrain	VillageTerrain	Whether the village is located on flat terrain; 1 = Yes, 0 = No	0.399	0.490	306
Instrumental variable	Agricultural production trusteeship situation of other farmers in the village	VillageOutsource	Proportion of other farmers in the village participating in agricultural production trusteeship	0.507	0.359	306

characteristics, decision-maker characteristics, and regional environmental characteristics.

3.3.2 Mediation effect model

The mediation effect model is a method for studying the effectiveness mechanism of explanatory variables, often used to discuss the guiding path and origin of economic phenomena. The mediation effect model is based on the influence of X on dependent variable Y. By adding a mediator variable M, if X affects Y through M, then a mediation effect exists. The basic form of the mediation effect model is as follows:

$$Efficient = \beta_0 + cProduction\text{-}services + \beta_1 Z + \varepsilon \quad (2)$$

$$Scale = \beta_0 + aProduction\text{-}services + \beta_1 Z + \varepsilon \quad (3)$$

$$Efficient = \beta_0 + c'Production\text{-}services + bScale + \beta_1 Z + \varepsilon \quad (4)$$

Among them, *Efficient* represents agricultural production efficiency, *Production - services* refers to agricultural production trusteeship, *Scale* is the mediator variable for scale efficiency, Z represents control variables, β_0 is the constant term, and ε represents the random disturbance term. c,a,b and c' are estimated parameters. c is the total effect of agricultural production trusteeship on agricultural production efficiency, a is the effect of agricultural production trusteeship on scale economy, b is the effect of scale economy on agricultural production efficiency under the influence of agricultural production trusteeship, and c' is the effect of agricultural production trusteeship on agricultural production efficiency after controlling for scale economy. Typically, the mediation effect is represented as the product of a and b, and c' is the direct effect. The total effect is the sum of ab and c'.

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4 Empirical results and analysis

4.1 Estimation results of the baseline regression model

This study utilizes STATA 16.0 software to estimate regression results with agricultural production efficiency as the dependent variable and agricultural production trusteeship as the core explanatory variable (Equation 1). Since the values of agricultural production efficiency range between (0,1), it is a constrained dependent variable. Compared with other multivariate regression models, the Tobit model is more suitable for constrained dependent variables (Li and Zhuang, 2021). Therefore, the Tobit model was selected for estimation. Prior to estimation, multicollinearity tests were conducted. According to the variance inflation factor (VIF) calculation, the mean VIF was 2.26, with a maximum value of 3.16, indicating no multicollinearity issues. The estimation results are shown in Table 2. Without adding control variables, agricultural production trusteeship has a significant positive effect on agricultural production efficiency, with a confidence level of 0.001. To mitigate omitted variable bias, household management characteristics, individual characteristics, and village environmental variables were successively added to the model. The results consistently show that agricultural production trusteeship significantly promotes the improvement of agricultural production efficiency at a 0.001 confidence level, thus validating hypothesis H1.

In addition to agricultural production trusteeship, village infrastructure also significantly promotes agricultural production efficiency. Therefore, rural infrastructure should be further improved to enhance agricultural production efficiency. Natural disasters significantly inhibit the improvement of agricultural production efficiency, highlighting the importance of strengthening early warning mechanisms for natural disasters and enhancing post-disaster recovery capabilities to reduce the losses in agricultural production efficiency caused by such events. The age of decision-makers also significantly

TABLE 2 Baseline regression model estimation results.

Variable	Without control variables	With household operation variables	With individual characteristics	With village environmental variables
AgriOutsource	0.101***	0.105***	0.091***	0.106***
	−0.023	−0.03	−0.03	−0.031
CropStruct		0.034	0.032	0.03
		−0.029	−0.028	−0.028
GrainArea		0	0	0
		0	0	0
CoopMember		−0.113***	−0.115***	−0.114***
		−0.026	−0.026	−0.026
DisastExp		−0.099***	−0.102***	−0.101***
		−0.032	−0.032	−0.032
DecAge			−0.003***	−0.003***
			−0.001	−0.001
DecEdu			0.002	0.005
			−0.02	−0.02
DecHealth			−0.021	−0.025
			−0.02	−0.02
DecGender			0.058	0.076
			−0.046	−0.046
VillageEcon				0.003
				−0.013
VillageInfra				0.008*
				−0.004
VillageTerrain				0.038
				−0.032
Constant	0.199***	0.275***	0.481***	0.433***
	−0.017	−0.038	−0.114	−0.115
Region Fixed	YES	YES	YES	YES
Sample Size	306	306	306	306

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01 confidence levels, respectively. Standard errors are in parentheses. The coefficient and standard error of the grain crop sown area are not actually zero; they appear so due to the limitation of decimal places retained.

inhibits agricultural production efficiency. As age increases, both labor time and labor intensity tend to decline, making it difficult for older individuals to undertake more labor-intensive production tasks, which hinders the improvement of agricultural production efficiency. Additionally, membership in cooperatives inhibits agricultural production efficiency. At present, there are still many "shell cooperatives" in rural areas, which operate irregularly. These "shell cooperatives" not only drain financial support from legitimate farmer cooperatives but also diminish farmers' confidence in cooperatives. The issue of "shell cooperatives" is a major obstacle to the development of agricultural cooperatives, and their poor management and formalism also impede the improvement of agricultural production efficiency.

4.2 Mediation effect analysis

The analysis of mediation effects in econometric models typically follows the stepwise approach recommended by Wen and Ye (2014). Accordingly, this study tests whether economies of scale play a significant mediating role in the mechanism by which agricultural production trusteeship affects agricultural production efficiency (Equations 2–4). As shown in Table 3, economies of scale serve as a mediating variable, and a significant mediation effect exists, thereby confirming hypothesis H2. In terms of the effect size, economies of scale account for 45.63% of the impact of agricultural production trusteeship on agricultural production efficiency. In other words, 45.63% of the total effect of agricultural production trusteeship on agricultural production efficiency is an indirect effect mediated by economies of scale. Enhancing agricultural production efficiency through economies of scale is a primary pathway by which agricultural production trusteeship achieves efficiency gains.

TABLE 3 Mediation effect estimation results.

	AgriEff	ScaleEff	AgriEff
AgriOutsource	0.106***	0.087**	0.058***
	−0.031	−0.038	−0.022
ScaleEff			0.556***
			−0.033
Household operation characteristics	YES	YES	YES
Decision maker's characteristics	YES	YES	YES
Village environmental characteristics	YES	YES	YES
Constant	0.433***	1.010***	−0.13
	−0.115	−0.143	−0.089
Region fixed	YES	YES	YES
Sample size	306	306	306

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01 confidence levels, respectively. Standard errors are in parentheses.

TABLE 4 Mediation effect estimation results under full outsourcing.

	AgriEff	ScaleEff	AgriEff
AgriOutsource	0.117***	0.111***	0.054*
	−0.036	−0.041	−0.028
ScaleEff			0.564***
			−0.043
Household operation characteristics	YES	YES	YES
Decision maker's characteristics	YES	YES	YES
Village environmental characteristics	YES	YES	YES
Constant	0.473***	0.805***	0.016
	−0.141	−0.162	−0.112
Region fixed	YES	YES	YES
Sample size	237	237	237

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01 confidence levels, respectively. Standard errors are in parentheses.

4.3 Heterogeneity analysis

To verify the differences in the impact of trusteeship intensity on agricultural production efficiency, the study further focuses on full-process trusteeship, assigning a value of 1 to households that fully participate in agricultural production trusteeship, and a value of 0 to households that do not participate. As shown in Table 4, under full-process trusteeship, the strengthening effect of agricultural production trusteeship on economies of scale is more prominent. In the total effect of agricultural production trusteeship on agricultural production efficiency, the contribution of economies of scale reaches 51.23%, thus confirming hypothesis H3. Furthermore, this analysis also supports the relative robustness of the study, indicating that the conclusions of hypotheses H1 and H2 are fairly reliable.

4.4 Robustness analysis

4.4.1 Model substitution

To enhance the robustness of this study, we referenced existing research (Chen et al., 2024; Huo et al., 2024) and replaced the Tobit estimation method with OLS to recheck the results. As shown in Table 5, agricultural production trusteeship significantly affects agricultural production efficiency, confirming the main hypothesis H1 and suggesting the reliability of the study's conclusions. Additionally, after switching to OLS, the mediation effect in terms of significance and magnitude remained similar to that of the main model. Under OLS estimation, economies of scale contribute an indirect effect of 45.47% to the total effect of agricultural production trusteeship on agricultural production efficiency, which is close to the 45.63% observed in the main model.

4.4.2 Endogeneity test

The primary factors leading to endogeneity typically include omitted variables and reverse causality. In the previous baseline regression, this study adopted a stepwise regression strategy, sequentially adding control variables across different dimensions to

TABLE 5 OLS estimation results.

	OLS	Tobit
AgriOutsource	0.106**	0.106***
	−0.031	−0.031
Household operation characteristics	YES	YES
Decision maker's characteristics	YES	YES
Village environmental characteristics	YES	YES
Constant	0.429***	0.433***
	−0.117	−0.115
Region fixed effects	YES	YES
Sample size	306	306

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01 confidence levels, respectively.

TABLE 6 Instrumental variable estimation results.

	IV-2SLS	IV-Tobit
AgriOutsource	0.247***	0.247***
	−0.095	−0.081
Household operation characteristics	YES	YES
Decision maker's characteristics	YES	YES
Village environmental characteristics	YES	YES
Constant	0.310**	0.314**
	−0.136	−0.135
Region fixed	YES	YES
F-statistic	20.347***	
Hausman test	3.69 **	
DWH test	3.724**	
Sample size	306	

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01 confidence levels, respectively.

mitigate the endogeneity problem caused by omitted variables. The main potential source of endogeneity now lies in the reverse causality between the dependent and explanatory variables. While agricultural production trusteeship significantly impacts agricultural production efficiency, regions with higher initial agricultural production efficiency are more likely to attract agricultural production trusteeship service organizations due to better operational conditions and infrastructure, which may cause endogeneity arising from reverse causality.

To address this, an endogeneity analysis was further conducted to strengthen the model's robustness. Methodologically, this study used the instrumental variable (IV) approach for the analysis. One of the key advantages of the instrumental variable method is that it can effectively mitigate endogeneity issues caused by reverse causality and omitted - variable bias, thereby serving as a reliable test for the robustness of the benchmark model and reflecting the robustness of the results of this study. The instrumental variable method typically uses two-stage least squares (2SLS) estimation. In the first stage, the exogenous component is isolated, and in the second stage, this component is regressed to obtain consistent estimates. Considering the nature of the dependent variable in this study, an IV-Tobit model was also added for comparison. The estimation results, shown in Table 6, demonstrate that under both the IV-2SLS model and the IV-Tobit model, agricultural production trusteeship significantly promotes the improvement of agricultural production efficiency, confirming that the effect of agricultural production trusteeship on agricultural production efficiency is robust. Additionally, under the instrumental variable approach, economies of scale continue to exhibit a significant mediating effect, with results consistent with those of the main model.

5 Conclusion and recommendations

This study utilizes micro-survey data from households in Shandong Province and applies a mediation effect model to analyze the impact and mechanisms of agricultural production trusteeship on agricultural production efficiency. The study confirms that agricultural production trusteeship can strengthen economies of scale and effectively improve agricultural production efficiency. The specific conclusions are as follows:

(1) Agricultural production trusteeship has a significantly positive impact on improving agricultural production efficiency. Even after considering the issue of endogeneity, the conclusions remain robust. Agricultural production trusteeship effectively addresses the challenges faced by smallholder farmers, resolving the efficiency dilemmas inherent in smallholder and family farming operations.

(2) Agricultural production trusteeship achieves "service-based scale operation," effectively mitigating the issue of land fragmentation and enhancing agricultural production efficiency through economies of scale. In the total effect of agricultural production trusteeship on agricultural production efficiency, economies of scale contribute an indirect effect of 45.63%, which is the primary pathway through which agricultural production trusteeship enhances efficiency.

(3) Under full-process trusteeship, the strengthening effect of agricultural production trusteeship on economies of scale becomes even more prominent, with the indirect effect of economies of scale in the total effect reaching 51.23%. Based on this conclusion, it can be further verified that the pathway of "land transfer → large-scale land operation → economies of scale in land → agricultural production efficiency" is not the only route. Achieving service-based scale operation through agricultural production trusteeship provides an alternative and effective path, one that aligns more closely with the fundamental national conditions of China as a large country with many small farmers.

Based on these conclusions, the following recommendations are proposed:

(1) Recognize the role of agricultural production trusteeship in improving agricultural production efficiency: It is important to explore region-specific development models for agricultural production trusteeship. Under the new path of "service-based scale operation," different regions should strengthen policy support and guidance, leveraging local advantageous resources, including natural environmental conditions, regional economic strengths, and crop structure advantages, to establish a cost-saving, efficiency-enhancing, and income-increasing development model based on agricultural production trusteeship, promoting high-quality agricultural development.
(2) Maximize the integration capacity of village collectives to implement a "whole-village trusteeship" service model: This will further strengthen economies of scale and enhance the effectiveness of improving agricultural production efficiency. By leveraging the integration capacity of village collectives, the needs of smallholder farmers can be consolidated, forming a connection mechanism of "smallholder farmers → village collectives → agricultural production trusteeship service organizations." With the assistance and promotion of village collectives, service organizations are more likely to achieve concentrated and contiguous service areas, reducing operational losses and saving operational costs.
(3) Prioritize subsidies for the agricultural machinery upgrades of agricultural production trusteeship service organizations: Improving the service capabilities of these organizations and fostering full-process trusteeship capacity is crucial. The service level of trusteeship organizations largely depends on the quality of agricultural machinery. Regions should pay special attention to the issue of machinery subsidies for agricultural production trusteeship service organizations, especially in areas that are still in the exploratory or early stages. Enhancing the agricultural machinery levels of service organizations is key to boosting service capacity, fostering full-process trusteeship, and improving local agricultural production efficiency.

6 Shortcomings

It should be acknowledged that there are limitations in the sample coverage of this study, as the survey was conducted only in Shandong Province, China. Beyond Shandong, regions such as Heilongjiang, Jilin, and Hebei have also made significant progress in agricultural production management, developing unique models that have played an important role in improving agricultural productivity. While major agricultural provinces share certain common characteristics, expanding the survey scope would yield a more diverse set of research samples, leading to more effective theoretical and empirical analyses. Therefore, future research can broaden the survey region, allowing for a deeper and more detailed study, telling a fuller story and improving the research overall. In addition, this study still has limitations in the selection of instrumental variables. Future research could further innovate the selection of instrumental variables, such as considering region-specific policy interventions or the social network characteristics of farmers in the survey, to enhance the explanatory power and reliability of the study.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CJ: Conceptualization, Data curation, Investigation, Project administration, Writing – original draft. WH: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft. TW: Conceptualization, Data curation, Investigation, Software, Writing – original draft. YZ: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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