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The Threshold Effect of Agricultural Socialized Service Scale on Promoting Agricultural Modernization

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Abstract

Agricultural socialized services are a key driver of China's agricultural modernization. Clarifying the "reasonable boundaries" of their scale not only helps build a service system suited to moderate-scale agricultural operations but also facilitates the optimal allocation of agricultural resources and a steady improvement in service efficiency. Based on the transaction–coordination dual-cost model, this study constructs a theoretical analytical framework for how agricultural socialized services promote agricultural modernization. This study integrates agricultural development data from 30 Chinese provinces for the period 2011–2023 and employs a threshold regression method to examine the impact of agricultural socialized services on the year-on-year growth rate of agricultural modernization, as well as any stage-specific differences. The results indicate that agricultural socialized services have a significant positive effect on the year-on-year growth of the agricultural modernization index; that is, improvements in the level of agricultural socialized services help accelerate the pace of agricultural modernization. This accelerating effect is more pronounced in the eastern regions and in areas with higher per capita disposable income; meanwhile, the impact of agricultural socialized services on the year-on-year growth rate of agricultural modernization exhibits a nonlinear effect based on the scale of the services. Accordingly, it is recommended to establish a targeted service delivery system, implement support policies tailored to local conditions, and promote high-quality development driven by two engines in order to fully unleash the promotional role of agricultural socialized services in agricultural modernization.

Keywords: agricultural socialized services; agricultural modernization; transaction costs; coordination costs; threshold effects

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1. Introduction

As a key force in promoting the modernization of agriculture with Chinese characteristics, clarifying the "reasonable boundaries" of the scale of agricultural socialized services not only helps to build a service system that suits the moderate-scale operation of agriculture, but also contributes to the optimal allocation of agricultural resources and the steady improvement of service efficiency. In the process of promoting agricultural modernization through agricultural socialized services, exactly what scale of service is needed to achieve a balance between avoiding service blind spots and preventing resource waste? The answer to this question is related to the optimal allocation and efficient utilization of agricultural resources. It not only provides theoretical support for building a reasonable agricultural

socialized service system and facilitating moderate agricultural operations, but also offers a basis for decision-making in addressing the trade-off between agricultural services tending towards "small but precise" differentiated supply and "large and comprehensive" standardized services.

Current academic research on the optimal scale of agricultural socialized services presents two opposing viewpoints. One viewpoint emphasizes that current agricultural socialized services suffer from issues such as incomplete coverage of service items and limited service scope. It is necessary to continue to expand the service scale to complete the transformation towards a "big and comprehensive" direction. The supply of agricultural socialized services is scattered, fragmented and monotonous, which makes it difficult for small-scale farmers to achieve unification and scale in terms of the demand and supply of agricultural socialized services [1]. For large-scale farmers, the demands for multiple service contents such as agricultural information services and agricultural machinery supporting services have not been fully met. The agricultural socialized service system needs to be further expanded and optimized [2]. At the same time, service organizations such as agricultural cooperatives have a limited service radius, with most operating only within their own villages, resulting in a lack of significant spillover effects on surrounding areas [3]. In light of this, efforts should focus on expanding the scale of agricultural socialized services and actively fostering diversified service providers. Measures such as establishing a special fund for large-scale agricultural socialized services and promoting cooperation among multiple cooperatives should be implemented to enhance service accessibility and coverage, thereby driving the improvement and development of the agricultural socialized service system [4]. In contrast, opposing viewpoints argue that the development of agricultural socialized services should shift toward a "small but precise" model to achieve more precise service provision. This approach focuses on the actual sense of benefit for micro-level entities and the efficiency of resource allocation, emphasizing that service supply must align with demand characteristics. Large-scale agricultural socialized services tend to exclude smallholder farmers, exacerbating the challenges they face in integrating with modern agriculture; therefore, greater emphasis must be placed on precision and adaptability; A small-scale yet precise model for agricultural socialized services is more aligned with smallholder farmers and better suits the characteristics of smallholder agricultural production, thereby better meeting their needs [5,6]. This has even led some service organizations to blindly expand their equipment and staff in order to secure national fiscal subsidies, resulting in resource waste and operational inefficiency [7]. Therefore, emphasizing the precision and efficiency of services is a crucial pathway to effectively optimize the allocation of agricultural service resources and enhance their effectiveness [8]. Overall, the academic debate regarding the scale of agricultural socialized services essentially represents a profound reflection on development priorities and core principles of resource allocation, reflecting the complexity and dilemmas faced in agricultural policy and service design under the specific national context of China.

This paper distinguishes itself from the simplistic binary thinking of existing research, which tends to view issues as "either/or." It argues that the impact of agricultural socialized services on the year-on-year growth rate of agricultural modernization exhibits a nonlinear "threshold effect" as the scale of services changes. To this end, this study constructs a theoretical framework based on transaction and coordination dual-cost theory under market mechanisms, using data from 30 Chinese provinces between 2010 and 2023. Applying threshold regression methods, it identifies the threshold values of agricultural socialized service scale and analyzes the differential characteristics of how these services promote agricultural modernization across different service scale ranges, aiming to explore the "reasonable boundary" of agricultural socialized service scale.

2. Theoretical Analysis and Research Hypothesis

2.1. Transaction and Coordination Dual Costs Under the Market Mechanism

Coase [9] was the first to introduce the concept of transaction costs to explain the rationale for the existence of firms under market mechanisms. He defined transaction costs as "the costs of using the price mechanism," which include the costs of finding a trading partner and determining a price, the costs of negotiation and contract formation, and the costs of monitoring contract enforcement. Building on this foundation, Williamson [10] expanded the theory by integrating the psychological assumptions of "bounded rationality" and "opportunism." He constructed an analytical framework centered on the key dimensions of asset specificity, uncertainty, and transaction frequency, thereby extending transaction cost theory from the study of firm boundaries into the fields of institutional economics and industrial organization. This framework is used to explain the impact of property rights systems and legal frameworks on transaction efficiency, as well as issues such as corporate alliances and antitrust regulation. Steven N.S. Cheung [11] enriched the transaction cost theory framework through empirical research, extending its application to multiple fields such as agricultural economics, contract analysis, and property rights and price controls, thereby establishing it as a core tool for explaining various economic institutions and practices. As research has deepened, the application of transaction costs has further penetrated fields such as agriculture, finance, and public policy, becoming a universal tool for analyzing institutional efficiency and organizational choice [12,13].

Hayek [14] was the first to view the price mechanism as an institutional arrangement designed to reduce the costs of "coordinating knowledge." Although he did not directly use the term "coordination costs," he highlighted the core idea that coordination consumes scarce resources. In the literature on mechanism design, Hurwicz [15] was the first to formally introduce the concept of coordination costs, defining them as the costs of information transmission, signal processing, and strategy adjustment required to achieve incentive compatibility and resource compatibility in an environment of dispersed information. Through mathematical modeling, he bridged the gap between theoretical concepts and measurable variables. Building on this, Becker and Murphy [16] integrated the division of labor, coordination costs, and knowledge into a single analytical framework, applying it to the analysis of endogenous economic growth and the boundaries of the firm. Xiaokai Yang [17] pointed out that coordination costs not only encompass the direct resource inputs of both parties in dimensions such as spatiotemporal matching and quality assessment, but also imply institutional losses arising from information asymmetry and contractual incompleteness. These studies have expanded the interpretive scope of coordination costs across various branches of economics, extending coordination cost theory from its early two-dimensional "firm-market" analysis to fields such as the platform economy, regional agriculture, and supply chain resilience governance [18–20].

In a market economy, economic agents face not only transaction costs arising from uncertainty in the external market environment, information asymmetry, and imperfect contracts, but also coordination costs stemming from divergent objectives, communication barriers, and decision-making delays within internal collaborative processes. Together, these factors influence agents' decision-making tendencies and behavioral choices. The complexity of economic activities and the diversity of participating agents determine that a one-dimensional cost analysis framework has inherent limitations in explaining the logic of resource allocation. Such a framework tends to overlook coordination costs while overemphasizing market transaction efficiency, or to discuss the value of organizational collaboration in isolation from transaction costs. A transaction and coordination dual-cost analysis framework aligns with the objective reality of the dual nature of economic activities—exchange and collaboration. It respects the regulatory role of market

mechanisms in managing transaction costs while also valuing the optimization function of organizational design in addressing coordination costs. By analyzing these dual costs, one can more accurately identify points of efficiency loss in economic activities, helping economic agents find the optimal balance between market transactions and organizational collaboration, and providing a scientific basis for optimizing resource allocation and enhancing the quality of economic operations.

2.2. The Dual-Cost Analysis of Agricultural Socialized Services in Promoting the Agriculture Modernization

In agricultural production, transaction costs include search costs, negotiation costs, implementation costs, monitoring costs, and default costs, among others, and they are key factors influencing farmers' production and trading decisions [21,22]; Coordination costs include the costs of scheduling resources such as agricultural machinery and inputs within service organizations, as well as the costs of communicating with dispersed farmers, liaising with the government, and negotiating with suppliers [23,24]. The introduction of agricultural socialized services helps overcome the production challenges faced by smallholder farmers and reduces the transaction and coordination costs associated with their integration into modern agriculture [25]. Regarding transaction costs, agricultural socialized services enable smallholder farmers to avoid sunk costs resulting from the idling of specialized assets; they consolidate smallholders' scattered, one-off service demands into centralized, routine transactions, thereby reducing the time and resource consumption associated with high-frequency, sporadic transactions; and they establish a full-chain information-sharing and standardized risk-sharing mechanism, reducing the decision-making and default costs incurred by farmers due to uncertainty [26]. Regarding coordination costs, agricultural socialized service organizations develop standardized production plans and market strategies, providing smallholder farmers with clear decision-making guidelines through one-stop, full-chain services. They consolidate the smallholders' fragmented, multi-party search for agricultural inputs, machinery, finance, and sales service providers into centralized contracting, thereby systematically reducing coordination costs between farmers and diverse economic actors [27]; By providing unified production outsourcing, field management, and market sales services, agricultural socialized services internalize small farmers' individual decisions into a unified operational plan, thereby eliminating coordination costs arising from inconsistent decision-making among farmers [28,29]. Overall, agricultural socialized services have reduced transaction and coordination costs in the process of connecting smallholder farmers to the broader market and facilitating collaboration among various actors in the industrial chain. This enables modern agricultural production factors—such as capital, technology, management, and data—to overcome the high barriers and high-risk barriers of the smallholder economy, allowing them to be embedded throughout the entire agricultural production process with lower thresholds and higher efficiency. This has expanded the penetration boundaries and diffusion depth of modern material equipment and technological factors within the agricultural system, providing ample space for the adaptive application and systematic coupling of modern agricultural production factors across all stages, thereby promoting the development of agricultural modernization. Based on the aforementioned theoretical logic, this paper proposes:

Hypothesis 1. *Agricultural socialized services can promote the modernization of agriculture.*

In the development of agricultural socialized services, changes in service scale lead to shifts in transaction and coordination costs. This process can be divided into three stages:

The initial stage of small-scale, high-cost operations. During this stage, agricultural socialized service organizations invest in specialized assets such as large-scale agricultural

machinery and smart equipment; however, the scale of services is insufficient to spread fixed costs, and the unit usage cost of specialized assets is high, resulting in relatively high per-mu operational costs [30]; Small-scale service organizations lack market bargaining power, resulting in higher procurement costs for agricultural inputs compared to larger-scale organizations, as well as higher per-mu service prices for agricultural machinery operations [31]; Service organizations must invest more resources to gather demand information from dispersed farmers and identify and screen suitable partners. Both parties need to engage in repeated negotiations and consultations regarding service content, quality standards, pricing, and liability for breach of contract, incurring negotiation costs [32]. At the same time, personnel and departments within the service organization have not yet fully adapted to the new business scale and processes, requiring extensive internal coordination efforts, resulting in high internal coordination costs; In the early stages of collaboration with external partners, service organizations may face inconsistencies in workflows and operational methods. This necessitates significant communication and negotiation costs to reach consensus and ensure seamless coordination across all stages [33]. Although the initial signs of economies of scale begin to emerge in agricultural socialized services during this phase, they are offset by high transaction and coordination costs, resulting in a limited impact on the advancement of agricultural modernization [34].

The stage of diminishing returns at moderate scale. At this stage, agricultural social service organizations, leveraging economies of scale, establish relatively comprehensive information databases and cooperation resource pools, enabling them to collect and match information more efficiently, thereby reducing the costs of information search and exchange; the standardization of service-related contracts and processes, along with the establishment of trust-based relationships with partners, reduces negotiation and implementation costs; service organizations also establish relatively comprehensive supervision systems, lowering the costs of monitoring contract fulfillment; High transaction frequency allows service organizations to spread fixed costs, thereby reducing unit transaction costs [35]. At the same time, as internal management within service organizations becomes more standardized and streamlined, departmental responsibilities are clearly defined, authority and accountability are transparent, and information flows efficiently. This fosters a smooth communication mechanism and a positive collaborative atmosphere, leading to a significant reduction in internal coordination costs; Through collaborative refinement, service organizations and their partners have gradually established stable and mature cooperative mechanisms. All parties not only achieve resource integration and complementary advantages but also form a collaborative governance framework based on shared benefits and risk-sharing, effectively controlling external coordination costs and driving them downward [36,37]. At this stage, the scale of services is sufficient to reduce market transaction costs and coordination costs, creating a virtuous cycle of "scale expansion—cost reduction—demand activation," thereby fully unleashing the catalytic effect of agricultural socialized services on agricultural modernization.

The phase of cost rebound due to excessive scale. At this stage, the excessive scale of agricultural socialized services requires a more robust supervision system and additional supervisory personnel, leading to increased supervision and implementation costs. To meet the demands for agricultural socialized services across larger regions and with greater diversity, service organizations must invest more resources in market research to understand the varying needs of farmers and market dynamics, resulting in higher information search costs. At the same time, an excessively large service scale leads to increased management span and complexity within service organizations, raising intra-departmental coordination costs. When service organizations collaborate with a greater number of partners and farmers, differences in interests and operational models necessitate

higher coordination costs to achieve effective synergy [38]. At this stage, the previously significant savings in transaction and coordination costs have largely been exhausted. If service organizations continue to expand their scale solely for the sake of growth, they may instead fall into a dilemma of diminishing returns, resulting in a relative weakening of the role of agricultural socialized services in promoting agricultural modernization [39]. Based on this, the following hypothesis is proposed:

Hypothesis 2. *The role of agricultural socialized services in promoting agricultural modernization follows a nonlinear relationship with service scale.*

There are differences among various regions in terms of resource endowments, economic development, and functional positioning [40]. In regions with well-developed information infrastructure, mature market mechanisms, and sound legal enforcement systems, the transaction costs incurred by farmers and service organizations in searching for service information, negotiating contracts, monitoring contract performance, and protecting their rights are relatively low. This low-transaction-cost environment enhances farmers' trust in and reliance on socialized services, thereby accelerating the introduction and diffusion of modern factors such as agricultural technology, machinery, and finance. Conversely, in regions characterized by information asymmetry, market fragmentation, a scarcity of service providers, and weak contract enforcement mechanisms, farmers face higher transaction costs. These high transaction costs not only suppress farmers' demand for external services but also weaken service providers' willingness to enter the market, leading to limitations in the coverage and quality of agricultural socialized services and, consequently, hindering the process of agricultural modernization. At the same time, the provision of agricultural socialized services often involves multiple stakeholders, including the government, enterprises, cooperatives, and farmers, and the efficiency of their coordination is highly dependent on local governance capacity and the degree of organization. In regions with abundant resources and strong technical capabilities, local governments possess robust fiscal capacity. Through institutional design, fiscal subsidies, and the establishment of public platforms, they can effectively reduce coordination costs, fostering a stable cooperative framework among stakeholders. This enables the scaled, specialized, and sustainable provision of services, thereby strengthening the endogenous momentum of agricultural modernization. However, in regions with scarce resources and weak technical capabilities, the government's ability to coordinate resources is limited, and the level of farmer organization is low, resulting in persistently high coordination costs. These high costs make it difficult for socialized services to establish effective supply-demand linkages and sustainable operational mechanisms, hindering their ability to systematically drive agricultural modernization. Based on this, we propose the following hypothesis:

Hypothesis 3. *The role of agricultural socialized services in promoting agricultural modernization exhibits regional heterogeneity.*

3. Materials and Methods

3.1. Data Declaration

Given the severe lack of data and geographical barriers in Hong Kong, Macao, Taiwan, and Tibet, and taking into account data availability and continuity, this paper selected data on agricultural socialized services and agricultural modernization from 2011 to 2023 across 30 provincial-level administrative regions nationwide. The data were primarily sourced from the (China Statistical Yearbook), (China Rural Statistical Yearbook), (China Leisure Yearbook), (China Agricultural Machinery Industry Yearbook), Annual Statistical Report

on China's Rural Policies and Reforms, Annual Statistical Report on China's Rural Management and Operations, China Green Food Development Center, and the statistical yearbooks and bulletins of various provinces. In this paper, all monetary variables are deflated using price indices to convert them into real values expressed in constant 2010 prices, thereby eliminating the impact of inflation. Specifically, expenditures on socialized agricultural services were deflated using the agricultural production services price index from the (China Statistical Yearbook); agricultural output value and agricultural income were deflated using the agricultural product production price index; and agricultural machinery operation costs were deflated using the agricultural machinery sub-index from the agricultural production materials price index. Linear interpolation was used to impute missing values.

This study was primarily conducted using StataSE 18, with IBM SPSS Statistics 27 serving as a supplementary analytical tool.

3.2. Model Construction

To examine the role of agricultural socialized services in promoting agricultural modernization, the following econometric model was constructed:

$$Score_{it} = \alpha_0 + \alpha_1 ASS_{it} + \alpha_2 X_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (1)$$

In this context, Score represents the agricultural modernization index and serves as the dependent variable in the model; ASS stands for agricultural socialized services and is the key independent variable, with its coefficient reflecting its impact on Score; Xit denotes the various control variables, and α_2 represents the coefficient of influence of each control variable on Score. The subscript i refers to different administrative regions, t refers to the year, μ_i and θ_t represent provincial and time fixed effects, respectively, and ε_{it} is the random error term. This paper uses provincial panel data from China for the period 2011–2023. Given that there are multiple observations for the same province across different years, and that the error terms may exhibit serial correlation within a province, all regressions employ cluster-robust standard errors at the provincial level. This approach allows the error terms for different years within the same province to be arbitrarily correlated, while assuming that the error terms across different provinces are independent of one another. Furthermore, since the model already controls for provincial fixed effects and time fixed effects, the clustering level aligns with the identification level of the fixed effects.

To investigate whether there is a threshold effect of agricultural socialized services on agricultural modernization across China's administrative regions, this paper selects the scale of agricultural socialized services as the threshold variable and establishes the following threshold regression model:

$$\begin{aligned} Score_{it} = {} & \beta_0 + \beta_1 ASS_{it} \times I(Sev_{it} \le \gamma_1) + \beta_2 ASS_{it} \times I(\gamma_1 < Sev_{it} \le \gamma_2) + \cdots + \beta_n ASS_{it} \times I(\gamma_{n-1} < Sev_{it} \le \gamma_n) + \\ & \beta_{n+1} ASS_{it} \times I(Sev_{it} > \gamma_n) + \theta_1 control_{it} + \mu_i + \theta_t + \varepsilon_{it} \end{aligned} \quad (2)$$

Sev_{it} is the threshold variable; $\gamma_1, \gamma_2, \ldots, \gamma_n$ are the threshold values for the respective threshold intervals; $\beta_1, \beta_2, \ldots, \beta_{n+1}$ are the estimated coefficients for the different threshold intervals; and I(x) is an indicator function that takes tssshe value 1 if the threshold variable satisfies the condition, and 0 otherwise. Standard errors also cluster at the provincial level.

3.3. Variable Definitions and Descriptive Statistics

3.3.1. Dependent Variable

Numerous policy documents have previously proposed structural adjustment, the upgrading of production methods, and innovation in management systems as key indicators for measuring the level of agricultural modernization. Agricultural modernization should

not be limited to the modernization of agricultural production and management; rather, it should be premised on ensuring a solid foundation for agricultural production and enhancing management efficiency. Building upon the optimization and adjustment of agricultural structure, it should achieve an organic unity of material conditions and spiritual wealth, thereby promoting the comprehensive progress and development of agriculture. Based on this, this paper draws on the research findings of Ling Xin [41] and Li Wang et al. [42] to construct an indicator system for evaluating the level of agricultural modernization from three dimensions—agricultural structure, production, and management. The definitions and weights of the indicators are shown in Table 1.

Given that the dimensions and units of the various indicator data differ, it is first necessary to perform preprocessing by standardizing the raw data. This step aims to eliminate the effects caused by differences in units and dimensions among various indicators, thereby ensuring the accuracy and reliability of subsequent data analysis. Through standardization, we can ensure that all indicators are compared and analyzed within the same framework, providing support for further in-depth research and decision-making. At the same time, since the various evaluation indicators have different effects on agricultural modernization—some positive and some negative—we classify them into positive and negative indicators to more accurately reflect their actual roles in agricultural modernization. Through this step, we have successfully minimized the potential impact of the units and dimensions of the raw indicator data on the indicator selection process, laying a solid foundation for subsequent analysis.

For positive indicators,

$$x_{ijt} = \frac{v_{ijt} - \min\limits_{1\le i\le n} v_{ijt}}{\max\limits_{1<i<n} v_{ijt} - \min\limits_{1<i<n} v_{ijt}} \tag{3}$$

For negative indicators,

$$x_{ijt} = \frac{\max\limits_{1<i<n} v_{ijt} - v_{ijt}}{\max\limits_{1<i<n} v_{ijt} - \min\limits_{1<i<n} v_{ijt}} \tag{4}$$

The extreme values (max and min) used in standardization should be determined once for the entire panel sample (all provinces, all years), rather than separately for each year.

Where i represents a province, j represents an indicator, and t represents a year.

Next are the steps for the entropy-weighted method: First, calculate the share of the i-th province under the j-th indicator in year t:

$$p_{ijt} = \frac{x_{ijt}}{\sum_i \sum_t x_{ijt}} \tag{5}$$

Then calculate the information entropy of this metric:

$$e_j = -\frac{1}{ln(NT)} \sum_i \sum_t p_{ijt} ln p_{ijt} \tag{6}$$

Here, N represents the number of provinces, and T represents the number of years.

Finally, determine the weights:

$$w_j = \frac{1 - e_j}{\sum_j (1 - e_j)} \tag{7}$$

In the entropy-weighted method, the proportions, information entropy, and weights should also be calculated once for the entire panel sample, rather than recalculating the weights each year.

Table 1. Indicator system for evaluating the level of agricultural modernization.

Primary Indicator	Secondary Indicator	Measurement Method	Attribute	Weight
Modernization of the agricultural structure	Per capita production of grain, vegetables, meat, eggs, and dairy (kg/person)	(grain production + vegetable production + meat production + poultry and egg production + dairy production)/total population of the region	+	0.0254
	Number of green agricultural products per 10,000 hectares	Product quality and cultivated land area covered by the Green Food logo in use tha year	+	0.0119
	Agricultural labor productivity (10,000 yuan/person)	Value added in the primary sector/number of employees in the primary sector	+	0.1659
	Percentage of the livestock industry (%)	(Output value of animal husbandry + output value of fisheries)/total output value of agriculture, forestry, animal husbandry, and fisheries	+	0.0359
	Percentage of agricultural processing (%)	Revenue from agricultural and food processing/total output value of agriculture, forestry, animal husbandry, and fisheries	+	0.0592
	Percentage of leisure agriculture (%)	Annual revenue from agritourism/total agricultural output value	+	0.0788
Modernization of agricultural production	Percentage of irrigated area (%)	Effectively irrigated area/total cropland area	+	0.0323
	Comprehensive mechanization rate for crop cultivation, planting, and harvesting (%)	Mechanized tillage rate × 40% + Mechanized seeding rate × 30% + Mechanized harvesting rate × 30%	+	0.0147
	Percentage of land under protected cultivation (%)	Greenhouse area/arable land area	+	0.1062
	Percentage of expenditures on agriculture, forestry, and water affairs (%)	Local expenditures on agriculture, forestry, and water affairs/general fiscal budget expenditures	+	0.0183
	Per capita investment in fixed assets for agriculture, forestry, animal husbandry, and fisheries (yuan/person)	Total fixed-asset investment in agriculture, forestry, animal husbandry, and fisheries/Total population of the region	+	0.0545
	Chemical fertilizer application rate (tons/1000 hectares)	Net application of agricultural fertilizers/Total cropland area	−	0.0105
Modernization of agricultural operations	Percentage of farm households engaged in large-scale farming (%)	Number of farming households cultivating 50 mu or more of farmland/total number of farming households in the region	+	0.0658
	Agricultural disaster prevention rate (%)	1 − (Area of crops affected by disasters/total area of crops planted)	+	0.1211
	Area of farmland transferred under the household contract system	Area of farmland transferred under the household contract system	+	0.0050
	Agricultural financial services	Total outstanding agricultural-related loans	+	0.1315
	Number of digital agriculture companies	Number of digital agriculture companies	+	0.0631

Agricultural modernization is a long-term evolutionary process accompanied by technological progress and institutional reform; even in the absence of changes in the scale of agricultural socialized services, its level may still increase due to the accumulation of basic factors or policy dividends. If the dependent variable were to directly use the absolute score of the current level of agricultural modernization, it would conflate the inevitable growth resulting from time trends with the incremental growth driven by changes in the scale of services. Therefore, this paper selects the index of change in the level of agricultural modernization (Score)—calculated as the current year's agricultural modernization score minus the previous year's agricultural modernization score divided by the previous year's agricultural modernization score—as the dependent variable. Standardized extreme values are determined uniformly based on the entire sample, and weights are calculated once for the entire panel sample rather than being recalculated separately for each year. The year-on-year changes measured by the Score can characterize differences in the pace of agricultural modernization across provinces on a common scale, ensuring comparability across years and thereby providing a reliable basis for dependent variables in subsequent tests of between-group differences and panel regressions. The scores for agricultural modernization were calculated using the entropy weighting method, and the results are shown in Table 2. As can be seen, during the period from 2010 to 2023, the overall level of agricultural modernization nationwide, as well as the modernization levels across the three dimensions of agricultural structure, production, and management, all showed a year-on-year upward trend. Here, the estimation period covers 2011–2023, while data from 2010 are used, where applicable, solely to construct the year-on-year change for 2011.

Table 2. 2010–2023 national agricultural modernization scores.

Year	Score for the Level of Agricultural Modernization	Score for Modernization of Agricultural Structure	Score for Modernization of Agricultural Production	Score for Modernization of Agricultural Operations
2010	0.0944	0.0368	0.0386	0.0190
2011	0.1023	0.0403	0.0403	0.0218
2012	0.1118	0.0440	0.0431	0.0247
2013	0.1222	0.0468	0.0470	0.0283
2014	0.1308	0.0489	0.0497	0.0322
2015	0.1400	0.0523	0.0527	0.0350
2016	0.1472	0.0542	0.0547	0.0383
2017	0.1574	0.0579	0.0545	0.0450
2018	0.1612	0.0580	0.0566	0.0466
2019	0.1705	0.0615	0.0587	0.0503
2020	0.1849	0.0684	0.0613	0.0552
2021	0.1972	0.0715	0.0613	0.0645
2022	0.2116	0.0714	0.0642	0.0760
2023	0.2275	0.0756	0.0642	0.0877

3.3.2. Independent Variables

The scope of agricultural socialized services is relatively broad, and different scholars have adopted different measurement methods. Aimin Hao (2011) selected rural fixed-asset investment as the variable to measure these services, while Han Yan et al. (2020) quantified them based on the number of employed persons in sectors closely related to agricultural socialized services [43,44]. However, due to the difficulty of precisely distinguishing relevant data for rural areas within existing datasets, both of these measurement methods suffer from a certain lack of precision. In light of this, this paper draws on the research methodology of Heng Zhang et al. (2021) and adopts the output value of specialized and auxiliary activities in agriculture, forestry, animal husbandry, and fisheries per unit

of sown area as an indicator to measure agricultural socialized services (ASS) [45]. The advantages of this indicator are as follows: First, the data originates from authoritative statistical sources and is readily available, thereby ensuring greater scientific rigor and validity. Second, the indicator design incorporates both scale and quality dimensions: the scale of output reflects the quantitative level of service development, while the intensity per unit of cultivated area reflects the degree of specialization and technological content of the services, thereby establishing a more scientific two-dimensional evaluation framework. The selection of this measurement method not only circumvents the statistical scope limitations of traditional indicators but also aligns with the modern development orientation of agricultural socialized services, which emphasizes "simultaneous improvement in both quantity and quality" [46].

3.3.3. Threshold Variable

This study uses the scale of agricultural socialized services (Sev) as a threshold variable. Due to data availability constraints, the study focuses on service-oriented agricultural cooperatives and calculates the ratio of the number of farming households to the number of service-oriented agricultural cooperatives. This indicator provides a clear picture of the average number of farming households served by each service-oriented agricultural cooperative, thereby reflecting the overall coverage of agricultural socialized services. Within a given region, assuming the total number of households remains constant, the fewer the number of service-oriented agricultural cooperatives, the greater the average number of households served by each cooperative, and the broader the service coverage that each individual cooperative must undertake. Although this indicator reflects the theoretical average service coverage rather than the actual service volume of each individual cooperative, it effectively captures the relative matching relationship between the scale of rural demand and the supply of agricultural socialized service organizations at the provincial level. This proxy has been widely adopted in provincial-level threshold and scale-effect studies, and it can objectively reflect the changes in organizational service density and service-bearing pressure across years and regions.

Data for 2011 on the number of green agricultural products per 10,000 hectares and the main business revenue of agricultural and food processing enterprises is missing. Given that the missing values exhibit trends across consecutive years and the proportion of missing values is low (all below 5%), this paper employs linear interpolation to impute the missing values. Linear interpolation assumes that a variable changes linearly between adjacent years. It is suitable for imputing short-term missing values in time series data and does not alter the overall trend or distribution characteristics of the variable. Compared to mean interpolation, linear interpolation better preserves the temporal dynamics of the variable.

The specific procedure for linear interpolation is as follows: For a variable with a missing observation in year t, if the data for the adjacent years t − 1 and t + 1 are complete, the interpolated value for year t is calculated using a linear function with the observations from these two years as endpoints. The interpolation formula is:

$$V_t = V_{t-1} + \frac{V_{t+1} - V_{t-1}}{(t+1) - (t-1)} \times (t - (t-1)) \quad (8)$$

That is, $V_t = (V_{t+1} + V_{t-1})/2$. V_t represents the estimate of a certain indicator in year t. For missing values in the first and last years of the sample period, the data were imputed by extrapolating from observations in adjacent years. All interpolations were performed separately at the provincial level to avoid interference from cross-provincial differences in the interpolation results.

3.3.4. Control Variables

Given that the level of agricultural modernization is influenced not only by core explanatory variables but also by other variables, and based on the conclusions of existing empirical studies, factors such as the intensity of fiscal investment, the supply of agricultural credit, the level of transportation infrastructure, the accumulation of rural human capital, and agricultural technological progress all have significant promotional effects on the process of agricultural modernization [47]. Building on this, and drawing on the research by Tian Yun et al. [48] and Han Guanghe et al. [49], this paper further focuses on the marginal contributions of the following variables to the level of agricultural modernization: urbanization rate (Urb), degree of aging (Age), level of green development (Sus), and level of infrastructure (Inf). The variable specifications and descriptive statistics for each variable are shown in Table 3.

Table 3. Description of variables.

Type of Variable	Name of Variable	Description of Variable	Mean	Standard Deviation	Min	Max
Dependent variable	Index of changes in the level of agricultural modernization (%)	(Agricultural modernization score for the current year/agricultural modernization score for the previous year) − 1	7.4141	7.5858	−26.1623	45.4700
Independent variable	Level of agricultural socialized services (10 million yuan/hectare)	Output value of agriculture, forestry, animal husbandry, and fisheries and related support activities/planted area	3.7276	2.6182	0.4200	17.3548
Threshold variable	Scale of agricultural socialized services (100 households)	Number of farming households/Number of regional service-oriented agricultural cooperatives	37.730	33.3911	2.1543	253.5040
Control variable	Urbanization rate (%)	Urban population/Total population	60.6356	11.9868	35.0425	89.5833
	Degree of aging (%)	Population aged 65 and over/Population aged 15–64	16.1044	4.7902	7.4400	30.6000
	Level of Green development (%)	Investment in Environmental Pollution Control/GDP	1.1430	0.8395	0.1570	4.6253
	Level of infrastructure development (10,000 km)	Total length of highway routes	15.6751	8.4225	1.2100	41.8254

4. Results

4.1. Baseline Regression Analysis

Before performing the baseline regression, a collinearity test was performed on the model, and the VIF values were found to be less than 10, indicating that there was no multicollinearity in this model. Based on the Hausman test results, it was concluded that the fixed effect model was more suitable for analysis. The regression results are shown in

Table 4. Column (1) did not include any control variables, while columns (2) to (5) gradually added relevant control variables.

Table 4. Baseline regression.

Variables	(1)	(2)	(3)	(4)	(5)
	Score	Score	Score	Score	Score
ASS	1.7119 ***	1.5799 ***	1.4363 ***	1.1429 ***	1.1658 ***
	(0.3300)	(0.3275)	(0.3339)	(0.3538)	(0.3555)
Urb		−0.7499 ***	−0.9199 ***	−0.9809 ***	−1.0509 ***
		(0.2221)	(0.2369)	(0.2367)	(0.2567)
Age			−0.5657 **	−0.6603 **	−0.6475 **
			(0.2830)	(0.2839)	(0.2846)
Sus				1.8879 **	1.8382 **
				(0.7916)	(0.7953)
Inf					0.2282
					(0.3222)
_cons	5.8458 ***	45.9956 ***	61.9320 ***	63.8457 ***	64.3795 ***
	(1.4544)	(11.9759)	(14.3440)	(14.2701)	(14.3003)
Province fixed effects	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES
N	390	390	390	390	390
R^2	0.1160	0.1442	0.1540	0.1678	0.1690

** $p < 0.05$, *** $p < 0.01$.

The results show that, regardless of the scenario, the coefficients of the explanatory variables are all positive and significant at the 1% level. This indicates that agricultural socialized services play a significant role in accelerating the year-on-year growth rate of agricultural modernization, which is consistent with theoretical expectations. A possible reason is that agricultural socialized services integrate and standardize the provision of modern agricultural production factors, effectively reducing farmers' information search costs and promoting the widespread adoption of modern agricultural technologies [50]; through models such as farm machinery operation outsourcing and equipment sharing, they aggregate dispersed demand to achieve large-scale utilization of farm machinery, thereby reducing both purchase and unit operation costs while mitigating the risk of asset specialization for farmers, thus promoting the introduction of modern agricultural machinery and equipment [51]. By providing services such as standardized production guidelines, quality testing, and brand certification, smallholder farming is integrated into a unified standards system. This significantly reduces supervision and quality assessment costs in downstream markets, promotes the transition of agriculture toward a quality- and efficiency-driven model, and lays a solid foundation for agricultural modernization [52,53].

From the perspective of control variables, the level of green development has a significant positive impact on agricultural modernization; the influence coefficient of infrastructure construction level on agricultural modernization is positive, but not significant; while the urbanization rate and aging have a negative correlation with agricultural modernization, and this correlation is significant at the 1% level. The possible reason is that green development reduces the technical adaptation cost and performance supervision cost by introducing green production technologies and equipment, and builds an ecological-economic collaborative goal to reduce the coordination cost of the main body, significantly promoting the endogenous development of agricultural social service entities, thereby promoting agricultural modernization [54]. The fragmentation of small-scale farming operations makes infrastructure difficult to exert scale effects, and general infrastructure cannot solve the problem of the specificity of agricultural transaction assets and information asym-

metry, and the potential cost savings have not been transformed into substantive gains. The increase in the urbanization rate causes a large number of young and middle-aged laborers to transfer to urban areas, and the agricultural production entities present an aging and part-time occupation feature. The shortage of labor force pushes up the transaction costs of agricultural production factors, and the collaboration ability between farmers, enterprises, and research institutions weakens, leading to an increase in coordination costs [55]. The aggravation of aging further amplifies the above effects. Elderly farmers have a low acceptance of modernization technologies, weak risk-bearing capacity, and are more inclined to traditional production modes, resulting in an increase in the technical adaptation and supervision coordination costs during the process of promoting agricultural modernization, and ultimately forming a negative impact.

4.2. Robustness Tests

To ensure the reliability of the regression results, the following several robustness test measures were adopted: First, replace the measurement method of the dependent variable. In the initial regression, the agricultural modernization level change index of the dependent variable was calculated based on the entropy method, using the agricultural modernization level score obtained through this method. Here, it was changed to calculate the agricultural modernization level score based on the entropy weight TOPSIS method, and the regression results are shown in column (1) of Table 5. Second, replace the control variables. Replace the control variables with urbanization rate, GDP, human capital and technological progress. The regression results are shown in column (2) of Table 5. Third, change the sample period. Delete the sample data from 2019 to 2021, which may be affected by unforeseen events, and the regression results are shown in column (3) of Table 5. Fourth, to reduce the potential impact of outliers on the estimation results, this paper applied Winsorization to the top and bottom 1% quantiles of the dependent variable, Score, and the regression results are shown in column (4) of Table 5. The signs and significance of the regression coefficients obtained by these four methods are consistent with the benchmark regression results, indicating that the regression results are robust.

4.3. Heterogeneity Analysis

The above analysis demonstrates that agricultural socialized services can significantly accelerate the year-on-year growth rate of agricultural modernization. However, from the perspectives of natural endowments and physical capital, agricultural modernization is influenced by a variety of factors. Therefore, this study further divides the sample into eastern and central-western regions, as well as high-income and low-income areas, to examine whether there are differences in the impact of agricultural socialized services on the year-on-year growth rate of agricultural modernization across regions with varying geographical locations and levels of affluence. The results are shown in Table 6.

The results in columns (1) and (2) indicate that the coefficient of agricultural socialized services is significantly positive in the eastern region, whereas it fails to pass the significance test in the central and western regions. This paper uses the nonparametric clustering bootstrap method to test for differences in coefficients between groups. The null hypothesis is that the regression coefficients for the eastern region and the central and western regions are equal, meaning that the difference between the two sets of coefficients is zero. First, group-based regression is performed on the original sample to obtain the coefficients for the two groups and their difference as the original statistic; second, the sample is resampled multiple times with replacement, and in each resampling, the regression model is re-estimated for each of the two subsamples, and the difference in coefficients is recorded for each resampling; Next, an empirical distribution of the coefficient differences is constructed

based on the results of numerous repeated resampling runs; finally, the relative position of the original statistic within this empirical distribution is calculated to obtain the empirical *p*-value. If the empirical *p*-value is less than the preset significance level, the null hypothesis is rejected, and the difference in coefficients between the groups is considered statistically significant. The *p*-value for the between-group difference between the eastern region and the central and western regions was 0.032, indicating that, at a 5% significance level, the null hypothesis is rejected—that is, there is a significant between-group difference in the impact of agricultural socialized services on the year-on-year growth rate of agricultural modernization between the eastern region and the central and western regions. This may be because the agricultural socialized service system in the eastern region developed earlier and is highly organized, with efficient logistics, information flow, and service organization operations, which significantly reduce transaction costs; The eastern region is predominantly flat, with contiguous land and regular plot shapes, making it naturally suited for the large-scale and standardized implementation of agricultural socialized services, resulting in lower coordination costs.

Table 5. Robustness test regression results.

Variables	(1)	(2)	(3)	(4)
	Score	Score	Score	Score
ASS	1.9502 ***	1.6214 ***	1.0038 **	1.0469 ***
	(0.4880)	(0.3512)	(0.4152)	(0.3291)
Urb	−0.8784 **	−0.8941 ***	−1.1194 ***	−1.0455 ***
	(0.3524)	(0.2520)	(0.3123)	(0.2376)
Age	−0.8948 **		−0.7786 **	−0.6793 **
	(0.3908)		(0.3423)	(0.2635)
Sus	2.3566 **		2.3957 **	1.8053 **
	(1.0917)		(0.9387)	(0.7362)
Inf	0.3633		0.2404	0.2333
	(0.4423)		(0.3979)	(0.2983)
GDP		17.0352 ***		
		(6.2921)		
Hum		0.0386		
		(0.2586)		
Tech		−0.8541		
		(0.7691)		
_cons	53.4278 ***	34.0302 **	68.8225 ***	64.6841 ***
	(19.6313)	(14.2086)	(17.4263)	(13.2381)
Province fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
N	390	390	300	390
R^2	0.1438	0.1635	0.1629	0.1842

** $p < 0.05$, *** $p < 0.01$.

To examine the specific impact of affluence, we calculated the average annual per capita disposable income for each province, ranked them from highest to lowest, and classified the top 50% of provinces by average annual per capita disposable income as regions with higher per capita disposable income, while the bottom 50% were classified as regions with lower per capita disposable income. The regression results are shown in columns (3) and (4) of Table 6. In regions with higher per capita disposable income, the coefficient of agricultural socialized services was significantly positive, indicating that agricultural socialized services have a significant positive impact on promoting agricultural modernization; however, in regions with lower per capita disposable income, this effect was not significant. Use the same method to test the coefficients of between-group differences,

the *p*-value was 0.028, indicating that, at a 5% significance level, the null hypothesis is rejected—that is, there is a significant between-group difference in the impact of agricultural socialized services on the year-on-year growth rate of agricultural modernization between the regions with high and low per capita disposable income. This may be because regions with higher per capita disposable income have well-developed infrastructure such as transportation and communications, as well as diversified information dissemination channels, allowing smallholder farmers and socialized service organizations to exchange information and conduct transactions more conveniently, thereby reducing transaction costs caused by information asymmetry; furthermore, these regions have fully developed markets, widespread market rules, a more standardized trading environment, and relatively lower negotiation and supervision costs. At the same time, regions with higher per capita disposable income have a higher level of economic development and a more refined social division of labor, leading to smoother collaboration between agricultural social service organizations, smallholder farmers, and relevant enterprises and institutions; farmers in these regions have relatively higher levels of education and scientific and technological literacy, as well as stronger abilities to accept and adapt to new things, which reduces coordination costs caused by poor communication and misunderstandings. Lower transaction and coordination costs enhance the service capacity and motivation of service organizations, promote the efficient delivery of agricultural socialized services, and thereby better advance agricultural modernization.

Table 6. Heterogeneity analysis.

Variables	(1) Eastern Region	(2) Central and Western Regions	(3) Regions with Higher per Capita Disposable Income	(4) Regions with Low per Capita Disposable Income
ASS	1.0773 *	0.3486	1.4080 ***	0.7555
	(0.5885)	(0.6640)	(0.5339)	(0.6178)
Urb	−0.9933 **	−0.5886	−0.9414 **	−1.0773 ***
	(0.4837)	(0.5372)	(0.4477)	(0.3205)
Age	−0.5690	−0.4804	−0.5609	−0.6615
	(0.4583)	(0.4148)	(0.4990)	(0.4289)
Sus	3.7468 *	1.0553	2.0924	2.1308 **
	(2.0229)	(0.8553)	(1.7703)	(0.8940)
Inf	0.4909	0.4157	−0.3637	0.5635
	(1.0306)	(0.3195)	(0.6301)	(0.3619)
_cons	62.6425 **	35.1144	65.7566 ***	59.1659 ***
	(27.1492)	(28.0572)	(24.7845)	(17.2500)
Province fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
N	156	234	195	195
R^2	0.2181	0.2129	0.2083	0.2122
p-value for the coefficient of variation between groups	0.032 **		0.028 **	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.4. Endogeneity Test

Bartik instrumental variables combine local and national information, providing a theoretical basis for the use of local instrumental variables. To address the endogeneity issue between agricultural socialized services and the year-on-year growth rate of agricultural modernization, this paper follows the approach of Che Chengcheng and others to

construct a Bartik instrumental variable using the share-shift method and estimates the model using 2SLS. It should be noted that 2SLS addresses only the endogeneity of the average treatment effect; it does not automatically resolve the endogeneity issues present in threshold regression models. The specific construction of the Bartik instrumental variable is as follows:

$$Bartik_{it} = Share_{i,2011} \times Shift_t \quad (9)$$

$Share_{i,2011}$ represents the density of agricultural socialized service organizations in province i in 2011 (the ratio of the number of agricultural socialized service organizations to the area of arable land), and $Shift_t$ represents the annual growth rate of the total central government subsidy for agricultural production socialized services at the national level in year t. The density of service organizations directly reflects the historical level of organization and the foundation of market development for agricultural socialized services in each province. Provinces with higher densities tend to have a more robust initial stock of service supply networks and may therefore be better positioned to absorb and amplify the expansion of nationwide agricultural machinery subsidies.

Column (1) indicates that in the first stage, the Bartik IV instrumental variable is significantly negatively correlated with the level of agricultural socialized services; Column (2) shows the results of the second-stage regression, under the assumption of instrumental variable validity, agricultural socialized services still have a significant positive impact on the year-on-year growth rate of agricultural modernization, which is consistent with the results of the baseline regression discussed earlier. The covariance estimators used in the underidentification test and weak instrumental variable are consistent with the standard error settings in the main regression: when cluster-robust standard errors at the provincial level are used in the main regression, the under-identification test employs the cluster-robust Kleibergen-Paap rk LM statistic, and the weak identification test employs the cluster-robust Kleibergen-Paap rk Wald F statistic. With regard to identification testing, The LM statistic for the underidentification test is 5.582, with a p-value of 0.018. At the 5% significance level, the null hypothesis of "insufficient identification of instrumental variables" is significantly rejected, indicating that the model is identifiable. The F-statistic for the weak identification test is 18.222, which is greater than the critical value of 16.38 for the Stock-Yogo test under a 10% maximum bias tolerance. This indicates that, under a 10% maximum bias tolerance, the weak instrumental variable problem does not pose a serious threat. It should be noted that this statistic does not strictly follow the Stock-Yogo critical value distribution under heteroscedasticity or clustering; therefore, comparing it to 16.38 should be regarded only as an empirical approximation. If the Kleibergen-Paap rk Wald F statistic is significantly greater than 16.38, it can be empirically concluded that there are no serious weak identification issues with the instrumental variables.

However, the validity of instrumental variables depends not only on the correlation condition but also on the exclusivity constraint. This paper provides indirect support for the exclusivity constraint in the following ways: First, the Bartik instrumental variable consists of the interaction term between the base-period industry share and the national-level industry growth rate. Its exogeneity stems from the quasi-random nature of national-level shocks relative to the regional level: since central government subsidies for agricultural socialized services are allocated uniformly through the central budget, individual provinces cannot exert a reverse influence on national-level budget arrangements, thereby constituting an exogenous budget constraint. This argument addresses the randomness at the shock level, whereas the interprovincial cross-sectional differences in baseline density—as a historical stock variable—have already been absorbed by the provincial fixed effects. Second, to test whether the instrumental variable is systematically associated with observable characteristics at the initial period, this paper conducts a regression of the Bartik IV

on the baseline agricultural modernization index and baseline per capita GDP. As shown in Column (3) of Table 7, none of the coefficients are significant. This indicates that the likelihood of provinces with higher base-period agricultural service supply density having more developed agricultural infrastructure and higher levels of economic development is not systematically reflected in the variation in the instrumental variables, thereby providing indirect support for the exclusionary constraint. Of course, the exclusionary constraint is, by its nature, not directly testable. The argument in this paper relies on the construction logic of the instrumental variables and indirect equilibrium tests; it cannot completely rule out the possibility that the instrumental variables influence agricultural modernization through unobserved channels. Therefore, the estimation results from Stage 2 should be understood as holding under the assumption of instrumental variable validity.

Table 7. Endogeneity analysis.

Variables	ASS	Score	Bartik IV
ASS		0.614 **	
		(0.2746)	
Bartik IV	−0.8835 ***		
	(0.3038)		
Control variables	YES	YES	YES
Province fixed effects	YES	YES	YES
Time fixed effects	YES	YES	YES
Kleibergen-Paap rk LM statistic	5.582 **		
Kleibergen-Paap rk Wald F statistic	18.222		
Score_2011			−0.8163
			(0.6757)
Avgdp_2011			0.8085
			(1.4279)
_cons			38.3437
			(49.0562)

** $p < 0.05$, *** $p < 0.01$.

4.5. Threshold Effect Analysis

Using Hansen's panel threshold model for analysis, we first tested the existence and number of threshold variables in the model [56]. Using the scale of agricultural socialized services as the threshold variable, after 500 bootstrap samples, the results of the three-threshold test for this model were not significant. The estimation results for the single-threshold and double-threshold models are shown in Tables 8 and 9, respectively. The single-threshold and double-threshold tests passed the threshold effect test respectively. The threshold value for the single-threshold test is 25.2091, which is significant at the 10% level; the two threshold values for the two-threshold test are 25.7756 and 26.0288, which are significant at the 5% and 10% levels, respectively.

Table 8. Single-threshold test results.

Threshold Variable	Threshold Value	*F* Value	*p* Value	95% Confidence Interval	
Sev	25.2091	11.47	0.0667	23.1190	25.2653

However, the two threshold values from the two-threshold test are 25.7756 and 26.0288, respectively, with a difference of only 0.2532 between them. The threshold range is too narrow, corresponding to a difference of only 25 households per unit in the actual scale of agricultural socialized services. As shown in Figure 1, which displays the likelihood ratio

(LR) functions for the two thresholds, the 95% confidence intervals corresponding to the two threshold values overlap significantly, and only eight data points were observed within the intervals of the two thresholds. From a statistical perspective, there is no evidence to support the existence of two distinctly different thresholds. The second threshold fails to provide structural information independent of the first threshold; it is likely merely a "shadow" or local perturbation of the first threshold resulting from the grid search, rather than a genuine structural inflection point. Forcing the retention of a dual-threshold setup would not only fail to improve model fit but would also lead to unstable parameter estimates and inflated standard errors due to overly fine threshold zoning and insufficient sample sizes in the medium-scale zones, thereby reducing the credibility of the conclusions. Therefore, this paper adopts a single-threshold model for subsequent further analysis. Given that the results of the threshold regression analysis indicate that the threshold effect of service scale is statistically significant at the 10% significance level, this paper interprets this finding as suggestive evidence that agricultural socialized services have a nonlinear impact on the year-over-year growth rate of agricultural modernization.

Table 9. Dual-threshold test results.

Threshold Variable	Threshold Value	*F* Value	*p* Value	95% Confidence Interval	
Sev	25.7756	11.47	0.0460	25.1828	26.0288
	26.0288	11.64	0.0740	25.7756	26.2862

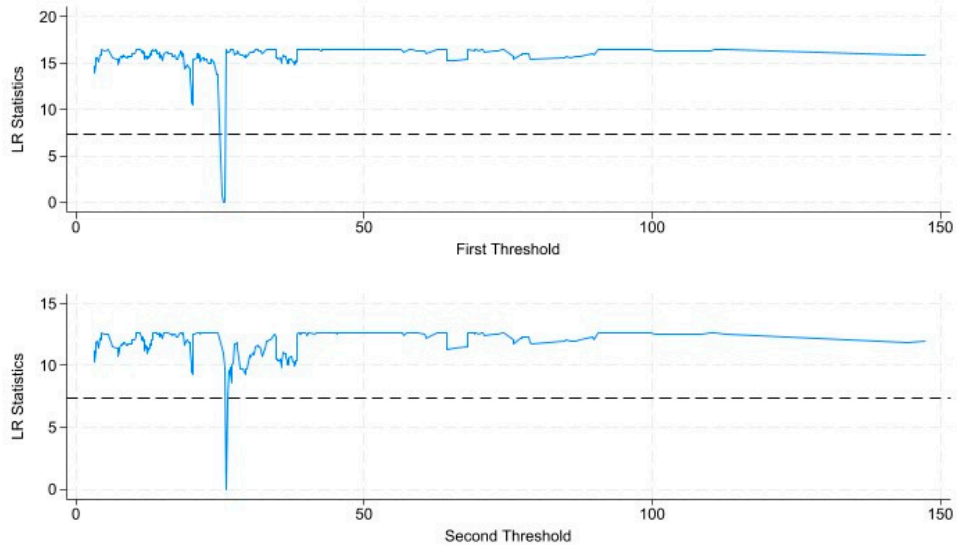


Figure 1. Likelihood-ratio profiles for the two thresholds.

The results of the panel threshold regression are presented in Table 10. The test results indicate that the promotional effect of agricultural socialized services on the year-on-year growth rate of agricultural modernization is influenced by the scale of such services, and that a nonlinear relationship exists between the two. There were 170 sample points below the threshold value and 220 sample points above the threshold value. In the threshold regression results, when the scale of services is below the threshold value (25.2091), the coefficient of influence of agricultural socialized services on the year-on-year growth rate of agricultural modernization is 1.3195; once the threshold is crossed, the coefficient of influence jumps to 2.0560. The results of the Wald test indicate that there is a significant difference between the coefficients for agricultural socialized services in the interval below the threshold and those in the interval above the threshold ($F = 10.77$, $p = 0.0011$), rejecting

the null hypothesis that "the coefficients in the two intervals are equal" at the 1% significance level. This suggests that the difference in coefficients between the two intervals is not due to chance but is statistically significant. This indicates that there is indeed a nonlinear effect of the scale of agricultural socialized services on the promotion of agricultural modernization, thereby confirming Hypothesis 2. It should be noted that Sev, the indicator used in this paper to characterize the scale of services, is defined as the ratio of the number of farming households to the number of service-oriented agricultural cooperatives. It represents the theoretical average coverage scale and does not reflect the actual number of farming households served by a single cooperative. Therefore, the threshold values and grouping results derived from the empirical analysis should be understood as statistical inflection points for this ratio within the model, rather than actual operational scales, optimal organizational sizes, or policy targets that can be directly implemented. The interpretation provided in this paper is limited to: the statistical threshold at which the relationship between agricultural socialized services and their promotional effect on the year-on-year growth rate of agricultural modernization changes, given the specified sample and model settings. The threshold values derived in this paper cannot replace an assessment of an individual cooperative's actual service capacity, nor can they be directly translated into a policy requirement specifying "how many farming households each cooperative should serve." When drawing on the conclusions of this paper, local authorities should interpret the threshold values as statistical indicators suggesting "a possible nonlinear relationship between agricultural socialized services and the year-on-year growth rate of agricultural modernization," rather than as uniform policy targets or evaluation criteria. In practical application, a comprehensive assessment must be made by considering factors such as the number of farming households in each region, the actual number of households served by each cooperative, the scope of services, the service radius, organizational models, and regional agricultural structures.

Table 10. Threshold regression.

Variable	Coefficient	Standard Error	*t* Value	*p* Value	95% Confidence Interval	
ASS × I (Sev < γ_1)	1.3195 ***	0.3155	4.18	0.000	0.6991	1.9399
ASS × I (Sev > γ_1)	2.0560 ***	0.3218	6.39	0.000	1.4232	2.6889
_cons	33.2938 ***	7.4334	4.48	0.000	18.6747	47.9129

*** $p < 0.01$.

4.6. Evidence of the Correlation Among Agricultural Socialized Services, Dual Costs, and Agricultural Modernization

The results of the threshold regression analysis presented earlier indicate that the promotional effect of agricultural socialized services on the year-on-year growth rate of agricultural modernization exhibits a single threshold based on service scale; once this threshold is crossed, the impact coefficient jumps from 1.3195 to 2.0560. In theoretical discussions, agricultural socialized services are often considered to be closely linked to the transaction–coordination dual costs in agricultural production. An expansion in the scale of services is typically accompanied by changes in these dual costs, which, in turn, are related to the year-on-year growth rate of agricultural modernization. To examine this relationship, this section divides the sample into a low-service-scale group (Sev $\leq$ 25.2091) and a high-service-scale group (Sev > 25.2091) based on a threshold value, and separately examines the correlation between agricultural socialized services and the "transaction–coordination dual costs, as well as the correlation between the transaction–coordination dual costs and the year-on-year growth rate of agricultural modernization. As shown in Table 11, this study introduces two indicators—intermediate consumption in agriculture,

forestry, animal husbandry, and fisheries, and the area of farmland management rights transferred by contracted farming households in the current year—and uses the entropy method to calculate their respective weights, thereby deriving the transaction–coordination dual costs variable. Given that increases in intermediate consumption and land transfers may influence agricultural modernization through channels other than transaction and coordination costs, this paper selected the rate of land transaction contract disputes (number of disputes/number of transaction contracts) and the degree of arable land fragmentation (number of arable land parcels/arable land area), using the entropy method to calculate proxy variables for the dual costs. The analysis results are robust. The regression results are presented in Table 12.

Table 11. Description of the transaction–coordination dual-cost variable.

Indicator	Measurement Method	Attribute	Weight
intermediate consumption in agriculture, forestry, animal husbandry, and fisheries	Intermediate consumption of materials in agriculture, forestry, animal husbandry, and fisheries + expenditures on production services	+	0.5064
the area of farmland management rights transferred by contracted farming households in the current year	The area of farmland subject to household-based contracts in that year, for which actual transfers of management rights took place through leasing, subleasing, equity participation, assignment, or exchange	+	0.4936
the rate of land transaction contract disputes	number of disputes/number of transaction contracts	+	0.3477
the degree of arable land fragmentation	number of arable land parcels/arable land area	+	0.6523

Table 12. Results of the correlation analysis.

Variable	Transaction–Coordination Dual Costs (1)	Score (2)	Transaction–Coordination Dual Costs (3)	Score (4)	Substitute Mediating Variable (5)	Score (6)	Substitute Mediating Variable (7)	Score (8)
ASS	0.3806 ***		−0.3710 ***		0.1661 **		−0.6427 ***	
	(0.1276)		(0.1077)		(0.0684)		(0.2116)	
Transaction–coordination dual costs		−0.2113		−1.5204 ***		1.0192		−0.4633 **
		(0.3652)		(0.4193)		(0.6839)		(0.2136)
Cons_	−4.5892	−9.6723	53.8882 ***	93.1748 ***	−3.3353 *	−5.4577	−24.9092 ***	84.3658 ***
	(3.1650)	(13.8063)	(1.4612)	(22.9664)	(1.6962)	(13.7960)	(2.8723)	(23.0899)
Control variable	YES	YES	YES	YES	YES	YES	YES	YES
Province fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
N	170	170	220	220	170	170	220	220
R^2	0.4986	0.2181	0.9310	0.1570	0.7042	0.2291	0.9915	0.1790

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Columns (1) and (5) indicate that in regions where the scale of services falls below the threshold value, there is a significant positive correlation between agricultural socialized services and transaction–coordination dual costs. This implies that at lower stages of service scale, an increase in the level of agricultural socialized services is accompanied by a rise in dual costs. Columns (2) and (6) show that the relationship between transaction–coordination dual costs and the year-on-year growth rate of agricultural modernization is not significant. This may be because, at the early stages of service development, the market scope for agricultural socialized services is limited, making it difficult to fully implement a specialized division of labor. Service organizations are fragmented, and the matching

of supply and demand is inefficient. Transaction frictions—such as information search, price negotiation, and contract enforcement—increase as service activities expand rather than being absorbed by organizational coordination; the expansion of service activities itself may initially "create" a portion of these transaction costs [57]. At the same time, land fragmentation constitutes the core constraint driving up coordination costs. When the scale of services is insufficient, scattered land parcels and discontinuous operational demands make it difficult for service organizations to carry out continuous operations and standardized scheduling; as a result, service costs per unit area rise rather than fall, and the mechanism for reducing coordination costs has not yet been activated [58]. However, although these dual costs are fluctuating, they have not yet formed a stable correlation with the year-on-year growth rate of agricultural modernization. This is because these costs can constrain agricultural modernization only if agricultural production has already come to rely, to a certain extent, on a socialized division of labor in services. At stages where the scale of services is low, agricultural production remains primarily self-sufficient or based on mutual aid among acquaintances. Information transmission and trust mechanisms within these social networks partially absorb transaction frictions, and coordination costs have not yet become a major obstacle to large-scale mechanized operations—since such operations do not yet exist [59]. Consequently, the constraining effect of dual costs on agricultural modernization is relatively weak and, statistically, insufficient to demonstrate a significant constraint on the year-on-year growth rate of agricultural modernization.

Columns (3) and (7) indicate that in regions where the scale of services exceeds the threshold value, there is a significant negative correlation between agricultural socialized services and dual costs. Columns (4) and (8) indicate that there is also a significant negative correlation between dual costs and the year-on-year growth rate of agricultural modernization. This may be because, once the scale of services exceeds the threshold value, the market capacity of agricultural socialized services is sufficient to support the deepening of the division of labor. Service organizations can aggregate dispersed operational demands into scaled service demands through standardized scheduling, contiguous operations, and cross-regional services, thereby reducing the coordination costs per unit of service and causing dual costs to decline as the scale of services expands [60]. At the same time, organizational innovation plays a key role at this stage: organizational forms such as service alliances, the involvement of rural collective economic organizations, and cooperatives effectively reduce transaction frictions in information search, price negotiation, and contract enforcement by improving contractual governance and adjusting the transaction radius, thereby further driving down dual costs [61]. As dual costs decline, farmers can outsource production processes at a lower cost, service organizations can carry out continuous operations and standardized scheduling, the utilization efficiency of machinery and equipment is enhanced, and the potential for economies of scale is unleashed, thereby creating conditions for advancing agricultural modernization. This chain of causality aligns with the theoretical framework of "deepening division of labor—reduction in transaction costs—expansion of market scope" in emerging classical economics, and it also echoes the empirical finding that agricultural socialized services expand the boundaries of the division of labor economy by reducing transaction costs. This difference provides a reference at the correlational level for understanding changes in the coefficient of the impact of agricultural socialized services on the year-on-year growth rate of agricultural modernization before and after the threshold.

5. Discussion

5.1. Theoretical Contributions

Existing research findings provide a useful framework for exploring the relationship between agricultural socialized services and modern agriculture, and are of universal

value. However, current research on the impact of agricultural socialized services primarily focuses on their role in agricultural production, with less attention paid to their comprehensive effects on various aspects of modern agriculture and the underlying mechanisms of these effects. Furthermore, existing studies mainly explore the linear effects of agricultural socialized services. This study engages with the existing literature in the following ways and offers some additional insights.

First, much of the existing literature assumes that the impact of agricultural socialized services on agricultural modernization is linear, or focuses solely on the average effect of service scale. This study finds that when service scale is below a threshold value, the coefficient of influence is 1.3195; once the threshold is crossed, it jumps to 2.0560. This finding engages in a dialogue with the research by Wander et al. [62] on the constraints of transaction costs on contractual arrangements for agricultural machinery services and provides empirical evidence of threshold nonlinearity in the economies of scale effects of agricultural socialized services.

Second, the marginal contribution at the policy level lies in providing empirical support for differentiated service-scale support strategies. The threshold identified in this study offers policymakers a clear reference point for service scale: in regions where service scale is below the threshold, policies should focus on reducing transaction and coordination costs; in regions where service scale exceeds the threshold, policies should shift toward strengthening the supporting conditions necessary to unlock service efficiency. This differentiated strategy addresses the controversy in the literature regarding the "one-size-fits-all" effects of agricultural socialized service policies and provides a more targeted policy pathway for achieving sustainable agricultural development goals. It should be noted that when local governments draw on the conclusions of this paper, they should interpret the threshold as a statistical indicator suggesting that "there may be a nonlinear relationship between agricultural socialized services and the process of agricultural modernization," rather than as a uniform policy target. Actual policy formulation must be based on a comprehensive assessment that takes into account factors such as the number of farming households in each region, the actual service capacity of service organizations, the scope of services, and organizational models.

Third, from the perspective of cost structure, this study reveals the scale-dependent boundary conditions under which agricultural socialized services promote agricultural modernization. While existing research has primarily focused on the average effects of agricultural socialized services on agricultural development, this study shows that when the scale of services is below a certain threshold, there is a significant positive correlation between the transaction–coordination dual costs and agricultural socialized services, whereas the relationship between the year-on-year growth rate of agricultural modernization and transaction–coordination dual costs is not significant; Only after the scale exceeds the threshold—does a significant negative correlation emerge between the transaction–coordination dual costs and agricultural socialized services, and a significant negative correlation also emerges between the year-on-year growth rate of agricultural modernization and the transaction–coordination dual costs. This finding defines the boundary conditions for applying transaction cost theory to the agricultural sector—namely, that the cost-reducing function of institutional arrangements depends on whether market scale has reached the critical level for an effective division of labor—and provides a theoretical basis for evaluating the "suitability" of medium-scale agricultural operations from the perspective of cost structure.

It should be noted that the Sev indicator, used as a threshold variable, depicts the theoretical average coverage of agricultural socialized services at the provincial level, rather than the actual volume of services provided by individual cooperatives. This indicator

effectively captures the relative alignment between the scale of rural demand and the supply of services by service organizations; it objectively reflects dynamic changes in service density and service capacity pressures across different years and regions, and possesses strong macro-level representational capabilities. However, its aggregated nature also means that this indicator cannot reflect the heterogeneity of services or operational differences at the micro-level, and thus has certain limitations when explaining specific mechanisms of action. Furthermore, the threshold value obtained from the threshold test passed the test at the 10% significance level and constitutes indicative threshold evidence, suggesting that there is some statistical support for the nonlinear effect of agricultural socialized services on the year-on-year growth rate of agricultural modernization. However, this is not an exact critical point under strong identification conditions, and its economic implications must be understood in the context of theoretical logic and institutional background. Finally, this study uses a regression model to identify the correlation among agricultural socialized services, transaction–coordination dual costs, and the year-on-year growth rate of agricultural modernization, rather than the mediating effect of transaction–coordination dual costs in the process by which agricultural socialized services influence agricultural modernization. Due to the limitations of the observed data and the model specification, the empirical design of this paper can only identify statistical associations among variables and is not yet sufficient to establish strict causality identification.

5.2. Policy and Management Implications

Based on the above empirical research results, this paper puts forward the following specific suggestions.

First, using the service scale threshold as a reference indicator, implement differentiated support policies for agricultural socialized services. The service scale threshold estimated in this paper suggests that when the service scale falls below this threshold, the promotional effect of agricultural socialized services on the year-on-year growth rate of agricultural modernization is relatively limited; once the service scale exceeds the threshold, this promotional effect strengthens. On this basis, localities can reassess the reference threshold levels applicable to their specific circumstances, taking into account factors such as the number of farming households, the actual service capacity of service organizations, service content, and organizational models. If the service scale has not yet reached the reference threshold, policy discussions should focus more on constraints related to transaction and coordination costs—such as establishing regional service information platforms, standardizing service contracts, improving access to agricultural machinery, and promoting contiguous land management—to help the service scale gradually approach the critical level for effective division of labor. If the service scale has already exceeded the reference threshold, policy discussions should focus more on the supporting conditions required to unlock the full potential of these services, such as technology extension, financial support, and integration into industrial chains. It should be noted that the threshold value in this paper is a theoretical average coverage scale derived from the ratio of the number of farming households to the number of service-oriented agricultural cooperatives; it does not represent the actual number of farming households served by a single cooperative, nor should it be directly interpreted as the actual operational scale, the optimal organizational scale, or a feasible policy target. The policy discussion above uses the threshold value as a reference statistical indicator; its policy value lies in highlighting that policy constraints may vary across regions with different service scales, rather than in providing a uniform standard for scale compliance.

Second, implement targeted support policies for different regions. In response to the significant disparities in the promotional effects across eastern, central, and western

regions, as well as between high- and low-income areas, a differentiated implementation mechanism tailored to regional development levels will be established. The eastern region's role as an innovation leader will be strengthened; leveraging its economic foundation and technological advantages, priority will be given to supporting the development of high-end and diversified services. We will increase support for the foundational infrastructure of central and western regions by establishing regional special funds. On the one hand, this will drive infrastructure upgrades such as the construction of high-standard farmland, mechanization-friendly renovations, and the development of logistics networks; on the other hand, it will foster local service providers by enhancing their professional capabilities through a "service-plus-training" model, thereby gradually strengthening the service capacity of central and western regions.

Third, incorporate the reduction in transaction–coordination dual costs into the policy framework for sustainable agricultural development. Reducing transaction and coordination costs not only helps advance agricultural modernization but also contributes to reducing resource waste and improving machinery utilization efficiency, which is intrinsically consistent with the goals of green agricultural transformation. Policies could consider integrating the development of information systems for service markets and the organized promotion of contiguous operations with sustainable agricultural development goals. However, it must be acknowledged that this paper does not directly examine the impact of reduced dual costs on environmental performance; this policy recommendation is largely an extension of theoretical logic, and its actual effectiveness requires further empirical testing.

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