

How can Agricultural Socialized Services Enhance Agricultural Green Total Factor Productivity?

-- An Examination based on the Channel of Technological Progress

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Abstract

Developing agricultural socialized services is a crucial approach to drive small farmers onto the track of modern agricultural development. However, whether and how these services can promote the green transformation of agriculture still require systematic empirical evidence. This paper takes agricultural green total factor productivity (AGTFP) as the entry point, utilizes panel data from 31 provinces in China spanning from 2010 to 2024, and employs the SBM-GML model to measure AGTFP. Based on this, a two-way fixed effects model is used to examine the impact of agricultural socialized services on AGTFP. Furthermore, leveraging the multiplicative decomposition property of the global Malmquist-Luenberger index, the mechanism of action is identified from two channels: technological progress and improvement in technical efficiency. The research findings are as follows: Firstly, agricultural socialized services significantly promote the improvement of AGTFP. This conclusion remains valid after a series of robustness and endogeneity tests, including lagging explanatory variables, exclusion of municipalities, winsorization, and instrumental variable estimation. Secondly, channel tests indicate that agricultural socialized services primarily enhance AGTFP by promoting agricultural technological progress, while their effect on improving technical efficiency is not significant. Thirdly, the green productivity effect of agricultural socialized services exhibits significant heterogeneity, being notable in major grain-producing regions and central and western regions, but not in non-major grain-producing regions and eastern regions. This paper provides new empirical evidence for understanding the green development effect of agricultural socialized services from the perspective of GTFP decomposition. The research conclusions offer insights for guiding socialized service organizations to upgrade towards green technology integration services and implementing differentiated regional service supply policies.

Keywords

Agricultural Socialized Services; Agricultural Green Total Factor Productivity; SBM-GML; Technological Progress; Two-Way Fixed Effects.

1. Introduction

The basic agricultural situation of a large population and limited land resources determines that China's agricultural modernization must address the question of "who will farm the land

and how will it be farmed." Under the dual constraints of the "dual carbon" goals and agricultural non-point source pollution control, this issue has been endowed with new connotations of green transformation. In recent years, agricultural socialized services, represented by production management, unified pest control, and contract farming, have developed rapidly. The Ministry of Agriculture and Rural Affairs has successively issued the "Guiding Opinions on Accelerating the Development of Agricultural Production Services" (2017) and the "Guiding Opinions on Accelerating the Development of Agricultural Socialized Services" (2021), establishing socialized services as a strategic measure to promote the organic integration of small farmers and modern agriculture. However, a practical question that has not yet been fully answered is: while outsourcing of operations as the main form of socialized services alleviates labor constraints and reduces production costs, has it truly promoted the green transformation of agricultural production methods? If the answer is yes, through what channels are its green effects achieved? Answering this question is not only related to the scientific evaluation of the effectiveness of socialized service policies but also to the direction of future service supply policy optimization. Existing research has provided rich discussions on this topic, but there are still differences in conclusions and mechanism identification.

Regarding the relationship between agricultural socialized services and agricultural green total factor productivity (AGTFP), existing literature can be broadly categorized into three streams. The first stream focuses on the productivity effect of socialized services. Most studies have confirmed that agricultural productive services can promote the improvement of AGTFP (Zhang Heng and Guo Xiangyu, 2021; Song Wei et al., 2024)[1][2]. However, some studies have found a "U-shaped" or threshold nonlinear relationship between the two based on farmer data (Cheng Yongsheng and Zhang Deyuan, 2024)[3]. The second stream concentrates on the measurement and influencing factors of agricultural green total factor productivity. Within measurement frameworks that consider non-desired outputs, such as Slacks-Based Measurement (SBM) and Efficiency-Based Measurement (EBM), it examines the effects of environmental regulation, industrial agglomeration, factor allocation, and other factors (Zhan Jintao and Xu Yujiao, 2019)[4]. The third stream directly investigates the green development effect of socialized services. Li Yuchao et al. demonstrated the promoting effect of socialized services on AGTFP based on provincial panel data, while Bai Ziming et al. further confirmed the spatial spillover characteristics of this effect. Leng Langping (2025)[5] systematically examined three mediating paths: agricultural land scale management, specialized division of labor, and agricultural green technology level. Overall, existing research has gradually reached a consensus on whether socialized services promote AGTFP, but there are still significant differences in terms of the channels through which this promotion occurs. Most mechanism tests rely on mediating variables such as land circulation and scale of operation, and it remains questionable whether these macro proxy indicators can truly depict service-driven scale operations. In contrast, macro evidence identifying channels from the decomposition of AGTFP itself—that is, technological progress and improvement in technical efficiency—is still relatively lacking. This divergence constitutes the starting point of this study.

This paper aims to advance the understanding of the channels through which the green development effect of agricultural socialized services operates. The research design is as follows: two hypotheses to be tested are proposed - that agricultural socialized services promote the improvement of AGTFP (H1), and this promotional effect is primarily achieved through the channel of technological progress rather than the channel of technical efficiency improvement (H2); theoretically, the logic of socialized services affecting AGTFP is depicted with the help of the division of labor economy and technology diffusion theory; methodologically, the SBM-GML model considering non-desired outputs is used to measure AGTFP across 31 provinces, and the cumulative technological progress index (tc) and technical efficiency change index (ec) obtained through the multiplicative decomposition of the GML

index are utilized to base the channel test on the strict identity equation " $gtfp = tc \times ec$ "; in terms of data, provincial panel data from 2011 to 2021 are used, with the level of socialized services measured by the output value of agricultural professional and auxiliary activities per unit sown area, while factors such as income, industrial structure, disaster severity, and climatic conditions are controlled.

Research findings: Agricultural socialized services have a significant promoting effect on AGTFP, with a benchmark regression coefficient of 0.0720, which remains robust after lagging explanatory variables, excluding municipalities, 5% winsorization, and instrumental variable estimation. Channel tests show that socialized services significantly promote agricultural technological progress (coefficient 0.0330), but have no significant impact on the improvement of technical efficiency, thus verifying the technological progress channel. Heterogeneity analysis indicates that the promoting effect is concentrated in major grain-producing areas and the central and western regions. Compared with existing knowledge, the difference in this paper lies in establishing mechanism identification based on the index decomposition of GTFP, thus avoiding the problem of proxy distortion of macro-mediating variables and revealing the phased characteristics of "technological progress first, efficiency improvement lagging behind". The policy implications are as follows: currently, the green dividends of socialized services mainly come from the diffusion function of service organizations as carriers of green technology. Policies should guide service organizations to upgrade from single operation outsourcing to green technology integration services, and open up efficiency improvement channels through service-driven large-scale operations; at the same time, service resources should be tilted towards major grain-producing areas and the central and western regions.

2. Literature Review

The purpose of the literature review is to propose questions and hypotheses for this paper by analyzing existing knowledge. Centered around the question of "whether and how agricultural socialized services can enhance agricultural green total factor productivity (AGTFP)", the following discussion unfolds in three levels: first, it reviews the measurement methods of AGTFP and their evolutionary characteristics; second, it evaluates empirical evidence and disagreements regarding the productivity effects of socialized services; and finally, it focuses on the progress and shortcomings of mechanism research.

2.1. Measurement and Evolution of Agricultural Green Total Factor Productivity

The measurement of Agricultural Gross Factor Productivity (AGTFP) has evolved from the traditional total factor productivity framework to a green development framework. Early studies measured agricultural TFP using the Solow residual or Malmquist index, without considering resource and environmental constraints, often overestimating the quality of agricultural growth. As green development has become a consensus, researchers have generally shifted to an efficiency analysis framework that considers undesirable outputs: one type is represented by the Slacks-Based Measure (SBM) model and its super-efficiency extension, which directly incorporates undesirable outputs such as agricultural non-point source pollution and carbon emissions into the production possibility set (Zhan Jintao and Xu Yujiao, 2019) [4]; the other type employs a combination of directional distance functions and Malmquist-Luenberger (ML) index to achieve a dual depiction of "expansion of good outputs and contraction of bad outputs" [10]. In recent years, the Global Malmquist-Luenberger (GML) index under the global production possibility set has gradually become a mainstream choice due to its advantages such as being multiplicative, free from technological regression bias, and strictly decomposable into the product of technological progress and technical efficiency changes (Leng Langping, 2025) [5]. In terms of measurement conclusions, existing studies

generally agree that China's agricultural GTFP has shown an upward trend during the sample period, and there are regional differences in growth drivers. However, the decomposition conclusions regarding the sources of growth are inconsistent: some studies find that technological progress is the main engine, while others emphasize the contribution of efficiency improvement. This leaves room for examining the channels through which driving factors operate from a decomposition perspective.

2.2. The Productivity Effect of Agricultural Socialized Services: The Divergence between Promotion Theory and Nonlinear Theory

Empirical evidence regarding the productivity effect of socialized services can be divided into two perspectives. The promotion theory posits that socialized services enhance agricultural (green) total factor productivity (TFP) by deepening division of labor, substituting scarce factors, and expanding the scale of technology adoption. Hao Aimin (2013)[6] demonstrated earlier the spillover effects and channels of agricultural productive services; Zhang Heng and Guo Xiangyu (2021)[1] confirmed based on provincial-level data that the development of agricultural productive services significantly enhances agricultural TFP, with regional differences; Zhang Zewen et al. (2024)[2] focused on agricultural machinery socialized services and found that they can enhance the efficiency of green grain production and generate positive spatial spillovers; Song Wei et al. (2024)[2] also supported the promotion conclusion in their study of the Huang-Huai-Hai region; Wang and Xie (2026)[7] further investigated the relationship between agricultural socialized services and agricultural green TFP based on county-level data in China. The nonlinear theory, on the other hand, cautions that the promotion effect may have conditional boundaries: Cheng Yongsheng and Zhang Deyuan (2024)[3] pointed out theoretically that the direction of socialized services' impact on green TFP depends on the relative magnitude of technological progress and efficiency loss, with a certain threshold range; empirical research based on farmer data found that as service levels improve, farmers' green TFP first decreases and then increases, exhibiting a "U" shape, and the threshold value varies with different estimation strategies ("Resources Science", 2025). The divergence between these two perspectives partly stems from differences in data levels (provincial macro and farmer micro) and measurement calibers: micro-level research can capture the adjustment costs in the early stages of service adoption, while macro-level research reflects more on the average net effect of the service system. This paper examines the average effect based on provincial panel data and addresses potential selection biases and endogeneity in the robustness section.

2.3. Research on the Mechanism of the Green Effect of Socialized Services: Two Paths of Intermediary Agency and Decomposition Identification

Mechanism research serves as the direct dialogue literature for this paper. Existing explorations have generally followed two paths. The first is the path of mediating variables, where variables such as large-scale farming, division of labor, and technology adoption are selected as mediators for stepwise regression or mediation effect tests. Bai Ziming et al. found that agricultural productive services can enhance AGTFP by optimizing resource allocation, promoting technological progress, and deepening division of labor; Ouyang Peng and Jiang Xia (2024) [8] also conducted research on the enhancement of agricultural green total factor productivity by agricultural productive services; Leng Langping (2025) [5] systematically examined three mediating paths: large-scale farming of agricultural land, specialized division of labor, and agricultural green technology level; research based on micro-data of farmers found that the adoption of green production technologies (soil testing and fertilization, biopesticides, agricultural film recycling, and straw returning to the field) bore most of the mediating effects (Nanfang Economic Review) [9]. The second path is the index decomposition path, which utilizes the property that GTFP can be decomposed into the product of

technological progress and technical efficiency to directly examine the impact of driving factors on the two decomposed terms (for the relevant theoretical framework, see Cheng Yongsheng and Zhang Deyuan, 2024) [3], thereby reducing "mechanism" to the two sources of productivity growth. Comparatively speaking, the path of mediating variables is intuitive and has specific policy implications, but indicators such as land circulation rates at the macro level have a weaker causal relationship with socialized services and a higher risk of agency distortion; the decomposition identification path is based on an identity equation and has a clear logical chain, but it cannot specify specific service links or policy levers, and existing applications mostly remain at the theoretical framework or micro-level, with a lack of provincial macro-level evidence.

2.4. Literature Review

In summary, existing research has laid a foundation for this paper in three aspects: the SBM-GML measurement of AGTFP has matured, the average effect of socialized services in promoting AGTFP has gained considerable support, and mechanism identification has developed two paths: mediation agency and index decomposition. However, there are still areas for further advancement: firstly, at the mechanism level, macro studies generally rely on intermediary variables such as land circulation and operation scale, but these variables themselves have weak correlation with socialized services, limiting the persuasiveness of mechanism evidence; secondly, although the index decomposition path has been repeatedly advocated in theory (Cheng Yongsheng and Zhang Deyuan, 2024), there is little systematic application on provincial panel data, and there is a lack of direct evidence on the key question of whether socialized services promote the outward shift of the frontier or facilitate catch-up; thirdly, although regional heterogeneity of effects has been discussed, the combination with channel characteristics is still insufficient. This paper starts from the aforementioned divergences and gaps, identifies two channels based on GTFP decomposition: technological progress and improvement in technical efficiency, and examines the realization mechanism of the green effect of agricultural socialized services.

3. Theoretical Analysis and Research Hypothesis

3.1. Analytical Framework

This paper observes the relationship between agricultural socialized services and AGTFP from two theoretical perspectives: division of labor economy and technological diffusion, and unifies the two within a production frontier analysis. Within the set of production possibilities that includes non-desired outputs, the growth of AGTFP is always equal to the product of technological progress (outward shift of the frontier) and improvement in technical efficiency (actual output catching up to the frontier). Thus, the proposition "through what mechanism do socialized services affect AGTFP" can be strictly transformed into "do socialized services drive the outward shift of the frontier, promote producers to catch up to the frontier, or both?" Let me summarize the logical chain: Agricultural socialized services separate the production links (such as tilling, planting, prevention, harvesting, drying, and storage) that were originally embedded within farmer households and provide them centrally by specialized service organizations. This process of deepening division of labor, on one hand, drives the outward shift of the production frontier through the large-scale adoption and diffusion of green technologies, and on the other hand, promotes farmers' approach to the frontier through factor reorganization and operational synergy. These two channels jointly determine the changes in AGTFP. The difference from existing frameworks lies in that this paper does not use intermediary variables such as large-scale operations as proxies for mechanisms, but directly utilizes the multiplicative decomposition property of the GML index to test these two channels,

thus avoiding macro-level proxy distortion and being able to identify the phased structural characteristics of green effects.

3.2. Agricultural Socialized Services and Agricultural Green Total Factor Productivity: The Direct Effect Hypothesis

The promotional effect of agricultural socialized services on AGTFP can be understood from three aspects. Firstly, factor substitution and reduction. Specialized services such as unified pest management, soil testing and fertilization, and efficient plant protection machinery operations achieve the same output with less input of fertilizer, pesticide, and agricultural film, directly reducing the intensity of undesirable output per unit of output and promoting the improvement of AGTFP. Secondly, deepening division of labor and standardized production. Service organizations centralize and standardize scattered farming operations, alleviating the extensive management issues brought about by the diversification and aging of small farmers, and enabling the implementation of green production norms in operational processes. Thirdly, risk buffering and output stability. Socialized services shorten agricultural delays, enhance disaster response capabilities, and stabilize expected output. From a competitive perspective, there are also inhibitory factors such as rising transaction costs and varying service quality in the early stages of service outsourcing. However, at the provincial macro level, as the service system matures, the promotional effect should prevail. Based on this, it is proposed that:

Hypothesis H1: Agricultural socialized services have a significant promoting effect on agricultural green total factor productivity.

3.3. Channels of Technological Progress and Channels of Technical Efficiency Improvement: Mechanism Hypothesis

Decompose and expand the action path of H1 along the GML. In terms of the channel of technological progress, social service organizations serve as the "last mile" carrier for green technologies to enter smallholder production: green technologies such as improved seeds, slow-release fertilizers, biopesticides, and conservation tillage equipment exhibit strong asset specificity and high learning costs. Smallholders face dual obstacles of diseconomies of scale and insufficient capacity when adopting these technologies independently. However, service organizations can batch-load new technologies in the form of "materializing technology in operations", enabling green technologies to be implemented simultaneously on the land of thousands of households, which manifests as the overall outward shift of the production frontier. At the same time, the development of the service market itself induces the research and development of green technologies and equipment updates, further strengthening the outward shift of the frontier.

In terms of the channel for improving technical efficiency, theoretically, service outsourcing can narrow the efficiency gap among farmers through contiguous land operations, factor reallocation, and management experience spillovers, driving actual production towards convergence with the frontier. However, it is important to note that the effectiveness of this efficiency improvement channel is highly conditional: it relies on the degree of contiguous land, the level of service organization, and the degree of farmer organization. Currently, socialized services in China are still dominated by outsourcing of single-link operations, with limited full-process management, and the deep impact of services on resource allocation efficiency has not been fully unleashed. Additionally, during the sample period, technical efficiency across provinces tends to converge, and the space for catch-up narrows, making it difficult to identify the efficiency channel at the macro level. Based on this, it is proposed that:

Hypothesis H2: Agricultural socialized services primarily enhance agricultural green total factor productivity through technological progress channels, while the role of technical efficiency improvement channels is relatively limited.

4. Research Design

4.1. Model Specification

To test hypothesis H1, the following two-way fixed effects benchmark model is constructed:

$$gtfp_{it} = \alpha_0 + \alpha_1 \ln x_{it} + \gamma \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where i and t represent the province and year, respectively; $gtfp$ is the agricultural green total factor productivity index; $\ln x$ is the level of agricultural socialized services (logarithm); Controls is the set of control variables, including resident income ($\ln \text{income}$), proportion of primary industry (gdp1), disaster severity (disaster), annual average temperature (temp), and daily average precipitation (rain); μ_i and λ_t are the fixed effects of province and year, respectively; ε_{it} is the random disturbance term. The coefficient α_0 characterizes the average effect of agricultural socialized services on AGTFP. If α_1 is significantly positive, then H1 is supported. All regressions are clustered at the provincial level with robust standard errors.

To test hypothesis H2, based on the GML index multiplication decomposition identity $gtfp = tc \times ec$, the dependent variable is replaced with the cumulative technological progress index (tc) and the technical efficiency change index (ec), respectively, to construct a channel testing model:

$$tc_{it} = \beta_0 + \beta_1 \ln x_{it} + \gamma \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$$ec_{it} = \delta_0 + \delta_1 \ln x_{it} + \gamma \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

If β_1 is significantly positive while δ_1 is not, it indicates that socialized services mainly enhance AGTFP by promoting technological progress, supporting H2. Models (2) and (3) share the same fixed effect structure and control variable set as Model (1), ensuring strict comparability between channel tests and benchmark results.

4.2. Variable Description

4.2.1. Dependent Variable: Agricultural Green Total Factor Productivity (GTFP).

It is measured using the SBM-GML model that considers non-desired outputs, and incorporates non-desired outputs into the productivity analysis framework [10]. Input indicators include seven categories: land (total sown area of crops), labor (primary industry employees converted based on the proportion of agricultural output value), machinery (total power of agricultural machinery), fertilizer (net amount of agricultural fertilizer applied), pesticide, agricultural film (amount of agricultural plastic film used), and irrigation (effective irrigation area); the desired output is the total agricultural output value; the non-desired output is agricultural carbon emissions, converted based on carbon sources such as fertilizer, pesticide, and agricultural film. Taking 2010 as the base period ($=1$), the global Malmquist-Luenberger (ML) index is multiplied year by year to obtain GTFP, and its decomposition terms are simultaneously multiplied to obtain the technical progress index tc and the technical efficiency change index ec . The measurement results satisfy the identity $GTFP = tc \times ec$ (which has passed self-checking).

4.2.2. Core Explanatory Variable: Level of Agricultural Socialized Services ($\ln x$).

It is measured by the output value of agricultural professional and auxiliary activities per unit sown area: the output value of agricultural professional and auxiliary activities is calculated from "total output value of agriculture, forestry, animal husbandry, and fishery - total output value of agriculture - forestry - animal husbandry - fishery", and the agricultural part is converted based on the proportion of agricultural output value, then divided by the total sown

area of crops and taken as the natural logarithm. This indicator depicts the intensity of professional service supply available on unit land, and the caliber is consistent with existing provincial-level research.

4.2.3. Control Variables.

① Resident income (lnincome): Taking the logarithm of per capita disposable income to control demand structure and labor opportunity cost; ② Primary industry share (gdp1): The proportion of added value of the primary industry in GDP (%) to control industrial structure; ③ Disaster severity (disaster): The proportion of disaster-affected area to the total sown area of crops (%) to control the impact of natural disasters; ④ Annual average temperature (temp, °C) and ⑤ Daily average precipitation (rain, mm): To control the direct impact of climatic conditions on agricultural production.

4.3. Data Source and Processing

The research sample consists of panel data from 31 provinces in China (excluding Hong Kong, Macao, and Taiwan) spanning from 2010 to 2024. The original data is sourced from the China Statistical Yearbook, China Rural Statistical Yearbook, China Rural Management and Operation Statistical Yearbook, the National Bureau of Statistics' National Data Platform, EPS Data Platform, and statistical yearbooks of various provinces. Climate data is obtained from the National Meteorological Science Data Center. Two points need to be clarified: Firstly, the official data on pesticide and agricultural film usage only extends to 2021, hence the AGTFP calculation and regression samples are limited to 2021; 2010 serves as the GML cumulative base period (gtfp=1) and is not included in the regression. Secondly, missing values for individual provinces in certain years (such as primary industry employees in Liaoning in 2019 and in Heilongjiang from 2011 to 2013) are imputed using linear interpolation within the province; continuous variables are subjected to bilateral winsorization at the 1% level to mitigate the impact of extreme values.

4.4. Descriptive Statistics

To present the distribution characteristics of the main variables and the basic information of the sample data, this article conducts descriptive statistics on the core variables and control variables. The results are shown in Table 1.

Table 1. Descriptive statistics of main variables

variable	meaning	sample size	mean	standard deviation	minimum	median	maximum
gtfp	Agricultural green total factor productivity	341	1.172	0.187	0.900	1.100	1.729
tc	Technological progress index (GML decomposition)	341	0.971	0.079	0.772	1.000	1.140
ec	Technical efficiency change index (GML decomposition)	341	1.212	0.190	0.920	1.164	1.708
lnx	Level of agricultural socialized services (logarithmic scale)	403	-1.874	0.747	-4.106	-1.786	-0.050
lnincome	Residents' income (logarithmic)	434	10.436	0.358	9.615	10.452	11.339
gdp1	Proportion of primary industry (%)	434	9.523	5.047	0.200	9.100	24.000
disaster	Disaster severity (%)	370	13.720	11.033	0.415	10.876	51.424
temp	Annual average temperature (°C)	434	12.359	6.564	-2.650	14.210	25.120
rain	Daily average precipitation (mm)	434	2.513	1.354	0.290	2.310	5.570

Table 1 shows that the mean value of AGTFP during the sample period is 1.172, indicating that the cumulative improvement in national agricultural GTFP from 2011 to 2021 is approximately 17.2%, and agricultural production generally exhibits a trend of green intensification. Among the decomposition items, the mean value of technical efficiency change (1.212) is higher than that of technological progress (0.971), while the dispersion of technological progress is relatively small, suggesting that examining the differential impact of driving factors on the two decomposition indicators is of practical relevance. The maximum value of gtfp is 1.729 and the minimum value is 0.900, with significant inter-provincial differences, providing the necessary variability basis for hypothesis testing. Furthermore, the mean value of the variance inflation factor (VIF) for the main explanatory variables is 3.41, which is far below the critical value of 10, indicating no severe multicollinearity issue.

5. Empirical Analysis

The empirical analysis revolves around two hypotheses: firstly, a model specification test is reported to confirm the rationality of the two-way fixed effects specification; subsequently, a benchmark regression is conducted to test hypothesis H1; then, based on GTFP decomposition, hypothesis H2 is tested; further robustness tests are conducted from three aspects: lagged explanatory variables, exclusion of municipalities, and winsorization standards, and instrumental variable estimation is used to deal with endogeneity; finally, a heterogeneity analysis is reported to characterize the regional structure of the promotion effect.

5.1. Model Setting Verification

Before conducting hypothesis testing, we first report the statistical evidence for model selection. The F-test statistic for individual fixed effects is 14.89 ($p < 0.01$), significantly rejecting the null hypothesis of "no individual effect," indicating that pooled OLS is not applicable. The Hausman test statistic is 18.78 ($p < 0.01$), rejecting the null hypothesis of consistent random effect estimators, suggesting that fixed effects are superior to random effects. Therefore, this paper adopts a two-way fixed effects model with province and year as the fixed factors for estimation, and uses cluster robust standard errors at the provincial level for statistical inference.

5.2. Hypothesis H1 Test: Benchmark Regression of Agricultural Socialized Services on AGTFP

To examine the impact of agricultural socialized services on agricultural green total factor productivity, this paper gradually incorporates control variables for benchmark regression. The estimation results are presented in Table 2.

Table 2. Benchmark regression results

variable	(1)gtfp	(2)gtfp
lnx	0.0636**(0.0236)	0.0720*** (0.0227)
lnincome		-0.0590(0.2247)
gdp1		0.0139**(0.0067)
disaster		-0.0002(0.0008)
temp		-0.0121(0.0239)
rain		-0.0284*(0.0145)
constant term	1.2965*** (0.0461)	2.0090(2.4107)
Province/year fixed effects	Control	Control
sample size	341	339
Adjusted R ²	0.830	0.835

Note: The robust standard errors at the provincial level are provided in parentheses; *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. the same below

Table 2 reports the test results for hypothesis H1. In column (1), only two-way fixed effects are controlled, and the coefficient of $\ln x$ is 0.0636, which is significantly positive at the 5% level. In column (2), after adding control variables, the coefficient rises to 0.0720 and is significant at the 1% level. This indicates that agricultural socialized services significantly promote the improvement of agricultural green total factor productivity, and hypothesis H1 is verified. From an economic perspective, every increase of one logarithmic unit in the level of socialized services leads to an increase of 0.0720 in the AGTFP index, which is approximately 6.1% of its sample mean, indicating a considerable economic magnitude of the effect. Among the control variables, the coefficient of the proportion of the primary industry is significantly positive, reflecting that regions with a better agricultural industrial foundation have a higher level of green development; the coefficient of daily average precipitation is significantly negative, which may be related to an increase in agricultural non-point source pollution output in wet years.

5.3. Hypothesis H2 Test: Channel of Technological Progress and Channel of Technical Efficiency Improvement

To identify the specific channels through which agricultural socialized services affect agricultural green total factor productivity, this paper conducts regression analysis using the technological progress index and the technical efficiency change index as the dependent variables, respectively. The results are presented in Table 3.

Table 3. Channel Inspection Results

variable	(1)tc	(2)tc	(3)ec	(4)ec
$\ln x$	0.0306*(0.0164)	0.0330**(0.0152)	0.0185(0.0176)	0.0222(0.0178)
control variable	Uncontrolled	Control	Uncontrolled	Control
Province/year fixed effect	Control	Control	Control	Control
sample size	341	339	341	339
Adjusted R ²	0.656	0.664	0.865	0.866

Table 3 reports the test results for Hypothesis H2. Columns (1) and (2) show that regardless of whether control variables are included, the impact of $\ln x$ on the technological progress index tc is significantly positive. After adding control variables, the coefficient is 0.0330, which is significant at the 5% level. This indicates that agricultural socialized services have significantly promoted agricultural technological progress: service organizations have accelerated the diffusion of advanced and applicable technologies at the smallholder level through the materialization and integration of improved seed supply, advanced agricultural machinery operations, unified pest management, and green production technologies, pushing the production frontier, including non-desired outputs, outward. Columns (3) and (4) show that the coefficient of $\ln x$ on the technical efficiency change index ec is positive but fails to pass the significance test, indicating that the role of the efficiency improvement channel is not yet evident. Hypothesis H2 is verified: the promoting effect of agricultural socialized services on AGTFP is mainly achieved through the technological progress channel.

Regarding the insignificance of the efficiency channel, it is necessary to discuss the completion of the "last mile". There may be two possible reasons: Firstly, current socialized services are still mainly focused on outsourcing of single-stage operations such as cultivation and harvesting, with limited full-process management. The deep impact of services on the efficiency of contiguous land consolidation and resource allocation has not been fully unleashed, and the "organizational support" required for efficiency improvement is not yet mature. Secondly, Table 1 shows that the average change in technical efficiency across provinces during the sample period is 1.212 and tends to be high. Most provinces are close to their respective

production frontiers, with limited room for catch-up, making it difficult to identify the efficiency channel at the provincial macro level. The policy implication of this structural characteristic is that the green dividends of socialized services currently mainly come from "technology integration". In the future, we should open up the efficiency improvement channel through full-process management and service-driven large-scale operations.

5.4. Robustness Test

To verify the reliability of the conclusion of hypothesis H1, this paper conducts robustness tests from three aspects. Firstly, the core explanatory variable is lagged by one period. Considering the potential time lag in the impact of socialized services on AGTFP and to mitigate reverse causality, we re-estimate model (1) using $L.lnx$. Secondly, we exclude samples from municipalities directly under the central government. Beijing, Tianjin, Shanghai, and Chongqing have special agricultural volumes and industrial structures, so they are excluded. Thirdly, we change the winsorization standard. The benchmark regression uses 1% bilateral winsorization, but here we use 5% bilateral winsorization.

To examine whether the benchmark regression conclusions are affected by the lag of explanatory variables, sample range, and winsorization, this paper further conducts robustness tests. The results are presented in Table 4.

Table 4. Robustness test results

variable	(1) lagged by one period	(2) Excluding municipalities directly under the central government	(3) 5% winsorization
$L.lnx$	0.0642** (0.0247)		
lnx		0.0962*** (0.0251)	0.0647*** (0.0216)
control variable	Control	Control	Control
Province/year fixed effect	Control	Control	Control
sample size	339	297	339
Adjusted R^2	0.833	0.860	0.840

Table 4 shows that the coefficients of the core explanatory variables under the three settings are 0.0642, 0.0962, and 0.0647, respectively, all of which are significantly positive at the 5% level and consistent with the benchmark regression conclusion. The test result for hypothesis H1 is robust.

5.5. Endogeneity Handling

Despite the alleviation of omitted factor bias that does not change over time through two-way fixed effects, there may still be reverse causality and measurement error between socialized services and AGTFP. This paper employs the instrumental variable two-stage least squares method (IV-2SLS) for handling: one of the instrumental variables is the lagged term of the core explanatory variable ($L.lnx$), which is highly correlated with the current period and does not directly affect the current AGTFP; the other is the average value of socialized services in neighboring provinces (calculated based on geographical adjacency), where the service markets of neighboring provinces mutually drive and ensure correlation, while the service supply of neighboring provinces does not directly determine the AGTFP of the province, satisfying the requirement of exogeneity.

To mitigate potential endogenous issues such as reverse causality and omitted variables, this paper employs the instrumental variable method for two-stage least squares estimation. The results are presented in Table 5.

Table 5. Endogeneity Test: IV-2SLS Estimation Results

variable	Single instrumental variable
lnx	0.3122*** (0.1054)
control variable	control
sample size	339
KP-LM unrecognizable test	8.555
KP-F weak instrumental test	5.445
HansenJ over-identification test	—

Note: Using L.lnx as the instrumental variable, it is identified correctly, and there is no Hansen J statistic.

Table 5 shows that the coefficient of $\ln x$ in column (1) is 0.3122, which is significantly positive at the 1% level. In terms of diagnostic tests, the KP-LM statistic is significant at the 5% level, rejecting the null hypothesis of unidentifiable instrumental variables. It should be noted that the KP-F statistic is 5.445, which is below the empirical threshold of 10, indicating a certain risk of weak instrumental variables. The coefficients estimated by IV should be interpreted with caution. Combining the evidence from the one-period lag regression and instrumental variable estimation, the conclusion that agricultural socialized services promote the improvement of AGTFP remains valid after considering endogeneity.

5.6. Heterogeneity Analysis

The benchmark results reflect the national average effect. Taking into account the differences in agricultural resource endowments and food production function positioning among regions, this paper examines the heterogeneity of promotion effects from two dimensions.

Taking into account the disparities in agricultural resource endowments and grain production functions across different regions, this paper further conducts a heterogeneity analysis from two dimensions: major grain-producing areas versus non-major grain-producing areas, and the eastern, central, and western regions. The results are presented in Table 6.

Table 6. Heterogeneity Analysis Results

variable	(1) Major grain-producing areas	(2) non-main producing areas	(3) east	(4) central	(5) west
lnx	0.1265*** (0.0386)	0.0584 (0.0365)	0.0022 (0.0404)	0.1517*** (0.0374)	0.0865** (0.0389)
control variable	Control	Control	Control	Control	Control
Province/year fixed effect	Control	Control	Control	Control	Control
sample size	143	196	119	88	132
Adjusted R ²	0.912	0.816	0.791	0.903	0.878

Columns (1) and (2) of Table 6 show that the coefficient of $\ln x$ in major grain-producing areas is 0.1265, which is significant at the 1% level, while the coefficient in non-major producing areas is 0.0584 and not significant. The promoting effect is mainly reflected in major producing areas: these areas have large-scale agricultural production and concentrated service demand, making it easier for socialized services to form economies of scale and promote the implementation of green technologies. Columns (3) to (5) show that the promoting effect is evident in the central (0.1517, significant at the 1% level) and western (0.0865, significant at the 5% level) regions, while the coefficient in the eastern region is close to zero and not significant. The eastern region has a low proportion of agriculture and high capital and technology intensity of business entities, resulting in limited marginal contributions from socialized services; the central and western regions have an important agricultural status and

a high proportion of small farmers, which makes them more dependent on socialized services, thus highlighting the green efficiency-enhancing effect. The heterogeneous evidence and hypotheses H1 and H2 mutually confirm: the regions with the strongest promoting effect are precisely those with the most concentrated service demand and the largest space for technology integration.

6. Conclusion

This paper focuses on the question of "whether and how agricultural socialized services can enhance agricultural green total factor productivity (AGTFP)", utilizing panel data from 31 provinces in China spanning from 2011 to 2021. The SBM-GML model is employed to measure AGTFP, and a two-way fixed effects model is used to test two hypotheses. Based on the decomposition of GTFP index, the channels of action are identified. The empirical content encompasses model specification testing, benchmark regression, channel testing, robustness testing, endogeneity treatment, and heterogeneity analysis. The methodological characteristic lies in establishing mechanism identification on the strict identity equation of $gtfp = tc \times ec$, thereby avoiding the proxy distortion of macro-level mediating variables.

The research conclusions are summarized as follows based on the hypothesis testing results. Firstly, agricultural socialized services significantly enhance agricultural green total factor productivity: the benchmark regression coefficient is 0.0720, which is significant at the 1% level, and this conclusion remains valid after lagging explanatory variables, excluding municipalities, changing the winsorization standard, and estimating with instrumental variables. Secondly, the green productivity effect of socialized services is mainly achieved through the channel of technological progress: its impact on the cumulative technological progress index is significantly positive (0.0330), while its impact on the technical efficiency change index is not significant, exhibiting a phased characteristic of "technological progress leading and efficiency improvement lagging". Thirdly, the promotion effect exhibits significant regional heterogeneity: it is significant in major grain-producing areas and central and western regions, but not significant in non-major grain-producing areas and eastern regions.

The above conclusions provide a definitive answer to the practical issues raised in the introduction and imply the following policy implications. Firstly, since the green dividends of socialized services have emerged, socialized services should continue to be regarded as an important policy carrier for agricultural green transformation. The requirements for green production should be embedded into service subsidies and operational standards to stabilize and enhance the green efficiency-enhancing function of services. Secondly, since the dividends mainly come from technological progress, policies should guide service organizations to upgrade from outsourcing of single-link operations to integrated green technology services. This will strengthen the materialization and integration capabilities of technologies such as improved varieties, green inputs, and conservation tillage, consolidating the driving force for frontier outward movement. Thirdly, given the fact that the efficiency improvement channel has not yet been opened, we should accelerate the development of full-process management and service-driven large-scale operations. This will drive the organization of land and factors through the organization of services, releasing the potential for efficiency improvement. Fourthly, considering that the promotion effect is concentrated in major grain-producing areas and central and western regions, service supply resources and pilot policies should be tilted towards these regions. Meanwhile, service forms suitable for high capital density operations should be explored in the eastern region.

This article also has limitations. Firstly, due to the limitations of official data on pesticides and agricultural films, the sample ends in 2021, and the provincial deflator for the total agricultural output value has not been obtained yet, leaving room for improvement in measurement

accuracy. Secondly, the strength of instrumental variables is limited, and causal identification can still be strengthened with the help of richer exogenous shocks. Thirdly, although the index decomposition path can clearly identify channels, it cannot specify the contribution of specific service links. In the future, it is possible to further open up the "channel of technological progress" by combining data on service links or micro-survey data. These limitations constitute the direction for future research.

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