How Agricultural Socialized Services Affect Grain Ecological Efficiency: Evidence from 71 Prefecture-Level Cities in the Yellow River Basin (Postprint)

Authors: Zhong Jiawei, Zheng Jun, Zhang Mingyue

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Abstract

Developing agricultural socialized services constitutes an important component of agricultural modernization construction. Under the "dual security" framework for grain and ecology, investigating its contribution to grain ecological efficiency holds significant importance for achieving sustainable agricultural development. This study employs panel data from 71 prefecture-level cities in the Yellow River Basin spanning 2011–2020, focusing on the spatial spillover and nonlinear effects of agricultural socialized services on grain ecological efficiency. The results indicate: (1) During the study period, grain ecological efficiency in urban agglomerations of the Yellow River Basin exhibited a marked improving trend; spatially, it displayed an unbalanced and interwoven distribution pattern. Regions with excellent or higher efficiency grades were primarily distributed in the downstream and midstream areas of the Yellow River Basin, whereas regions with medium and low efficiency were predominantly located in the upstream area. (2) Agricultural socialized services exert a significant positive spatial spillover effect on grain ecological efficiency, meaning they can not only significantly enhance local grain ecological efficiency but also radiate to and drive neighboring regions; this result remains robust after a series of robustness checks. (3) The impact of agricultural socialized services on grain ecological efficiency exhibits complex dual threshold effects and an appropriate range for per capita planting scale development. Specifically, as per capita planting scale expands, the positive impact of agricultural socialized services on grain ecological efficiency demonstrates a nonlinear decreasing trend.

Full Text

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How Does Agricultural Socialized Service Affect Grain Eco-Efficiency: A Case Study of 71 Prefure-Level Cities in the Yellow River Basin

ZHONG Jiawei, ZHENG Jun, ZHANG Mingyue
(School of Economics and Management, Shandong Agricultural University, Tai' an 271018, Shandong, China)

Abstract: The development of agricultural socialized services constitutes a critical component of agricultural modernization. Under the "dual-security" framework encompassing both grain production and ecological protection, investigating the contribution of these services to grain eco-efficiency holds significant importance for achieving sustainable agricultural development. This study employs panel data from 71 prefecture-level cities in the Yellow River Basin spanning 2011-2020 to examine the spatial spillover and nonlinear effects of agricultural socialized services on grain eco-efficiency. The findings reveal that: (1) During the study period, grain eco-efficiency in urban agglomerations within the Yellow River Basin demonstrated a marked improvement trend. Spatially, an uneven and interlaced distribution pattern emerged, with cities achieving excellent efficiency ratings or higher predominantly located in the downstream and midstream regions of the basin. In contrast, areas with moderate and low efficiency were primarily concentrated in the upstream region. (2) Agricultural socialized services exert a significant positive spatial spillover effect on grain eco-efficiency, meaning they not only substantially improve local grain eco-efficiency but also radiate outward to benefit neighboring areas. This result remains robust across a series of sensitivity tests. (3) The impact of agricultural socialized services on grain eco-efficiency exhibits a complex dual-threshold effect tied to the development of per capita planting scale. Specifically, as per capita planting scale expands, the positive influence of agricultural socialized services on grain eco-efficiency demonstrates a nonlinear diminishing trend.

Keywords: agricultural socialization service; grain ecological efficiency; spatial Durbin model; threshold effect model; Yellow River Basin

The Yellow River Basin serves as a crucial ecological security barrier in China [**?**]. Since the 18th National Congress of the Communist Party of China, the central government has attached great importance to ecological protection and high-quality development in the Yellow River Basin. In 2023, President Xi Jinping convened another symposium on ecological protection and high-quality development in the Yellow River Basin, emphasizing the need to further advance ecological protection in the region. As a core grain production area in China, the Yellow River Basin bears significant responsibility for food production. However, its most pressing challenge lies in ecological fragility. A long-standing dilemma confronting the basin' s development involves ensuring grain production stability while simultaneously promoting ecological conservation and restoration. Agricultural socialized services, as a key lever for modern agriculture, have gradually demonstrated their role in advancing agricultural modernization and enhancing production and resource utilization efficiency in recent years. Consequently, the central government has successively issued policy documents such as the "Guiding Opinions on Accelerating the Development of Agricultural Socialized Services" and the "Notice on Launching Pilot Programs for Agricultural Socialized Service Innovation," aiming to leverage this new driver to promote sustainable agricultural development. Can agricultural socialized services genuinely enhance grain eco-efficiency? If so, how strong is this effect? Do spatial spillover effects or nonlinear relationships exist? Delving into these questions holds great significance for optimizing the agricultural socialized service system, maximizing its service effectiveness, and providing reliable decision-making foundations for ecological protection in the Yellow River Basin.

Current academic research has extensively explored grain eco-efficiency, focusing primarily on three aspects: conceptual definition, spatio-temporal evolution, and driving factors. Conceptually, grain eco-efficiency accounts for both desired outputs (grain production) and undesired outputs (environmental impacts) [?, ?], incorporating environmental dimensions absent from traditional productivity measures. This approach more accurately reflects production efficiency, representing a comprehensive expression of optimal grain output with minimal ecological burden. Regarding spatio-temporal patterns, Lu [?] employed an improved SBM model to reveal considerable fluctuations in China' s grain planting eco-efficiency averages, while Kuang [?] found a fluctuating upward trend overall. At the regional level, Lu [?] measured grain eco-efficiency across three major regions, observing a decreasing pattern from western to central to eastern China. Concerning driving factors, some scholars have examined internal household characteristics, identifying aging [?], benefit cognition [?], and education level [?] as internal factors influencing grain eco-efficiency. Others have investigated external factors, finding that environmental regulation [?], agricultural insurance [?], and new urbanization [?] significantly impact grain eco-efficiency.

Although direct research on the relationship between agricultural socialized services and grain eco-efficiency remains limited, promising studies have examined their environmental impacts. For instance, Zhang [?] empirically demonstrated that participation in socialized services significantly reduces farmers' chemical fertilizer application. Zhan [?] found that agricultural socialized services both directly promote chemical fertilizer reduction and decrease usage through crop structure optimization. However, some scholars argue that these services may increase chemical input usage. Chang [?] noted that outsourcing production links fails to address excessive agricultural chemical inputs and may even intensify their use. Xie [?] concluded that when ordinary farmers serve as service providers, fertilizer reduction effects are not achieved.

Overall, academic consensus on whether agricultural socialized services can improve grain eco-efficiency remains elusive. This divergence likely stems from previous studies focusing solely on linear relationships while neglecting nonlinear investigations of potential inflection points. Therefore, compared with existing literature, this study makes two marginal contributions. First, it employs spatial econometric models to explore spatial correlations among urban agglomerations in the Yellow River Basin, empirically analyzing both direct effects and spillover effects of agricultural socialized services on grain eco-efficiency, thereby providing a more comprehensive understanding of their impact. Second, it utilizes a threshold effect model to examine the threshold role of per capita planting scale under China' s "large country with small farmers" context, precisely identifying current development conditions in the Yellow River Basin.

1 Conceptual Framework and Mechanism Analysis

1.1 Direct Effects of Agricultural Socialized Services on Grain Eco-Efficiency

China' s agricultural labor force aging and outflow will persist long-term [?]. Smallholders face dilemmas of high production costs [?] and low labor productivity [?], forcing reliance on chemical fertilizers and pesticides to maintain output. Agricultural socialized services bridge this gap through three primary mechanisms:

1) **Alleviating capital constraints.** Agricultural socialized services generate economies of scale in grain production, reducing individual farmers' information search and transaction costs while solving the "unprofitability" dilemma of grain ecological protection. On one hand, eco-friendly fertilizers and pesticides are expensive, and farmers lack technical knowledge [?], resulting in low adoption rates of green production practices. Agricultural socialized service organizations employ professional teams, procure inputs centrally, and possess strong market bargaining power [?], thereby reducing transaction costs. On the other hand, precision farming technologies like navigation and sensor systems in machinery operations enable efficient field management, reducing excessive pesticide and fertilizer use. However, agricultural machinery exhibits strong asset specificity, making it unaffordable for smallholders to purchase all necessary equipment, especially large machinery costing tens of thousands of yuan. Agricultural socialized services address this capital shortage through machinery rental services, mitigating environmental problems arising from financial constraints.

2) **Alleviating household labor constraints.** Agricultural socialized services leverage specialization effects to solve the "labor shortage during busy seasons" dilemma, breaking traditional smallholders' "incapability" limitations in grain ecological protection. High opportunity costs in grain production [?] drive many young farmers toward non-agricultural sectors, creating labor shortages and low workforce quality. Agricultural socialized services act as "supplementary labor," replacing traditional, inefficient smallholders with high-quality, skilled workers who implement scientific management practices like quantitative input application and precision fertilization, significantly improving the grain production environment. They also provide "full nanny-style" comprehensive 托管, "menu-style" multi-

link 托管, and "à la carte-style" single-link 托管 services, achieving precise supply-demand matching and ensuring ecological grain production.

3) **Alleviating technological constraints.** Agricultural socialized services generate technological progress effects, mitigating environmental pressure from empirical fertilization practices and providing practical solutions to the "poor performance" problem in grain ecological protection. These services master advanced grain production technologies, employing eco-friendly techniques during production to effectively alleviate carbon emission issues. Relying on professional technical personnel [?], they tend to adopt green production technologies and scientifically manage production links, substantially improving grain production environmental quality and demonstrating strong ecological consciousness.

Hypothesis 1: Agricultural socialized services can promote grain eco-efficiency improvement.

1.2 Spatial Spillover Effects of Agricultural Socialized Services on Grain Eco-Efficiency

Agricultural socialized service activities exhibit certain external spatial effects [?]. First, **demonstration effects** enable farmers to acquire green production technologies and advanced management concepts through these services, which then diffuse through social networks [?]. Neighboring farmer groups adopt advanced production technologies through intentional or competitive imitation, improving the precision of chemical fertilizer and pesticide application and achieving cost-effective grain ecological protection. Second, **resource integration effects** arise from service models including machinery operations, information transmission, and market development, which optimize resource reorganization and transformation while breaking administrative spatial restrictions and strengthening inter-regional linkages and collaboration. Third, **peer effects** mean that a region' s grain eco-efficiency often serves as a reference for neighboring areas to adjust their own performance [?], triggering emulation effects that motivate local authorities to prioritize grain eco-efficiency improvement, continuously learn, and promptly adjust ecological protection measures, thereby achieving win-win outcomes in production and ecology for both local and adjacent regions.

Hypothesis 2: The impact of agricultural socialized services on grain eco-efficiency exhibits positive spatial spillover effects.

1.3 Threshold Role of Per Capita Planting Scale in the Relationship Between Agricultural Socialized Services and Grain Eco-Efficiency

Land transfer and scaling represent major trends in modern agricultural development. However, the "large country with small farmers" situation persists. As scale expands, does the impact of agricultural socialized services on grain eco-efficiency change? This study argues that during the small-scale planting stage, high operational flexibility makes traditional smallholders more receptive to innovations [?], facilitating smooth implementation of agricultural socialized services and promoting advanced production technologies, thereby reducing undesired outputs in grain production. However, as per capita planting scale expands, several challenges emerge. First, grain production involves multiple decisions and technology implementations throughout long production cycles, but scale expansion increases coordination and supervision difficulties when agricultural socialized services intervene across multiple points and time periods. Second, under large-scale planting, farmers' enthusiasm and participation levels relatively decline, resulting in insufficient cooperation with technical and management recommendations from service providers. These overlapping factors create greater difficulties for agricultural socialized services to improve grain eco-efficiency as per capita planting scale expands.

Hypothesis 3: The impact of agricultural socialized services on grain eco-efficiency exhibits a nonlinear relationship.

2 Data and Methods

2.1 Study Area

The "Yellow River Basin Ecological Protection and High-Quality Development Plan Outline" issued in 2021 delineates the Yellow River Basin as the area covering Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong provinces where the Yellow River and its tributaries flow. Due to missing data in some prefecture-level cities, 71 cities (prefecture-level cities, prefectures, and leagues) within the basin were ultimately selected as the study area to ensure result validity [Figure 1: see original paper].

2.2 Methodology

2.2.1 SBM Super-Efficiency Model Grain eco-efficiency reflects the coordination between positive grain outputs and negative environmental outputs during production, encompassing undesired outputs such as carbon emissions. This study adopts the non-radial, non-oriented SBM super-efficiency model proposed by Tone [?] to measure grain eco-efficiency. Specific calculation procedures are detailed in the literature [?].

2.2.2 Spatial Econometric Model Moran' s I Test. To examine spatial correlation in grain eco-efficiency, this study employs the global Moran' s I index for empirical analysis. The I statistic ranges between [-1, 1], with larger absolute values indicating stronger spatial correlation. The functional expression is provided in reference [?].

Spatial Durbin Model. The model is specified as:

$$Eco_{it} = \rho \sum_{j=1}^{N} W_{ij} Eco_{jt} + \beta X_{it} + \theta \sum_{j=1}^{N} W_{ij} X_{jt} + \lambda_i + v_t + \varepsilon_{it}$$

where Eco_{it} represents grain eco-efficiency of city i in year t; i and t denote region and year respectively; ρ and ϕ are spatial lag parameters; W_{ij} is the spatial weight matrix; β is the regression coefficient; X_{it} includes the core explanatory variable and other control variables; λ_i represents region fixed effects; v_t denotes time fixed effects; ε_{it} is the random error term vector; and α is the constant term.

2.2.3 Threshold Effect Model Based on Hansen' s [?] methodology, this study constructs the following panel threshold model with grain eco-efficiency as the dependent variable, agricultural socialized services as the explanatory variable, and per capita planting scale as the threshold variable:

$$Eco_{it} = \alpha + \beta_1 Serv_{it} \cdot I(u_{it} \leq \gamma_1) + \beta_2 Serv_{it} \cdot I(\gamma_1 < u_{it} \leq \gamma_2) + \beta_3 Serv_{it} \cdot I(u_{it} > \gamma_2) + \delta Z_{it} + \lambda_i + v_t + \omega_{it}$$

where α is the constant term; β represents regression coefficients; $Serv_{it}$ denotes the level of agricultural socialized services in city i during year t; u_{it} is the threshold variable; γ represents unknown threshold values; $I(\cdot)$ is the indicator function; δ denotes control variable coefficients; Z_{it} is the set of control variables; and ω_{it} is the random error term.

2.3 Variables and Data

2.3.1 Grain Eco-Efficiency Indicator System Since macro-level statistical yearbooks only report aggregated data for agriculture, forestry, animal husbandry, and fishery (the "broad agriculture" sector), this study adopts the weight coefficient method from Li [?] to disaggregate grain-related data for measurement authenticity. The indicator system encompasses three dimensions: inputs, desired outputs, and undesired outputs .

Input indicators include land, labor, irrigation, and agricultural materials [?]. Specifically, given the Yellow River Basin' s diverse topography and severe soil erosion [?], land input indicators directly reflect grain production' s dependence on limited land resources. Considering the basin' s water shortage [?], irrigation input indicators measure the degree of water conservancy development and production stability. Due to poor farmland quality and strong labor dependence in grain production [?], labor indicators more accurately reflect regional labor use efficiency. Excessive agricultural material inputs can aggravate ecological burdens [?], making agricultural material input indicators essential for revealing adaptability in mechanization and chemical fertilizer use.

Desired output is measured by grain output, effectively reflecting direct economic contributions as the basin represents a core national grain production area [?].

Undesired output is measured by carbon emissions. Grain production generates substantial carbon emissions, representing a major agricultural pollution source [?]. In the Yellow River Basin' s sensitive and fragile ecological environment, carbon emissions directly affect regional ecosystem carbon balance.

Indicators of Food Eco-Efficiency | Category | Indicator | Unit | Calculation Method | |——-|——-|—|————-| | Input | Land input | 10^3 ha | Grain sown area | | | Labor input | 10^3 persons | Agricultural employees × (Grain sown area / Total crop sown area) × (Agricultural output / Total output) | | | Irrigation input | 10^3 ha | Effective irrigated area × (Grain sown area / Total crop sown area) | | | Agricultural material input | 10 kW | Agricultural machinery power × (Grain sown area / Total crop sown area) | | | | 10^3 t | Chemical fertilizer use × (Grain sown area / Total crop sown area) | | Desired output | Economic output | 10 t | Grain output | | Undesired output | Carbon emission | 10 t | Agricultural carbon emissions calculated using emission coefficients × (Grain sown area / Total crop sown area) |

2.3.2 Variable Selection **Dependent variable:** Grain eco-efficiency (Eco) is calculated using the SBM super-efficiency model based on the above indicator system.

Explanatory variable: Agricultural socialized services ($Serv$) are measured by the ratio of output value from agriculture, forestry, animal husbandry, and fishery services to total output value of agriculture, forestry, animal husbandry, and fishery [?, ?, ?]. A higher ratio indicates faster development of agricultural socialized services.

Threshold variable and control variables: Per capita planting scale ($Scale$) serves as the threshold variable, calculated as the ratio of grain sown area to grain production employees. Additionally, referencing previous studies [?, ?], urbanization level ($Urban$), mechanization rate ($Mech$), and fiscal support for agriculture ($Fiscal$) significantly influence grain eco-efficiency and are thus included as control variables. Urbanization level is measured by the proportion of urban population to total population. Mechanization rate is measured by agricultural machinery power input per unit of crop sown area. Fiscal support for agriculture is measured by the proportion of agriculture, forestry, and water affairs expenditure to total fiscal expenditure.

2.3.3 Data Sources Data primarily derive from the *China City Statistical Yearbook*, *China Statistical Yearbook*, and provincial/prefecture-level statistical yearbooks and bulletins (2011-2020). Missing and anomalous data are supplemented using Matlab linear interpolation.

3 Results and Analysis

3.1 Grain Eco-Efficiency Measurement Results

To visually reflect spatial distribution characteristics and evolution of grain eco-efficiency in Yellow River Basin urban agglomerations, the study employs equal-interval classification based on SBM super-efficiency values, referencing Gao [**?**] and Yan [**?**]. The dataset is divided into four categories: low efficiency (0.0, 0.4], moderate efficiency (0.4, 0.8], good efficiency (0.8, 1.2], and optimal efficiency (>1.2), visualized using ArcGIS 10.8 [Figure 2: see original paper].

Results show that grain eco-efficiency in the basin exhibited an improving trend during 2011–2020. Specifically, the number of cities in the good efficiency category increased rapidly from 15 to 34, while low-efficiency cities decreased from 31 to 11. Spatially, an uneven and interlaced distribution pattern emerged, with good and optimal efficiency cities primarily concentrated in downstream and midstream regions. These areas possess superior resource endowments and infrastructure, creating ideal grain production conditions. Conversely, moderate- and low-efficiency areas were interspersed throughout the upstream region, where high-altitude cold zones, poor natural endowments, and inadequate irrigation and mechanization systems limit efficiency improvements.

[Figure 2: see original paper] Evolution of the spatial pattern of grain ecological efficiency in the Yellow River Basin

3.2 Spatial Econometric Analysis

3.2.1 Spatial Autocorrelation Test presents Moran' s I test results for grain eco-efficiency. The global Moran' s I values are all positive and significant at the 1% level, indicating significant positive spatial correlation in grain eco-efficiency across the Yellow River Basin. In other words, improvements in local grain eco-efficiency boost performance in neighboring regions.

Spatial Autocorrelation Tests of Grain Eco-Efficiency in the Yellow River Basin | Year | Moran' s I | Z-value | P-value | |—|——-|——|——| | 2011 | 0.187 | 3.821 | 0.000 | | 2014 | 0.201 | 4.102 | 0.000 | | 2017 | 0.215 | 4.384 | 0.000 | | 2020 | 0.228 | 4.651 | 0.000 |

3.2.2 Spatial Econometric Model Selection reports Lagrange Multiplier (LM) and Hausman test results under the inverse geographic distance matrix. Both spatial error and spatial lag models pass significance tests at the 1% level, indicating that the spatial Durbin model is optimal. The Hausman test results are significant, confirming that fixed effects models are superior to random effects models. Further testing shows that time fixed effects are significant, leading to the selection of a time-fixed-effects spatial Durbin model for precise estimation.

Results of LM Test and Hausman Tests | Test | Statistic | P-value | |—|——-|——| | LM test for spatial error model | 45.21 | 0.000 | | Robust LM test for spatial error model | 38.67 | 0.000 | | LM test for spatial lag model | 52.34 | 0.000 | | Robust LM test for spatial lag model | 45.80 | 0.000 | | Hausman test | 28.45 | 0.000 | | Time fixed effects test | 15.23 | 0.000 |

3.2.3 Spatial Durbin Model Regression Results presents estimation results from the time-fixed-effects spatial Durbin model under the inverse geographic distance matrix. The spatial lag coefficient (Spatial-rho) is positive and significant at the 1% level, confirming positive spatial spillover effects in grain eco-efficiency. To obtain unbiased estimates, this study employs LeSage and Pace' s [?] partial derivative method to decompose effects into direct, indirect, and total effects.

Direct effects capture the impact of agricultural socialized services on local grain eco-efficiency, including both direct influences (model coefficients) and feedback effects within the region. The coefficient of agricultural socialized services on grain eco-efficiency is 0.182 ($P<0.01$), indicating that improved local agricultural socialized services significantly enhance local grain eco-efficiency. This likely occurs because service improvements attract new elements, technologies, and high-quality production factors while reducing traditional input losses, accompanied by the dissemination of advanced production techniques and management experience that encourage farmers to emulate green production practices and reduce environmental pollution.

Indirect effects represent the average influence of local agricultural socialized services on grain eco-efficiency in other regions. The coefficient is 0.095 ($P<0.01$), demonstrating that agricultural socialized services significantly promote grain eco-efficiency in both local and neighboring regions, consistent with findings from Zhang [?] and Zhang [?]. As discussed in the theoretical analysis, agricultural socialized services provide green production technologies and eco-friendly agrochemical usage methods that spread through farmer networks, attracting surrounding farmers. Additionally, these services build diversified platforms for resource transformation, upgrading, and remote allocation, breaking administrative spatial restrictions. In terms of transmission pathways, direct effects exceed indirect effects, suggesting that with equal or similar service levels, labor tends to first affect local grain eco-efficiency before influencing other regions.

Estimation Results of the Spatial Durbin Model with Time Fixed Effects Using the Inverse Geographic Distance Matrix | Variable | Direct Effect | Indirect Effect | Total Effect | |——-|———–|————-|———-| | Agricultural socialized services | 0.182*** (3.45) | 0.095*** (2.87) | 0.277*** (4.12) | | Urbanization level | 0.156** (2.34) | 0.078* (1.92) | 0.234** (2.56) | | Per capita planting scale | -0.089* (-1.78) | -0.045 (-1.23) | -0.134* (-1.89) | | Mechanization rate | 0.123** (2.12) | 0.056 (1.45) | 0.179** (2.34) | |

Note: Figure translations are in progress. See original paper for figures.

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