frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 21 May 2024
DOI 10.3389/fsufs.2024.1371520

OPEN ACCESS

EDITED BY
Antonio Santoro,
University of Florence, Italy

REVIEWED BY
Nawab Khan,
Sichuan Agricultural University, China
Zhong Ren,
Shandong Normal University, China

*CORRESPONDENCE
Meseret Chanie Abate
✉ abatemeseretchanie3407@huse.edu.cn

RECEIVED 17 January 2024
ACCEPTED 29 April 2024
PUBLISHED 21 May 2024

CITATION
Cai B, Wangda L, Shi F, Abate MC, Geremew B and Addis AK (2024) Agricultural socialized services and Chinese food security: examining the threshold effect of land tenure change.
Front. Sustain. Food Syst. 8:1371520.
doi: 10.3389/fsufs.2024.1371520

Agricultural socialized services and Chinese food security: examining the threshold effect of land tenure change

Baozhong Cai[1], Liao Wangda[2], Fang Shi[3], Meseret Chanie Abate[1]*, Betelhemabraham Geremew[4] and Amsalu K. Addis[5]

[1]Research Institute of Rural Revitalization, Hunan University of Science and Engineering, Hunan, China, [2]College of Economics, Hunan Agricultural University, Changsha, China, [3]School of Humanities and Management, Hunan University of Chinese Medicine, Changsha, China, [4]School of Public Administration, Hunan Agricultural University, Changsha, China, [5]School of Business, Hubei University, Wuhan, China

Revolutionary agricultural structural reforms in the supply chain and cutting-edge institutional mechanisms are pivotal in catalyzing a quantum leap in food production. China's focus on achieving self-sufficiency in grain production for domestic security necessitates structural reforms in the agricultural supply chain and innovative institutional mechanisms. The emergence of socialized agricultural institutions plays a pivotal role in providing essential services to smallholder farmers. However, a dearth of studies evaluating the efficacy of these services in enhancing grain production exists. This study aims to fill this gap by analyzing provincial panel data from China spanning 2011 to 2020 to evaluate the impact of Agricultural Socialized Services (ASS) development levels on grain production. Employing panel and panel threshold models for empirical analysis, the research investigates how this impact varies between major grain-producing regions and non-major grain-producing regions. Findings indicate a significant positive effect of ASS on grain production, with a correlation coefficient of 1.3555. While its impact is less pronounced in grain-producing regions, it proves beneficial in non-grain regions. Moreover, the transfer of farmland use rights amplifies ASS's influence on grain production, with a threshold value of 33.18%. The study concludes by outlining policy implications from various perspectives, providing practical recommendations for policymakers and stakeholders in the agricultural sector.

KEYWORDS

grain yield, agricultural socialized services, farmland use right transfer, threshold effect, land tenure policy

Introduction

Maintaining grain security is a top priority on China's political agenda due to its close link with food security (Niu et al., 2022). To achieve self-sufficiency in grain production and ensure domestic security, the agricultural sector in China prioritizes continuous promotion of structural reform on the supply side and institutional mechanism innovation (Zhan, 2017). Despite these efforts, China faces significant challenges in meeting its growing grain demands, including a rising population and increased demand for animal products. By 2030, China will require 776 million metric tons of grain, a 35.9% increase from its best year on record (Li et al., 2014). Rapid urbanization poses a significant threat to agricultural land availability, leading to low resource efficiency, resource scarcity, declining yield response, competition for non-agricultural land usage, and environmental degradation (Li et al., 2014). In response to these challenges, institutions such as agricultural machinery cooperatives, specialized service organizations, farmer professional cooperatives, and individual service providers provide services to smallholder farmers in the form of agricultural socialized services (ASS). These services have been crucial in bridging the gap between smallholder farmers and modern agriculture, contributing to food security. However, few studies have examined the effectiveness of these services in improving grain production.

As nations globally grapple with the complexities of food security and sustainable agricultural practices, there is an escalating realization of the pivotal role played by agricultural services in bolstering smallholder farmers and enhancing productivity. Leveraging insights from experiences in countries such as India, Brazil, and Thailand, where analogous initiatives have been executed to elevate agricultural productivity and guarantee food security, can furnish invaluable comparative perspectives for small-scale agricultural countries. These nations have delved into diverse models of agricultural services and land tenure reforms to cater to the exigencies of smallholder farmers and amplify food production. In India, for instance, the establishment of farmer producer organizations (FPOs) has wielded a pivotal influence in furnishing collective support and services to small-scale farmers, culminating in enhancements in agricultural productivity and market access (Nayak, 2016). Brazil's encounter with land tenure regularization and agrarian reform programs has underscored the potential advantages of secure land rights in fostering investment and productivity in agriculture (Reydon et al., 2015). Likewise, Thailand's endeavours to foster agricultural cooperatives and extension services have contributed to augmenting farmers' capacities and amplifying food production (Promkhambut et al., 2023). Comprehending how distinct models of socialized agricultural services have impacted food security and agricultural productivity across varied socio-economic and agro-ecological contexts is imperative for informing effective policy decisions and interventions.

Recent studies have underscored the pivotal role of ASS in China, offering smallholder farmers with a necessary path for modern agricultural advancement (Shi et al., 2023). These services serve as a transformative link between conventional small-scale farming practices and cutting-edge agricultural technologies and techniques employed in contemporary agriculture (Huan et al., 2022). By tapping into ASS, smallholder farmers receive access to resources and support that were previously unavailable for their operations (Chen et al., 2023). ASS encompass a diverse array of assistance, including irrigation, pest control, technical guidance, and support for farmers (Hao et al., 2023). These services ultimately enhance productivity and efficiency through the introduction of modern farming methods and technologies. Notably, these services surmount the constraints of small landholdings by consolidating petite plots into larger farms through farmland transfer and consolidation, enabling economies of scale and substantial investment in advanced technologies (Zang et al., 2022). Furthermore, ASS provide access to knowledge-sharing networks and market intelligence, empowering farmers to make informed decisions regarding crop selection, planting schedules, and pricing strategies (Yang et al., 2023). Nonetheless, the mechanism by which ASS affects grain production has not been fully explored.

Currently, there exist three fundamental types of land transfer (Zhou et al., 2021). The first type entails the relinquishment of property rights from village collectives to the State. The second type concerns the transfer of land contractual rights, which was more widespread before the current trend of land transfers. However, it is the third type, the transfer of land management rights that has been the primary catalyst behind the extensive consolidation of land into commercial entities in recent years. This study specifically focuses on the type of land transfer, which is commonly known as land transfer, farmland transfer, farmland use right transfer, or agricultural land transfer in the literature. It is worth noting that this transfer has led to an enormous amount of land being amalgamated into commercial units in recent years.

The transfer of farmland use rights in China represents a critical shift of agricultural land from individual farmers to larger farming entities or agricultural corporations (Ou and Gong, 2021), driven by compelling factors. The urgent demand for agricultural modernization and heightened productivity is a key impetus behind this phenomenon (Ye, 2015; Kuang et al., 2021). The consolidation of small, fragmented plots into more efficient farms facilitates the adoption of cutting-edge farming techniques, cleaner grain production, mechanization, and economies of scale (Zhu et al., 2018; Duan et al., 2021), ultimately bolstering agricultural productivity, strengthening food security, and supporting ongoing rural development efforts.

Moreover, rapid urbanization and infrastructural development have an additional influence on farmland transfer (Wang et al., 2021; You et al., 2021), as burgeoning urban areas demand land for residential, commercial, and industrial purposes, leading to the conversion of agricultural land for non-agricultural uses (Li et al., 2020; Xu et al., 2020). In response to these multifaceted challenges, the Chinese government has enacted policies and regulations to ensure equitable compensation, safeguard farmers' rights, and promote sustainable land management practices during the farmland transfer process (Ma et al., 2020). While the favourable function of farmland use transfer is acknowledged, further research is needed to determine how it improves smallholder farmers' usage of ASS.

Although abundant research has been conducted on the effect of ASS on smallholder farmers' agricultural production, suggesting that it incentivizes the adoption of pro-environmental agricultural practices (Cai et al., 2022; Chen Z. et al., 2022; Cheng et al., 2022; Ren, 2023), increase the demand for large- and middle-sized agricultural machinery and promotes labour transfer among grain producers (Chen T. et al., 2022), and mitigates the negative effects induced by rural labour migration (Wang and Huan, 2023), slight regard has been paid to the effect of land tenure change which causes farmland scale variation on smallholder farmers' accessibility and utilization of services provided by social entities. This study investigates the effect of farmland use right transfer on the ability of smallholder farmers to access ASS in the context of grain production output in China.

The empirical exploration of the interplay between farmland transfer, ASS, and grain yield in China remains notably inadequate. Presently, there exists a dearth of evidence to substantiate the existence of a threshold effect of farmland transfer on the impact of ASS on grain yield. The transfer of farmland has the potential to significantly influence the delivery of ASS, encompassing critical components such as irrigation, pest control, technical support, and various forms of assistance extended to farmers. By consolidating small plots into larger farms, farmland transfer facilitates heightened investment in modern technologies and reaps the benefits of economies of scale (Duan et al., 2021). However, beyond a certain scale, the advantages of farmland transfer may reach a point of saturation or even decline (Fei et al., 2021). This can be primarily attributed to the emergence of coordination challenges and inefficiencies as farms expand in size. The formidable scale of large-scale farming operations may impede the effective provision of ASS (Zang et al., 2022), leading to difficulties in efficiently applying pesticides or fertilizers across extensive areas and potentially diminishing grain yield. Consequently, this could counteract any potential gains derived from consolidation. The optimal scale of farms is depends on various factors, including regional conditions, infrastructure development, and governmental policies (Ren et al., 2019). Striking a balance between farm scale and the availability of socialized services is crucial for maximizing agricultural productivity and ensuring robust food security.

The empirical significance of this study is underscored by its robust methodological approach and revelatory findings. Utilization of the panel threshold model and the formulation of an index evaluation system, this study yields invaluable insights into the dynamic interplay between ASS and grain yield. These empirical contributions will enrich our understanding of the pivotal role played by ASS in strengthening food security and provide pragmatic implications for policymakers and stakeholders in the agricultural sector. From a theoretical perspective, this study contributes to our understanding of the factors influencing the effectiveness of ASS in ensuring food security. By examining the threshold effect of farmland transfer, the study delves deeper into the complex relationship between ASS and grain yield. This analysis will enhance our theoretical comprehension of the mechanisms through which ASS can promote agricultural development and food security. From a practical perspective, this study lies in its policy implications for promoting food security. By providing guidance on how to strengthen the link between ASS, land transfer, and food security, this study offers practical insights for policymakers working towards sustainable agricultural development and improved food security. The aim of this study is threefold: (1) to examine the impact of the development level of ASS on grain production by analysing provincial panel data from China between 2011 and 2020. (2) To explore how this effect varies between the main grain-producing areas and non-main grain-producing areas. (3) To determine whether farmland use right transfer has a threshold effect on the relationship between ASS and grain yield.

Literature review

Improving the inclusivity of agricultural services is crucial for ensuring sustainability, as it provides small and socio-economically marginalized farmers with equal access to the knowledge and resources needed for adopting advanced agricultural practices and securing thriving livelihoods, irrespective of factors such as landholding, gender, age, or caste (Dogan and Adanacioglu, 2024; Sahu et al., 2024). The frequency of agricultural extension visits and the application of participatory approaches in extension services are key factors in explaining variations in technical efficiency among grain producers, which in turn can help bridge identified efficiency gaps (Djuraeva et al., 2023). This growing body of research is dedicated to exploring the nexus between agricultural services and grain yield specifically within the context of smallholder farmers.

Previous literature on grain yield in China focuses on several key topics. Firstly, there is a strong emphasis on grain production technology and innovation (Zhang D. et al., 2021; Zhang S. et al., 2021; Deng et al., 2022). This includes studying new crop varieties, irrigation techniques, fertilizers, and pest control measures to enhance grain yields. Secondly, there is a substantial attention to agricultural policies and subsidies to evaluate their impact on grain production (Song et al., 2021; Bai et al., 2022; Fan et al., 2023). This entails evaluating the role of government policies, price support mechanisms, land use policies, and agricultural input subsidies. Thirdly, there is a notable stress on land use and management, with researchers looking into the consequences of land fragmentation, land use patterns, and the benefits of land consolidation, mechanization, and scale management (Verburg et al., 2000; Wang et al., 2020; Xie et al., 2020; Ma et al., 2023). Fourthly, the pronounced emphasis on the impact of climate change and variability on grain yields is also a significant research focus, with efforts underway to identify adaptation strategies (Alexandrov and Hoogenboom, 2000; Kukal and Irmak, 2018; Bento et al., 2021; Habib-ur-Rahman et al., 2022; Hasegawa et al., 2022). Fifthly, some scholars also explore the relationship between grain yields and rural development, poverty reduction, and the role of rural infrastructure, education, and health in improving productivity (Wang et al., 2015; Ge et al., 2018). Finally, market access and international trade are examined to understand the effects on domestic grain prices and production (Chan, 2022; Falsetti et al., 2022). This study examines the impact of the development level of ASS on grain production by analysing provincial panel data from China between 2011 and 2020, an area that has received little attention in previous research.

ASS have become an important tool for promoting sustainable agriculture, involving the provision of agricultural services to smallholders through collective action and shared resources. One impact of ASS is their potential to promote sustainable agricultural technology among smallholders, hence supporting the transition from conventional to sustainable agriculture (Huan et al., 2022). Additionally, these services improve collective action for the governance of irrigation commons, mitigating the negative effects of rural labour migration (Wang and Huan, 2023). Farmers who receive ASS are more likely to adopt sustainable practices such as using organic fertilizers and soil testing (Shi et al., 2023).

Increased ASS encourage small farmers to transfer more farmland, incentivize the adoption of soil testing and straw returning technology among farmers, leading to improved cultivated land quality protection (Cai et al., 2022; Cheng et al., 2022). Household characteristics, biophysical conditions, community attributes, and rules-in-use jointly generate the action situation in the process of smallholders' cooperative utilization of ASS (Zang et al., 2022). Furthermore, ASS positively influences farmers' behavior regarding the application of organic fertilizer, while also reducing the intensity of agricultural carbon emissions (Chen T. et al., 2022; Ren, 2023). These services can provide essential support, production, operational, financial, and distribution services for the agricultural production chain, significantly reducing the intensity of agricultural carbon emissions (Chen Z. et al., 2022). They can also boost demand for large- and middle-sized agricultural machinery and facilitate labour transfer among maize farmers (Chen T. et al., 2022; Yang and Li, 2022). In general, ASS have been found to positively impact on various aspects of agricultural practices and outcomes. These include promoting sustainable agriculture, encouraging collective action, reducing negative impacts of rural labour migration, adopting sustainable agricultural practices, transferring more farmland, improving land quality protection, incentivizing organic fertilizer application, reducing carbon emissions intensity, and promoting labour transfer (Chen T. et al., 2022; Chen Z. et al., 2022; Yang and Li, 2022; Ren, 2023). Further research is necessary to identify best practices for implementing ASS in different contexts and better understand their mechanisms of impact.

Incidentally, scholars have examined various aspects of the relationship between farmland and grain yield. This includes changes in land distribution, usage patterns, consolidation, and the effects of land tenure and management practices (Ge et al., 2018; Wang et al., 2019; Duan et al., 2021). The role of technological advancements (Tong et al., 2023), environmental factors (Ma et al., 2022), policy interventions (Yu and Wu, 2018), and socio-economic factors (Arhin et al., 2023), are also explored. For instance, Ge et al. (2018) highlight the importance of regulating the farmland transition process as it provides a basis for decision-making regarding appropriate grain production scales for farmers. Another factor influencing grain production is the subsidy payments for contracted farmland. Zhang D. et al. (2021) find that a 10% increase in grain subsidy payments leads to a 1% increase in farmland rental prices. Ultimately, the goal is to provide insights into this complex relationship to support sustainable agricultural practices.

In terms of farmland quantity, Li et al. (2023) observed that, despite a decline in farmland in China's major grain-producing regions, grain production has increased. This is due to the decoupling of grain production from farmland quantity, especially in central-eastern China. They emphasize the need for sustainable decoupling to guarantee food security without compromising ecological security. Additionally, Liu et al. (2018) discovered that households renting land often cultivate larger quantities of grain. The amount of land rented positively correlates with the amount of grain planted. However, their study did not find a significant impact on grain acreage in relation to farmland rental. Qiu et al. (2020), on the other hand, focused on the impact of land renting-in on grain acreage, finding that land renting-in has a positive effect on grain acreage, particularly in situations where agricultural labour is limited. This effect is achieved as lessees increase machinery utilization in rice production. However, some argues that this increase in machinery usage does not extend to cash crops, as mechanization is more feasible for grain crops in rural China (Huo et al., 2022), while others disagree regarding agricultural production (Peng et al., 2022).

The establishment of nature reserves also has implications for grain production. Chen T. et al. (2022) found that nature reserves reduce average grain production, with a greater impact in high-yield areas. These reserves also decrease both grain yield and the area of cultivated farmland in counties where they are implemented. Similarly, land factors have a substantial effect on grain production dynamics in China, as highlighted by Pan et al. (2020). They emphasize the importance of considering land-related factors when analysing and planning for grain production. Additionally, the spatial mismatch between grain production and farmland resources is a significant challenge in China. For instance, Li et al. (2017) highlight various factors contributing to this mismatch, including regional structure imbalances, ecological risks, agricultural production risks, and the volatility of food prices. Addressing this spatial mismatch is crucial to mitigate the decline in grain yield caused by these imbalances, which this study aims to investigate through empirical analysis of the nexus between ASS and grain yield. Furthermore, Zhu et al. (2022) explore the relationship between farm size and fertilizer use efficiency. They found that larger farm sizes positively affect fertilizer use efficiency. This is not due to an increase in grain yield, but rather through a reduction in fertilizer use while maintaining the grain yield at a relatively constant. In conclusion, the relationship between farmland and grain yield in China is complex, influenced by various factors such as farmland rental, land factors, fertilizer utilization, farm size, nature reserves, and spatial mismatch. Understanding these dynamics is essential for policymakers to make informed decisions regarding grain production and ensure food security while considering ecological and economic sustainability.

Theoretical framework

The influence of ASS on grain production can be observed from two perspectives. Firstly, it involves the input of various factors, including labor, land, and materials. Secondly, it encompasses technology investment, as service organizations can assist small farmers in adopting advanced technologies to enhance their agricultural production processes and improve overall efficiency. Building upon this understanding, this article aims to analyze the impact of ASS on grain yield by constructing a growth accounting model and adopting the Cobb Douglas production function.

$$Y = A\mathrm{Labor}^{\beta_1}\mathrm{Land}^{\beta_2}\mathrm{Material}^{\beta_3} \tag{1}$$

Where: Y, represents grain yield, A, represents technological progress, Labor, represents the input of labor, Land, represents the input of land factors, and Material, represents the input of material factors.

$$X = f_x(\mathrm{ASS}) \tag{2}$$

$$X = A, \mathrm{Labor}, \mathrm{Land}, \mathrm{Material} \tag{3}$$

$$\frac{dY}{Y} = \frac{1}{A}\frac{\partial f_A(\mathrm{ASS})}{\partial ASS}d\mathrm{ASS} + \frac{\beta_1}{\mathrm{Labor}}\frac{\partial f_{\mathrm{Labor}}(\mathrm{ASS})}{\partial ASS}d\mathrm{ASS} + \frac{\beta_2}{\mathrm{Land}}\frac{\partial f_{\mathrm{Land}}(\mathrm{AS})}{\partial AS}d\mathrm{ASS} + \frac{\beta_3}{\mathrm{Material}}\frac{\partial f_{\mathrm{Material}}(\mathrm{AS})}{\partial AS}d\mathrm{ASS} \tag{4}$$

The Equations 1–4 highlight that changes in grain output are attributed to modifications in labor factors, land factors, material factors, and technological progress. Additionally, the development of ASS contributes to increasing grain production through its impact on factor inputs and technological advancements.

The rural labor force in China has been shrinking as a result of workers to urban areas, raising concerns about its impact on grain output. Despite this tendency, China's grain production has remained consistent at 1.3 trillion pounds for seven years in a row (Global Times, 2021), demonstrating that labor transfer has had little impact on grain production. This begs the question of what factors contribute to a rise rather than a reduction in agricultural output. From a demand perspective, an aging population and part-time employment of the rural labor force have generated a pressing need for ASS among many farmers. These services handle labor shortages, relieve issues associated with substantial land management or land abandonment, and maintain food security. From a supply perspective, ASS act as a conduit for human capital and intellectual capital, successfully alleviating labor constraints in agricultural operations and compensating for labor shortages. This substitution effect significantly reduces the farmers' labor intensity, boosts their enthusiasm for large-scale operations, and ultimately leads to increased food output (Liao et al., 2019; Yang and Li, 2022).

Small-scale farming has been the predominant agricultural model in China, characterized by low productivity levels, weak resistance to natural disasters, and high production costs. Arable land fragmentation leads to high cultivation costs and low profits, while the decentralization of operations incurs high organizational, coordination, and management costs. This hinders the development of rural public infrastructure and the sustainability of production and life. The innovative development of ASS can assist small farmers in centralizing land transfers, achieving moderate-scale operations in agriculture. The integration of land resources can enhance the quality of arable land, thereby increasing food output (Ren et al., 2019; Cai et al., 2022; Huan et al., 2022; Shi et al., 2023).

The development of ASS plays an essential role in concentrating and integrating agricultural production materials within a certain range, enabling more effective and environmentally friendly production activities. This includes the incorporation of green production factors, utilizing organic fertilizers and low-toxicity pesticides to promote sustainable and environmentally friendly agricultural development. Additionally, the integration of agricultural production materials with scientific and technological research and development resources is crucial, leading to sustained growth in food production. ASS not only enhance overall agricultural productivity but also attract high-quality capital and technical expertise, optimizing resource allocation and driving improvements in the quality of grain production (Huan et al., 2022; Zang et al., 2022; Shi et al., 2023).

ASS contribute to increased utilization of agricultural technology and equipment, reducing production costs and improving efficiency. Furthermore, these services facilitate the upgrading and modernization of agricultural machinery, guiding farmers in adopting advanced agricultural technology. By providing socialized services related to agricultural machinery, ASS help alleviate the need for farmers to purchase expensive production materials and tools, thereby improving overall productivity in the food production process (Chen T. et al., 2022).

ASS play a pivotal role in empowering farmers with essential knowledge and skills related to crop management, pest control, and soil conservation. Beyond knowledge transfer, ASS also grant farmers access to critical resources including irrigation facilities, fertilizers, and modern machinery, thereby enhancing their agricultural practices. This comprehensive support system provided by ASS contributes significantly to the improvement of grain yield among farmers. However, the impact of ASS on grain yield is influenced by factors such as farmland transfer dynamics and the resilience of rural communities. Figure 1 illustrates the intricate relationship between ASS, farmland transfer processes, and ultimately, the resulting grain yield outcomes. Understanding and optimizing this interplay is vital for sustainable agricultural development and enhanced productivity in rural.

Data sources and methodology

Data sources

The panel data used in this study were collected from various sources from 2011 to 2020. As depicted in Table 1, data on grain yield, agricultural socialized services, agricultural structure coefficient, and farmland use transfer were obtained from China's Rural Statistics Yearbook (CRSY). Data on urbanization rate and openness to the outside world were derived from the National Bureau of Statistics (NBS), while data on the primary industry were extracted from China's National Statistics Yearbook (CNSY).

Due to data availability constraints, this study excluded Tibet, Hong Kong, Macao, and Taiwan as research areas, leaving a total of 30 provinces, cities, and autonomous regions in mainland China. Based on the research conducted by Yu et al. (2019), the primary regions responsible for grain production in China consist of 13 provinces and autonomous regions, namely Shandong, Jiangsu, Anhui, Jiangxi, Liaoning, Heilongjiang, Jilin, Hebei, Inner Mongolia, Henan, Hubei, Hunan, and Sichuan (see Figure 2).

Dependent variable

The dependent variable in this context is the level of grain yield (GP). Grain yield refers to the amount of grain produced in a given area or region. It is an important measure of agricultural productivity, as it reflects the efficiency of crop production and the capacity of a region to meet its food needs. To measure the level of grain yield, the study uses the total grain production level of each region. This measure reflects the actual quantity of grain produced in a particular region, taking into account the different types of grains and their respective yields. The study aims to capture the overall grain yield performance of each region, providing insights into potential factors that may affect this performance, such as ASS level and changes in farmland tenure.

Independent variable

The primary objective of this study is to investigate the direct impact of ASS on grain yield, as well as its indirect influence through farmland transfer as a threshold effect. Thus, the core independent variable being examined is the level of ASS. This concept builds upon the research of scholars, such as Shi et al. (2023) and incorporates further innovation. To assess ASS, an evaluation index system has been developed based on five key dimensions: agricultural means of production services, agricultural infrastructure services, rural science and technology and information services, agricultural financial services, and rural public services. Each dimension consists of a set of sub-services, resulting in a total of 19 evaluation indicators. It is important to note that all these indicators are positive indicators, implying that higher scores indicate better performance in each dimension. Refer to Table 2 for a detailed breakdown of these indicators. The establishment of this evaluation index system allows

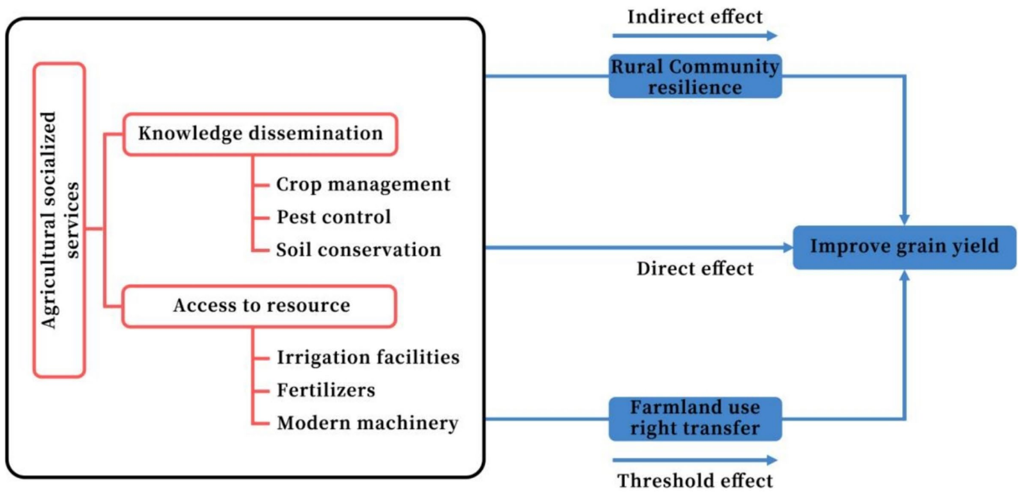

FIGURE 1
Theoretical framework connecting agricultural socialized services and farmland use right transfer to grain yield. Source: authors' conceptualization.

TABLE 1 Variables and data sources.

Denote	Variables	Measurement	Data source
Dependent variable			
GD	Grain yield	The total grain production level of each region	CRSY
Independent variable			
ASS	Agricultural socialized services	Based on the evaluation index system for agricultural socialized services	CRSY
Control variables			
UR	Urbanization ratio	The proportion of urban population to the total population	NBS
TR	Extent of trade openness ratio to the outside world	The ratio of total import and export volume to regional GDP	CRSY
IN	Primary industry	The ratio of the output value of the primary industry to the regional GDP	CNSY
AI	Agricultural structure coefficient	The ratio of grain planting area to total crop planting area is used	CRSY
Threshold variable			
FT	Farmland use right transfer	The ratio of the area of transferred land to the area of contracted land	CRSY

for a comprehensive assessment of the various aspects of ASS, providing valuable insights for policymakers and researchers to analyze and improve the overall effectiveness of these services in supporting agricultural development and rural well-being.

Based on the evaluation index system, the first step is to standardize each of the indicators. This standardization process ensures that all indicators are transformed to a common scale, allowing for meaningful comparisons between them. After standardization, the next step involves calculating the weight of each indicator using the entropy method. This mathematical approach assesses the relative importance or contribution of each indicator to the overall evaluation. The equation is:

$$Z_{ij} = \sum w_j x_{ij} \tag{5}$$

In Equation 5, the variable w_j represents the weight assigned to each indicator. The standardized value of each indicator is denoted by x_{ij}. This standardization process ensures that all indicators are transformed to a common scale, allowing for meaningful comparisons and aggregations. By standardizing the values, variations in measurement units and scales are eliminated, enabling a fair and consistent evaluation across different indicators. It accounts for the dispersion and distribution of values across the indicators. Once the weights of all the indicators are determined using the entropy method, the ASS development index can be calculated. This index serves as a comprehensive measure of the overall performance and development level of ASS.

Control variables

Based on the previously mentioned framework analysis, this study identified key factors that significantly influence grain yield. These factors encompass urbanization rate, extent of openness to the outside world, the proportion of the primary industry, agricultural structure coefficient.

10.3389/fsufs.2024.1371520

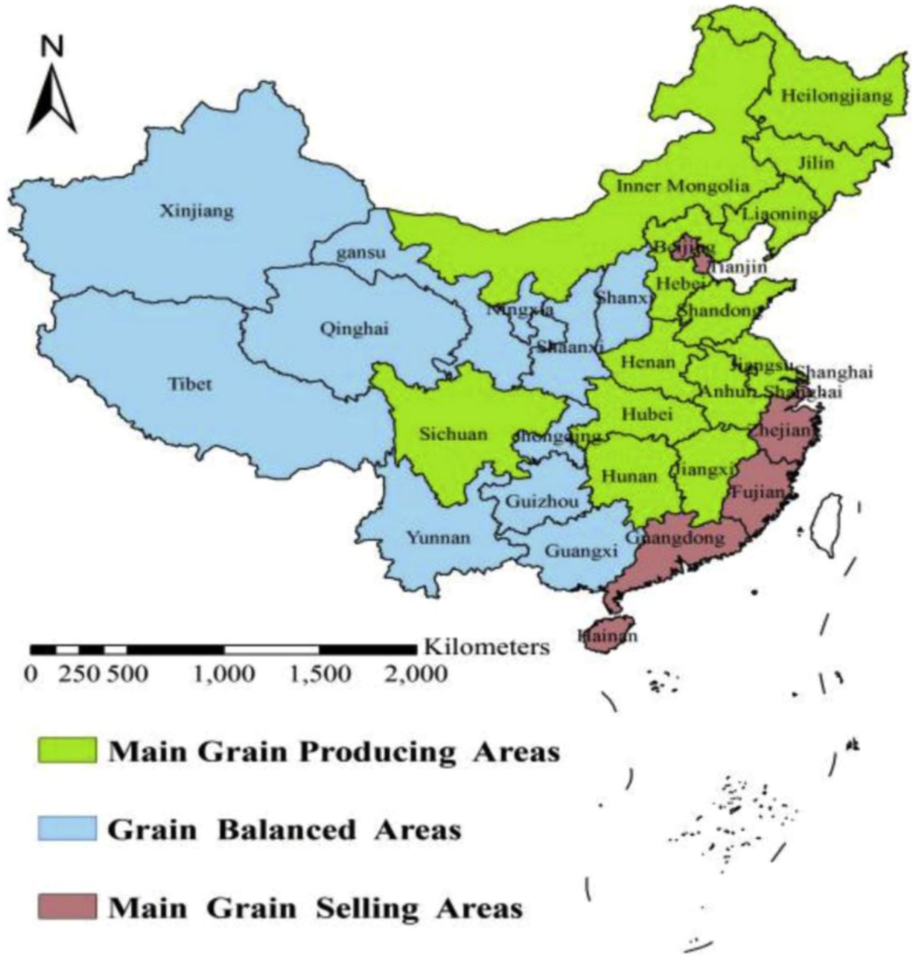

FIGURE 2
Classification of regions based on the proportion of grain production in China. Source: adopted from Yu et al. (2019).

Urbanization rate: The impact of urbanization on grain yield can be understood through two main factors (Shen et al., 2024). Firstly, urbanization typically leads to a reduction in available arable land area, directly contributing to decreased grain production capacity. However, urbanization also has indirect effects on grain yield. As urban areas expand, there is a concentration of population and growth in non-agricultural sectors. This agglomeration and economic diversification can influence the input factors and scale structure of grain production. For example, the increased demand for food in urban areas may drive technological advancements and investment in agricultural practices, leading to improved productivity and efficiency in grain production. Secondly, urbanization often brings about changes in land use patterns, with a shift towards more intensive and specialized farming practices. This shift can lead to higher yields per unit of land, compensating for the reduction in overall arable land area.

The extent of openness to the outside world: It can have a significant impact on grain yield. This is measured by the trade openness ratio (TR), which represents the ratio of total import and export volume to regional GDP. A higher level of trade openness indicates increased imports of agricultural products, which can potentially affect domestic grain production (Hu et al., 2024). When a region becomes more open to foreign markets, it may rely more on imported agricultural products, including grains, rather than producing them domestically. This shift towards reliance on imports may result in a decline in domestic grain production.

The proportion of the primary industry. A higher proportion of the primary industry, particularly agriculture, generally leads to increased food production. This is because a greater focus on agricultural activities can result in more resources and investments being allocated to the industry, leading to improved productivity and efficiency in grain production (Zhang et al., 2022). However, there are potential challenges associated with a high proportion of the primary industry. The development of high-end industries may attract rural labour away from agriculture, leading to a decrease in the number of full-time farmers. This shift in labour allocation may have an influence on the availability of skilled agricultural workers and potentially affect grain production. An upgraded industrial structure, on the other hand, may provide advanced technologies and abundant resources to the agricultural sector. This integration of advanced technology and resources from other industries into agriculture can contribute to

TABLE 2 Evaluation index system for ASS.

Sub-item	Specific indicators	Indicator calculation method	Indicator attribute
Service level of agricultural means of production	Usage of agricultural plastic film	Agricultural plastic film usage (tons)	+
	Fertilizer supply	Chemical fertilizer conversion rate	+
	Pesticide supply	Pesticide usage	+
	Agricultural machinery supply	Total power of agricultural machinery	+
	Agricultural production price index	Agricultural Production Price Index	+
Agricultural infrastructure service level	Water infrastructure	Effective irrigation area (1,000 hectares)	+
	Electricity infrastructure	Rural electricity consumption (100 million kilowatt hours)	+
	transport infrastructure	Highway mileage (10,000 kilometers)	+
Rural science and technology informatization service level	Rural internet application level	Rural broadband access users (10,000 households)	+
	Rural mobile phone usage level	Number of mobile phones owned by rural residents per hundred households at the end of the year (unit)	+
	Rural computer usage level	Home computer ownership	+
Agricultural finance and insurance service level	Agricultural insurance premium level	Agricultural insurance premium income (million)	+
	Development level of agricultural loans	Balance of agricultural loans (100 million yuan)	+
	Compensation level of agricultural insurance	Agricultural insurance compensation expenses (million)	+
Rural public service level	Financial support for agriculture expenditure	Local fiscal expenditure on agriculture, forestry, and water resources (100 million yuan)	+
	Development level of logistics services	Rural delivery routes (kilometers)	+
	Soil erosion control level	Soil erosion control area (1,000 hectares)	+
	Reservoir construction level	Number of reservoirs	+
	Prevention and control level of agricultural natural disasters	1-Disaster rate	+

innovation, improved farming practices, and ultimately enhance grain yield.

Agricultural structure coefficient. It indicates a larger proportion of land dedicated to grain cultivation. Allocating more land resources to growing grains can directly contribute to increased grain output. This is because an increased grain planting area allows for greater cultivation and production of grains, leading to higher yields. Managing and controlling the agricultural structure coefficient is crucial in promoting increased grain yield (Yu et al., 2021). Optimizing the allocation of land resources and ensuring a higher proportion of land is devoted to grain cultivation can enhance agricultural productivity. Taking into account and controlling variables such as the availability of land resources, this study aims to explore the influences of these factors on grain production and yield.

Threshold variable

This study aims to determine whether farmland use right transfer has a threshold effect on the relationship between ASS and grain yield (Ding et al., 2024). The transfer of farmland is selected as a threshold variable to explore the non-linear relationship between ASS and grain yield increase. This threshold can significantly influence the efficiency of ASS scale operations and their effectiveness in increasing total grain yield. When the rate of agricultural land transfer surpasses a certain threshold, it positively impacts the relationship between ASS and grain yield. An increased rate of land transfer can lead to larger-scale agricultural operations, resulting in improved efficiency, access to modern technology, and the utilization of advanced farming techniques. These factors can ultimately contribute to increased grain yield. However, it is important to note that there may be a threshold beyond which further increases in the rate of land transfer could result in diminishing returns or even negative effects on grain yield. This may be due to issues such as land fragmentation, lack of skills and expertise, or inadequate management of large-scale operations.

Methodology

This empirical study examines the impact of ASS on grain yield while considering regional differences. However, measuring ASS in a specific region may result in selection bias due to the complexity of ASS, which arises from diverse and interconnected factors that support agricultural production, rural development, and the well-being of farmers. The complexity arises from the involvement of multiple stakeholders, including government agencies, financial institutions, technology providers, extension services, and rural communities. Managing this complexity requires a holistic approach, coordination among different actors, adaptive strategies, and continuous monitoring and evaluation to ensure the effectiveness and efficiency of services in supporting sustainable agricultural development. To address selection bias, this study developed an evaluation index system for ASS (see Table 2).

The study also developed a linear panel data model to verify the impact of the development level of ASS on grain yield. Ample evidence exists on the role of panel regression model in analyzing data that involves both cross-sectional and time-series dimensions (Arellano and Bond, 1991). This model provides a robust framework for accounting for individual heterogeneity, capturing time-specific effects, increasing efficiency and statistical power, handling endogeneity, and exploring dynamics and causal relationships. The linear panel data model is commonly used to examine the linear relationship between dependent and independent variables while accounting for individual heterogeneity and time-specific effects. In this model, the relationship can be expressed as follows:

$$Y_{it} = \beta X_{it} + \mu_i + \varepsilon_{it} \tag{6}$$

In Equation 6, Y represents the dependent variable for individual i at time t. X_{it} represents the vector of independent variables for individual i at time t. β represents the coefficients associated with the independent variables, μ_i represents individual-specific effects that are constant over time, and ε_{it} represents the error term.

The specific form of a linear panel data model for this study constructed as follows.

$$GP_{it} = \beta_0 + \beta_1 ASS_{it} + \beta_2 M_{it} + \varepsilon_{it} \tag{7}$$

In Equation 7, i refers to the province and t indicates the year. The dependent variable GP represents grain yield. The independent variable ASS represents the development level of socialized agricultural services. M represents control variables, while the term ε denotes the random error term. To examine the non-linear association between the independent variable (ASS) and the dependent variable (GP), this study used farmland use right transfer as the threshold variable. Thus, the study employed the most commonly used panel threshold model developed by Hansen (1999), as it is useful to explore the relationship between dependent and independent variables in panel data (Yi and Xiao-li, 2018; Miao et al., 2020). Particularly, it is essential when there is a non-linear relationship between the variables such that the relationship changes abruptly at a certain point or threshold value of the independent variable. The fundamental equation is:

$$Y_{it} = u_i \beta_1 X_{it} I(q_{it} \le \gamma) + \beta_2 X_{it} I(q_{it} > \gamma) + \varepsilon_{it} \tag{8}$$

Where, i represents the province, t represents the year, q_{it} represents the threshold variable, γ stands for the threshold value to be estimated, and ε_{it} signifies the random error. The individual intercept u_i denotes the fixed effect and $I(q_{it} > \gamma)$ signify the indicative function. If the condition inside the parentheses holds true, the function takes the value of 1; otherwise, 0. By drawing on Equation (8) and consulting the available literature, the study formulated the threshold panel model for assessing how the services provided by social organization affect grain production output, with farmland transfer serving as the threshold variable.

TABLE 3 Descriptive statistics of the main variables.

Variables	Mean	SD	Min	Max	Observations
GP	0.21	0.18	0.002	0.76	300
ASS	0.25	0.13	0.04	0.56	300
UR	0.57	0.12	0.38	0.88	300
TR	0.27	0.31	0.01	1.53	300
IN	0.09.	0.05	0.00	0.26	300
AI	0.66	0.14	0.36	0.97	300
FT	0.33	0.17	0.03	0.92	300

$$GP_{it} = \alpha_1 ASS_{it} I(FT_{it} \le \gamma) + \alpha_2 ASS_{it} I(FT_{it} > \gamma) + \alpha_3 M_{it} + \mu_{it} \tag{9}$$

In Equation 9, the threshold value is denoted by γ, while the control variable is represented by M. The threshold variable, which plays a significant role, is farmland transfer (FT). α1, α2, and α3 are the coefficients to be estimated. ε_{it} is the error term representing unobserved factors.

Results

Descriptive statistics

Table 3 shows the results of the descriptive statistics. The mean grain yield is 0.21 with a standard deviation of 0.18, indicating that grain production varies moderately across the sample. For the ASS, the study developed an index evaluation system to fully understand the development level of these services in each region. The average level of ASS is 0.25, suggesting that such services are neither scarce nor uncommon. The standard deviation of 0.13 indicates that although the average level is 0.25, there is variability around this average. This implies that in some cases, the level of ASS may be significantly higher or lower than the average in different regions.

The average urbanization rate of 0.57 reflects that, on average, approximately 57% of the population in the studied areas is concentrated in urban regions. With a standard deviation of 0.12, there is considerable variation in urbanization rates among the observations, signifying that certain areas exhibit markedly higher or lower levels of urbanization compared to the average. The observed urbanization rates, ranging from 0.38 to 0.88, vividly illustrates the diversity within the dataset, showcasing instances of modest urban development alongside areas with significantly advanced urban landscapes. These statistical insights provide researchers a through overview of the urbanization context under scrutiny, thereby facilitating the contextualization of the interplay between urbanization and grain yield, as well as its potential correlation with other pertinent variables. The mean extent of trade openness to the outside world being 0.27 suggests that, on average, the areas under study exhibit a moderate level of engagement with external entities and global influences. However, the relatively large standard deviation of 0.31 indicates a wide range of variability in the extent of trade openness across the 300 observations. This implies that some areas have a significantly higher degree of increased imports of agricultural products, which can potentially affect domestic grain production, while others have a substantially lower level.

The proportion of the primary industry is 0.09, with a standard deviation of 0.05, meaning that, across the studied areas, the primary industry, which includes activities like agriculture, forestry, fishing, and mining, contributes to approximately 9% of the regional GDP on average. This suggests that the primary industry plays a relatively modest role in the overall economic output of the areas under consideration. The mean agricultural structure coefficient is 0.66, with a standard deviation of 0.14, indicating that the ratio of grain planting area to total crop planting area is relatively high across the studied areas. This suggests that a significant proportion of the total crop planting area is dedicated to grain cultivation, reflecting a substantial focus on grain production within the agricultural structure. The statistics on farmland use right transfer provide important insights into grain yield. The mean value of farmland use right transfer is 0.33, indicating that 33% of the grain cultivated land is transferred. This demonstrates a moderate level of transfer activity for farmland use rights across the studied areas, suggesting some degree of movement in the right to use farmland within grain production. This implies that there is a degree of activity in transferring the rights to use farmland from one party to another within the grain production.

Empirical results

Table 4 provides an overview of the ASS development index in China and its 30 provinces from 2011 to 2020. The index demonstrates substantial growth in China's overall ASS development, with the average level increasing from 0.223 during 2011–2015 to 0.27 during 2016–2020.

Regional disparities in China lead to varying levels of ASS development among provinces, influenced by resource endowments. Among others, 14 provinces have a higher development level of ASS compared to the national average. In descending order, they are, include Shandong, Jiangsu, Henan, Guangdong, Hunan, Hebei, Sichuan, Anhui, Hubei, Zhejiang, Heilongjiang, Jiangxi, Yunnan, and Inner Mongolia. These regions are predominantly situated in the country's principal grain-producing areas and coastal provinces with well-developed agricultural machinery manufacturing. Notably, provinces such as Guangdong exhibit high levels of agricultural science and technology, contributing to the development of ASS through scientific innovation. Similarly, Heilongjiang, with its large land area and substantial grain production, provides a significant market for ASS. This underscores the importance of both production supply capacity and market demand in driving the development of the ASS market.

Conversely, there are 14 provinces where the development level of ASS is lower than the national average. In descending order, they are, Xinjiang, Guangxi, Liaoning, Fujian, Gansu, Shaanxi, Jilin, Guizhou, Shanxi, Chongqing, Shanghai, Beijing, Hainan, Ningxia, Tianjin, and Qinghai. These regions consist of economically developed areas where the secondary and tertiary industries play a significant role in the economy, such as Tianjin, Beijing, and Shanghai. They also include less economically developed provinces in central and western regions, for instance, Qinghai, Ningxia, and Shanghai. Additionally, provinces with challenging geographical landscapes, like mountainous and hilly areas, face difficulties in implementing large-scale ASS, for instance, Hainan and Fujian.

TABLE 4 The development level of ASS in different provinces from 2011 to 2020.

Area (provinces)	Agricultural socialization service index (provinces above the national average)			Area (provinces)	Agricultural socialization service index (provinces below the national average)		
	2011–2015	2016–2020	2011–2020		2011–2015	2016–2020	2011–2020
Beijing	0.088	0.106	0.097	Hubei	0.306	0.360	0.333
Tianjin	0.061	0.065	0.064	Hunan	0.349	0.422	0.385
Hebei	0.361	0.399	0.380	Guangdong	0.373	0.434	0.403
Shanxi	0.170	0.190	0.179	Guangxi	0.198	0.263	0.231
Inner Mongolia	0.227	0.281	0.254	Hainan	0.071	0.091	0.081
Liaoning	0.220	0.236	0.228	Chongqing	0.126	0.161	0.143
Jilin	0.173	0.203	0.188	Sichuan	0.327	0.425	0.376
Heilongjiang	0.253	0.316	0.285	Guizhou	0.145	0.215	0.180
Shanghai	0.110	0.157	0.131	Yunnan	0.246	0.309	0.278
Jiangsu	0.426	0.500	0.463	Shaanxi	0.177	0.206	0.192
Zhejiang	0.306	0.358	0.332	Gansu	0.188	0.223	0.206
Anhui	0.300	0.366	0.333	Qinghai	0.048	0.074	0.061
Fujian	0.204	0.247	0.225	Ningxia	0.061	0.080	0.071
Jiangxi	0.260	0.302	0.281	Xinjiang	0.205	0.279	0.242
Shandong	0.502	0.541	0.522	Nationwide	0.223	0.270	0.247
Henan	0.410	0.481	0.445				

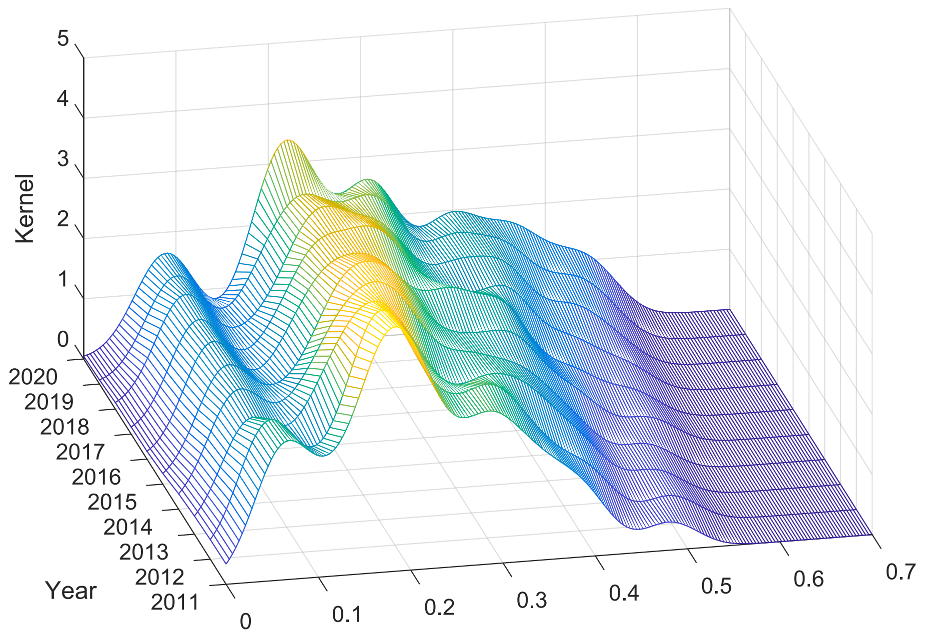

FIGURE 3
Kernel density estimation.

TABLE 5 Results of unit root test.

Variable	LLC	*p* value
GP	−12.2765***	0.0000
AS	−5.4498***	0.0000
UR	−2.9556***	0.0000
TR	−14.3457***	0.0000
IN	−64663***	0.0000
AI	−29.0224 ***	0.0000
FT	−10.8181***	0.0090

*, **, *** stands for 10, 5 and 1% significant level, respectively.

Furthermore, the study conducted kernel density graph analysis to show that the development of China's ASS reveals several noteworthy trends, as depicted in Figure 3. The kernel density graph effectively illustrates the evolving landscape of ASS in China. It highlights the overall progress made while shedding light on the persisting challenges associated with regional disparities in development. There is a clear rightward shift in the main peak, indicating a gradual increase in the level of ASS in China over time. Additionally, the height of the main peak is decreasing while its width is expanding. This suggests that the level of ASS is becoming more dispersed across different regions, with entities operating within this sector are working to bridge the development gap between regions. Moreover, the distributional ductility exhibits a trailing pattern to the right, reaffirming the substantial disparities in the development levels of China's ASS. The persistence of this phenomenon emphasizes the prominent issue of unbalanced development among regions.

Incidentally, to prevent spurious regression due to data instability, unit root tests are performed prior to conducting empirical analysis. Commonly used unit root tests include the LLC test, IPS test, Fisher test, and HT test. In this study, the most widely employed LLC test is utilized (Westerlund, 2009). The results in Table 5 indicate that all variables reject the null hypothesis of non-stationarity. This implies that there is no presence of spurious regression when the data is stationary.

Additionally, the results of the panel data regression for the three models are presented in Table 6, and the Hausman test indicates that the null hypothesis should be rejected at a significance level of 1%, suggesting that fixed effects should be used for analysis. Model (1) in Table 6 is the benchmark regression without any control variables. The results show that the level of ASS has a significantly positive impact on grain yield, as evidenced by the coefficient of 0.9172, which is significant at the 10% significance level. This finding suggests that an increase in the level of ASS can lead to a higher level of grain yield.

In Model (2), control variables have been incorporated into the regression analysis. The results reveal that the coefficient for the relationship between the level of ASS and the total grain yield is 1.3555, which is significantly positive at the 1% significance level. This finding supports the notion that ASS can indeed have a positive impact on grain production, even after accounting for other variables that may influence grain yield. The panel data regression results suggest that increasing the level of ASS is associated with increased grain production. The inclusion of control variables to the analysis further strengthens this conclusion by demonstrating the robustness of the relationship between ASS and grain yield, even when considering other potential factors that could influence grain production.

The analysis, considering the control variables, reveals several significant positive correlations between various factors and grain yield. There is a significant positive correlation exists between the level of urbanization and grain yield, as indicated by the coefficient of 1.1870. This suggests that despite urbanization may reduce rural labour, the infusion of production inputs and adjustments in

TABLE 6 Results of panel data regression analysis.

Variable	Model (1)	Model (2)	Model (3)
	Grain yield		
Agricultural socialized service level	0.9172* (1.83)	1.3555*** (3.97)	1.9887*** (4.51)
Urbanization rate		1.1870*** (2.88)	1.2018*** (2.63)
Extent of trade openness to the outside world		0.6427*** (6.25)	0.5728*** (5.46)
Proportion of primary industry		2.4062*** (4.32)	2.7654*** (4.54)
Agricultural structure coefficient		2.6091*** (11.05)	2.8024*** (11.06)
Constant term	6.8832*** (63.08)	3.9755*** (15.39)	3.6953*** (12.36)
N	300	300	270
Time	Regular	Regular	Regular
Area	Regular	Regular	Regular

*, **, *** stands for 10, 5 and 1% significant level, respectively.

TABLE 7 Result of sub-sample regression.

	Model (4)	Model (5)
	Main grain producing areas	Non-main grain producing areas
Agricultural socialized service level	0.0370 (0.14)	2.4798*** (4.32)
Urbanization rate	−0.4095 (−1.01)	2.0316*** (3.32)
Extent of trade openness to the outside world	0.3010** (2.46)	0.4895*** (3.52)
Proportion of primary industry	2.1743*** (6.66)	0.9502 (0.77)
Agricultural structure coefficient	0.8778*** (3.42)	2.8933*** (8.66)
Constant term	7.2932*** (25.90)	2.7776*** (6.48)
Sample size	130	170
Time	Regular	Regular
Area	Regular	Regular

*, **, *** stands for 10, 5 and 1% significant level, respectively.

agricultural practices resulting from urban development have contributed higher grain yields per unit area. In essence, the advancement of urbanization has had a beneficial impact on grain production. The correlation coefficient between the degree of trade openness to the outside world and grain yield is 0.6427, surpassing the 1% statistical significance level. This implies that increased openness to international trade led to the adoption of advanced agricultural production and management technologies, resulting in improved grain yields. Furthermore, a significant positive relationship exists between the share of the primary industry (agriculture) in the economy and grain yield. This study suggests that an increase in the agricultural share in the overall economy can positively improve grain yield. This improvement is likely attributable to the increased allocation of resources, investments, and attention to the agricultural sector, which in turn enhances grain production and subsequently yields. These findings underscore the importance of accounting for control variables in examining the correlation between agricultural factors and grain yield. Urbanization, trade openness, and the share of primary industry each exhibit significant positive associations with grain yield, highlighting the complex nature of agricultural production and the diverse factors that influence its success.

The coefficient of the agricultural structure significantly promotes grain yield, with an impact coefficient of 2.6091. This indicates that an increasing the proportion of land allocated crop planting can lead to a higher grain yield. To address the issue of endogeneity and eliminate any potential bias stemming from the causal relationship between the independent and the dependent variable, Model (3) was implemented. In this model, the lagged period of the development level of ASS was chosen as the instrumental variable to handle endogeneity. Additionally, Generalized Moment Estimation (GMM), renowned for its efficiency in addressing heteroscedasticity problems, was selected for the regression analysis. The results show that the level of ASS significantly contributes to an increase in gran yield at 1% significance level. This further strengthens the robustness and reliability of the regression results, indicating that the relationship between ASS and grain yield is dependable and unaffected by endogeneity issues. The results highlight the positive impact of the agricultural structure, specifically the proportion of crop planting area, on grain yield. The employment of instrumental variables and the application of GMM provide a solid approach to addressing potential endogeneity problems, reinforcing the credibility of the findings from the regression analysis.

Furthermore, to investigate the impact of ASS on grain yield in both main grain-producing and non-main grain-producing areas, this study categorized 30 provinces and cities across China accordingly. The impact of ASS on total grain yield in different regions was examined, and the regression results are presented in Table 7. Models (4) corresponds to the regression outcomes for main grain-producing regions, while Model (5) represent the regression results for non-main grain-producing regions. The study found that in main grain producing regions, the coefficient of the impact of ASS on grain production is 0.0370; however, this finding did not withstand the robustness test, signifying that the development of ASS in these regions does not have a significant effect on grain production.

Conversely, in non-main grain-producing regions, there is a significant correlation between ASS and grain production. The correlation coefficient is 2.4798, statistically significant at the 1% statistical level. This suggests that in non-main grain-producing areas, challenges such as farmers' part-time employment and non-main grain-production areas are more evident. These regions face greater constraints in terms of technology, land availability, labour force, and efficiency. Consequently, the demand for ASS among farmers is higher and more realistic. This study indicates that many hilly and mountainous regions are either lack access to ASS or face high prices, leading to the abandonment of arable land or suboptimal farming practices. Therefore, in non-main grain-producing regions, the level of ASS has a significant impact on grain production.

The development of ASS in non-main grain-producing regions is relatively advanced. The availability of service subsidy funds and the

TABLE 8 The results of the existence test of threshold effect.

Threshold variable	Model	F value	*p* value	10% critical value	5% critical value	1% critical value	BS frequency
Farmland transfer rate	Single threshold	33.65	0.0467	25.1807	34.7560	67.3120	300

TABLE 9 Results of the threshold value test.

Threshold variable	Threshold	Estimated value	Lower bound of 95% confidence interval	Upper bound of 95% confidence interval
Farmland transfer rate	Thresholdγ_1	0.3318	0.3269	0.3328

overall level of agricultural productivity contribute to the positive impact of ASS on grain yield in these regions. These services effectively support farmers in improving their agricultural practices, leading to an increase in grain production. Although ASS do not show a significant impact on grain yield in main grain producing regions, they play a crucial role in non-main grain-producing regions. The higher demand for these services, coupled with their advanced development, contributes to increased grain yield in these regions. The study underscores the necessity of taking into account regional variations and specific agricultural contexts when examining the relationship between ASS and grain production.

Tables 8, 9 presents the results of the threshold effect existence test and threshold value test, respectively. As mentioned earlier, this study introduces farmland transfer rate as a threshold variable to examine the non-linear relationship between the ASS development and grain yield increases. The study reveals that ASS exhibit a significant threshold effect on grain yield. The analysis indicates that there is a specific threshold value for the farmland transfer rate, which is determined to be 0.3318 based on the empirical findings. This threshold value signifies that once the rate of farmland transfer surpasses this threshold, the influence of ASS on promoting grain production becomes significantly stronger.

Moreover, the regression analysis results presented in Table 10 demonstrate that the impact of different agricultural land transfer rates on ASS and grain yield varies significantly. The results indicate that when the agricultural land transfer rate is below 33.18%, there is no significant correlation between ASS and grain yield. In other words, at lower levels of land transfer, the influence of ASS on grain production is not statistically significant. However, a significant shift is observed once the farmland transfer rate exceeds 33.18%. In such cases, the coefficient of influence between ASS and grain yield is calculated to be 1.1338, with both variables are statistically significant at the 1% significant level. This indicates a positive relationship between farmland transfer rate and the effectiveness of ASS in enhancing grain yield, aligning with the theoretical predictions (Chen T. et al., 2022; Yang and Li, 2022). The transfer of farmland can facilitate and enhance the positive effects of ASS on increasing grain yield. It implies that promoting farmland transfer, particularly when it surpasses the identified threshold, can be beneficial for optimizing the impact of ASS on grain production.

Discussion

Food security has consistently been a significant concern for China, a populous developing nation with a population exceeding 1.4 billion. The concept of food security in China has consistently prioritized ensuring a sufficient grain supply. This emphasis on grain sufficiency has been a fundamental aspect of China's national agenda for food security (Bishwajit et al., 2013) for several decades. For instance, China's economic reform commenced by undertaking a substantial overhaul of the agricultural sector, placing immense emphasis on the cultivation of cereal grains (Nolan, 1983). The process of de-collectivization, initiated in the late 1970s, was instrumental in bolstering both farm output and efficiency, leading to remarkable advancements (Nolan, 1983; Unger, 1985). Regional grain self-sufficiency has been a predominant catalyst behind these notable achievements (Yifulin and Jameswen, 1995). China's achievement of grain self-sufficiency is due to two primary approaches (Niu et al., 2022). The first is the successful implementation of agricultural restructuring, rural infrastructure improvement, technological advancement, price support with subsidies, and land management policies. The second strategy involves China positioning itself as a net importer of grain, leveraging policies that encourage market openness to maintain its self-sufficiency.

Grain security is a fundamental aspect of food security, given that grains like rice, wheat, and maize constitute staple foods for a significant portion of the global population (Albahri et al., 2023; Hu et al., 2023). Meanwhile, China's grain security encounters several persistent challenges. These include the loss of arable land to degradation and urbanization, water resources scarcity, natural disasters, the effects of climate change, growing demand due to population growth and rising living standards, a small-scale agricultural economy dominated by smallholder farmers, and outdated agricultural infrastructure, among various other factors (Wang et al., 2009). Additionally, the development of urban-based industries has attracted huge rural labour migration to cities. To address these challenges, there has been a shift towards part-time management in agricultural production. Many farmers have opted to utilize services like agricultural mechanization to minimize the opportunity costs associated with dividing their time between farming in rural areas and seeking employment in urban areas (Zang et al., 2022; Wang and Huan, 2023).

During the first decade of reform and opening up (1983–1990), there was significant progress in the establishment of ASS entities (Huang et al., 2020). This period primarily focused on the initial development of these services, with a particular emphasis on public welfare-driven initiatives. Gradually, the industry structure for ASS established. The emergence of producer service industry, centred on production trusteeship, has played a pivotal role in driving China's agricultural development to a new phase, laying the groundwork for the strategic positioning of ASS as a key industry. As of the end of

TABLE 10 The results of the threshold effect regression.

Variables	Threshold variable: rural land transfer rate
	Model (6)
	Grain yield
ASS level (farmland transfer rate < γ 1)	0.6119 (1.23)
ASS level (farmland transfer rate > γ 1)	1.1338** (4.57)
Urbanization rate	1.8034*** (0.73)
Extent of trade openness to the outside world	0.0986 (0.80)
Proportion of primary industry	3.1239*** (3.60)
Agricultural structure coefficient	1.7553*** (4.79)
Constant term	0.1587*** (10.59)
Sample size	300

*, **, *** stands for 10, 5 and 1% significant level, respectively.

2020, approximately 900,000 providers of ASSs in China had served an extensive area of farmland exceeding 107 million hectares. Of this, 60 million hectares were allocated for grain cultivation (Huan and Zhan, 2022; Wang and Huan, 2023).

The effect of ASSs on grain yield

This study conducted a detailed investigation of the agricultural services provided by social organizations, exploring how these services affect the grain production output. The study established an index evaluation system and identified five ASS types of ASS to evaluate their comprehensive effect on grain production output (Table 2). According to the empirical results, ASS has a significantly positive impact on grain yield, indicating that an increase in the level of ASS can lead to a higher grain yield level. This finding is consistent with the recent studies that have investigate the effect of ASS (Cheng et al., 2022; Huan et al., 2022). Surprisingly, the role of ASS in enhancing grain yield remains persistent even after controlling for other factors that could potentially influence grain yield. In essence, the study's results demonstrate that the positive impact of ASS on grain yield cannot be readily attributed to other influencing factors, emphasizing the importance of these services in improving agricultural productivity (Chen T. et al., 2022).

Furthermore, Lu and Huan (2022) conducted research on the impact of agricultural labour transfer on grain production in China. They found that this transfer positively affects grain production both directly and indirectly, facilitated through increased use of agricultural machinery. This study corroborates these findings, indicating that smallholder farmers primarily receive agricultural machinery via ASS entities. These services help to reduce input costs and ease the adoption of agricultural machinery, thereby making it more accessible to smallholder farmers. This underscores the significance of ASS in promoting the use of agricultural machinery and boosting grain production in China.

The regional disparity of ASS effect on grain yield

This study finds that the influence of ASS on grain yield varies significantly between main grain-producing regions and non-main grain-producing regions. Interestingly, it reveals that the positive effect of ASSs on increasing grain yield is more pronounced in non-main grain-producing regions than in main grain-producing regions. This result implies that the implementation and impact of ASS could boost grain yield in regions where agriculture is not the primary focus. This may be attributed to the relatively lower levels of existing agricultural support and infrastructure in these regions. These results underscore the importance of considering regional agricultural dynamics and resource allocation when designing and implementing agricultural development strategies. This is particularly pertinent for non-main grain-producing regions where the potential impact of ASS on grain yield appears to be more substantial.

According to Wang and Huan (2023) argument, grain production efficiency in China exhibits an unbalanced spatial development, characterized by a decreasing trend from the central area towards the eastern and western regions. This variation in efficiency may stem from the capacity differences of smallholder farmers to access agricultural inputs and the level of developmental state of ASS organizations that provide these inputs. The study suggests that the uneven distribution of grain production efficiency among regions may stem from the varied availability and accessibility of agricultural inputs. This variation can depend on the capacity of smallholder farmers to obtain these inputs and the extent to which ASS organizations in providing support services. These findings highlight the necessity of focused interventions aimed at improving agricultural infrastructure and support services in underdeveloped regions, thereby promoting more balanced and sustainable development of grain-producing regions in China.

The threshold effect of farmland use right transfer on the effect of ASS on grain yield

According the results of the threshold model analysis, the impact of ASS on grain yield increase is not linear (Table 10). A critical point exists where farmland use right transfer triggers a notable effect on grain yield. Once the rate of farmland transfer exceeds this threshold, the contribution of ASS to enhancing grain production becomes more evident. These findings suggest that the impact of ASS on grain yield varies with different levels of farmland transfer, and there is a critical point where the transfer of farmland has a notable effect on this relationship. These insights can inform policy interventions designed to promoting sustainable agricultural development and improving the efficiency of ASS in China.

The threshold effect observed in the relationship between farmland use transfer and the effect of ASS on grain yield can be explained to several factors. For instance, when the rate of farmland uses transfer falls below the identified threshold, it implies that there might not be significant changes in farmland ownership or management. Under these circumstances, the impact of ASS on grain yield could be limited since the existing farmers may already possess the necessary resources and support. Consequently, the correlation between ASS and grain yield is not statistically significant. Conversely, when the rate of farmland use transfer surpasses a certain threshold, it indicates a higher level of land circulation and potentially more significant changes in the agricultural production system. The transfer of farmland can result in the consolidation or aggregation of farmland, enabling economies of scale and improved resource allocation. This, in turn, creates opportunities for ASS to exert notable significant effect on grain yield. Additionally, when there is a higher rate of farmland use transfer, it implies increased participation of different stakeholders, such as agricultural cooperatives or large-scale farming enterprises. These entities typically have improved access to resources, technologies, and knowledge, which can be enhanced through ASS. Consequently, the synergistic impact of farmland use transfer and ASS becomes more significant in boosting grain yield.

Furthermore, farmland transfer serves as an effective method for reducing transaction costs associated with ASS, while also enabling farmers to consolidate small-scale and dispersed farmland. For instance, conventional agricultural machinery services face challenges when operating on fragmented farmland, which can be fuel consuming and inaccessible. Additionally, farmers are approaching service providers individually to negotiate fees. As a result, agricultural machinery services become reluctant to operate in villages with a lower degree of farmland transfer, preferring instead to collaborate with large-scale farmers who can offer more competitive unit prices. Thus, regions with a higher degree of farmland transfer tend to attract more agricultural machinery services t compared to regions with fewer farmland transfers.

Conclusion and policy implication

Given the rapid population growth, urbanization, and climate change, it is crucial to support smallholder farmers by empowering them, reducing inequalities, and ensuring inclusive participation in the pursuit of global food security and sustainable development. In order to overcome these challenges, smallholder farmers require specialized training through knowledge transfer and training programs, adoption of appropriate agricultural technologies, market access, and resource availability. Although extensive research has examined the effects of ASS on smallholder farmers' agricultural production, suggesting that these services encourage the adoption of environmentally friendly agricultural practices (Cai et al., 2022; Chen Z. et al., 2022; Cheng et al., 2022; Ren, 2023). It also increases the demand for large- and medium-sized agricultural machinery, and promote labour transfer among grain producers (Chen T. et al., 2022), as well as mitigate the negative effects of rural labour migration (Wang and Huan, 2023). Little focus has been paid on the direct effect of these services on smallholder farmers' grain production in China. This study analyses the impact of the development level of ASS on China's food production. An evaluation index system for ASS was developed to assess its influence on grain yield improvement, utilizing provincial panel data from 2011 to 2020. The study also examined how this effect varies between the main grain-producing regions and non-main grain-producing regions. Additionally, the study investigated the role of farmland use right transfer as a threshold variable that influences the relationship between ASS and grain yield.

The main findings of this study are threefold: (1) the development of ASS has a significantly positive impact on increasing food production, evidenced by a correlation coefficient of 1.3555 at the 1% significance level. (2) In the main grain-producing regions, the influence of ASS on food production is not significant. In contrast, in areas that do not primarily produce grain, ASS contribute to an increase in food production. (3) When considering the level of farmland use right transfer as a threshold variable, a distinct threshold value emerges at 33.18%. Farmland use right transfer enhances the impact of ASS on increasing food production.

Incidentally, this study outlined several policy implications from three distinct perspectives:

Policy implications arising from the regional variation of ASS effect on grain yield improvement

This empirical study evidenced that the development of ASS has a positive and significant effect on the improvement of grain yield. Other scholars have provided a similar assertions (Huan et al., 2022; Yang and Li, 2022; Wang and Huan, 2023). This implies that policymakers should prioritize the development of ASS to promote sustainable agricultural growth in China. A potential policy intervention could involve increase public investment in ASS infrastructure, including irrigation systems, agricultural machinery, and storage facilities. Improving the accessibility of these services for farmers, particularly those who are small-scale and may lack access to necessary resources independently, is possible. Additionally, policies that encourage private sector investment in ASS can enhance both the availability and quality of these services, ultimately contributing to increased grain yield.

An essential policy implication lies in the imperative need to tackle barriers impeding the widespread adoption of Agricultural Support Services (ASS). Awareness gaps among farmers and financial constraints often hinder the effective utilization of these services. Addressing these challenges requires decisive policy interventions, including targeted educational initiatives, comprehensive training programs, and strategic subsidies to facilitate ASS utilization. Such measures are crucial in dismantling barriers and catalyzing the widespread adoption of these services. This underscores the critical role of investing in ASS as a cornerstone for driving sustainable agricultural progress in China. To drive agricultural productivity, alleviate poverty, and bolster food security, policymakers must prioritize the advancement and advocacy of these vital services with unwavering commitment.

Policy implications derived from the regional characteristics of ASS effect on grain yield improvement

The implications drawn from this study, which highlighted the varying effects of ASS on grain yield between main grain-producing and non-main grain-producing regions, hold significant implications for policy-making. The findings emphasize the necessity for targeted development approaches based on regional characteristics. Main grain-producing regions should focus on integrating ASS with current farming practices to maximize grain yield. In contrast, non-main grain-producing regions require increased investment and prioritization to boost their agricultural productivity. Moreover, understanding the varying effects of ASS on grain yield can guide decisions regarding resource allocation.

Non-main grain-producing regions show a greater potential for increased grain yield through the implementation of ASS, highlighting the importance of appropriate resource allocation to bolster their agricultural development. By recognizing the varying effects of ASS in different regions, policymakers can strive toward promoting equitable agricultural development. Strategies ought to focus on narrowing the gap between main and non-main grain-producing regions, ensuring that every region has access to essential resources and support to enhance their grain yield production. The insights gained from these implications are crucial for policymakers in designing effective strategies to foster sustainable agricultural growth and achieve equitable grain production across different regions.

Policy implication arising from the threshold effect of farmland use right transfers on the effect of ASS on grain yield

The findings that the impact of ASS on grain yield growth is not linear, and that there exists a critical threshold at which farmland use right transfer triggers a notable effect on grain yield, carries significant policy implications. Policymakers should consider developing tailored interventions that reflect the level of farmland transfer. For example, policies that encourages ASS adoption in regions where the rate of farmland transfer exceeds this threshold could significantly enhance grain production. Policymakers should prioritize investments in improving the efficiency of ASS to maximize their impact on grain production. This may involve focusing on specific types of services proven to significantly boost grain productivity, especially in regions where farmland transfer has surpassed a critical threshold. Similarly, policymakers should work to facilitate farmland transfer in a sustainable and equitable manner, considering the needs of different stakeholders, including small-scale farmers and rural communities. In doing so, policymakers can foster sustainable agricultural development and enhance the overall efficiency of ASS in China.

This research paper holds empirical, theoretical, and practical significance. Its empirical contributions shed light on the relationship between ASS, farmland transfer, and grain yield, revealing the diverse impacts across different regions. The theoretical contributions deepen our understanding of the complex dynamics involved in promoting food security through ASS. Its practical implications provide guidance to policymakers and stakeholders in developing strategies that strengthen the impact of ASS on agricultural productivity and food security. In conclusion, this study highlights the essential role of ASS in enhancing grain yield in China. It provides valuable insights for policymakers and stakeholders working to enhance agricultural productivity and improving the lives of Chinese farmers.

While this study has its merits, it is not without limitations. This study does not consider the indirect effects that ASS have on grain yield, such as those achieved by strengthening of rural community resilience. Through promoting cooperation, resource sharing, and collective action, ASS can contribute to building stronger, more resilient agricultural communities, which could in turn positively affect grain yields. These limitations underscore the importance of further research and comprehensive data collection to fully understand the complex dynamics between ASS, grain yield and land tenure changes.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: data on grain yield, agricultural socialized services, agricultural structure coefficient, and farmland use transfer were obtained from China's Rural Statistics Yearbook (CRSY) https://www.stats.gov.cn/zs/tjwh/tjkw/tjzl/202302/t20230215_1907997.html. Data on urbanization rate and openness to the outside world were derived from the National Bureau of Statistics (NBS) https://data.stats.gov.cn/, while data on the primary industry were extracted from China's National Statistics Yearbook (CNSY) https://www.stats.gov.cn/sj/ndsj/2022/indexeh.htm.

Author contributions

BC: Writing – review & editing, Conceptualization, Data curation, Funding acquisition, Methodology, Resources, Software, Supervision, Visualization, Writing – original draft. LW: Writing – review & editing, Methodology, Formal analysis. FS: Visualization, Writing – review & editing, Conceptualization, Methodology, Project administration, Resources. MA: Conceptualization, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation. BG: Conceptualization, Methodology, Visualization, Writing – review & editing, Software, Writing – original draft. AA: Conceptualization, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Provincial Social Science Foundation of Hunan under grant number: XSP21ZDI023. The funder had no involvement in the study's design, development, or submission to the journal.

Conflict of interest

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

Publisher's note

References

Albahri, G., Alyamani, A. A., Badran, A., Hijazi, A., Nasser, M., Maresca, M., et al. (2023). Enhancing essential grains yield for sustainable food security and bio-safe agriculture through latest innovative approaches. *Agronomy* 13:7. doi: 10.3390/agronomy13071709

Alexandrov, V. A., and Hoogenboom, G. (2000). The impact of climate variability and change on crop yield in Bulgaria. *Agric. For. Meteorol.* 104, 315–327. doi: 10.1016/S0168-1923(00)00166-0

Arellano, M., and Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Rev. Econ. Stud.* 58, 277–297. doi: 10.2307/2297968

Arhin, I., Mei, H., Li, J., Gyamfi, E., Antwi-Boasiako, A., Chen, X., et al. (2023). Analysis of the determinants of sustainable agricultural technologies adoption in tea production in China: A systematic review. *Int. J. Agric. Sustain.* 21:2239047. doi: 10.1080/14735903.2023.2239047

Bai, J., Wang, Y., and Sun, W. (2022). Exploring the role of agricultural subsidy policies for sustainable agriculture based on Chinese agricultural big data. *Sustain Energy Technol Assess* 53:102473. doi: 10.1016/j.seta.2022.102473

Bento, V. A., Ribeiro, A. F. S., Russo, A., Gouveia, C. M., Cardoso, R. M., and Soares, P. M. M. (2021). The impact of climate change in wheat and barley yields in the Iberian Peninsula. *Sci. Rep.* 11:15484. doi: 10.1038/s41598-021-95014-6

Bishwajit, G., Sarker, S., Kpoghomou, M.-A., Gao, H., Jun, L., Yin, D., et al. (2013). Self-sufficiency in rice and food security: A south Asian perspective. *Agric. Food Secur.* 2:10. doi: 10.1186/2048-7010-2-10

Cai, B., Shi, F., Huang, Y., and Abatechanie, M. (2022). The impact of agricultural socialized services to promote the farmland scale management behavior of smallholder farmers: empirical evidence from the rice-growing region of southern China. *Sustain. For.* 14:316. doi: 10.3390/su14010316

Chan, J. (2022). Farming output, concentration, and market access: evidence from the 19th-century American railroad expansion. *J. Dev. Econ.* 157:102878. doi: 10.1016/j.jdeveco.2022.102878

Chen, T., Rizwan, M., and Abbas, A. (2022). Exploring the role of agricultural services in production efficiency in Chinese agriculture: a case of the socialized agricultural service system. *Land* 11:347. doi: 10.3390/land11030347

Chen, Z., Tang, C., Liu, B., Liu, P., and Zhang, X. (2022). Can socialized services reduce agricultural carbon emissions in the context of appropriate scale land management? *Front. Environ. Sci.* 10:1039760. doi: 10.3389/fenvs.2022.1039760

Chen, L., Zhang, Z., Li, H., and Zhang, X. (2023). Maintenance skill training gives agricultural socialized service providers more advantages. *Agriculture* 13:1. doi: 10.3390/agriculture13010135

Cheng, C., Gao, Q., and Qiu, Y. (2022). Assessing the ability of agricultural socialized services to promote the protection of cultivated land among farmers. *Land* 11:8. doi: 10.3390/land11081338

Deng, F., Jia, S., Ye, M., and Li, Z. (2022). Coordinated development of high-quality agricultural transformation and technological innovation: A case study of main grain-producing areas, China. *Environ. Sci. Pollut. Res.* 29, 35150–35164. doi: 10.1007/s11356-021-18020-1

Ding, Z., Zhang, Q., and Tang, Y. (2024). Nexus between farmland transfer, agricultural loans, and grain production: empirical evidence from China. *Front. Sustain. Food Syst.* 8:1229381. doi: 10.3389/fsufs.2024.1229381

Djuraeva, M., Bobojonov, I., Kuhn, L., and Glauben, T. (2023). The impact of agricultural extension type and form on technical efficiency under transition: an empirical assessment of wheat production in Uzbekistan. *Econ. Anal. Policy* 77, 203–221. doi: 10.1016/j.eap.2022.11.008

Dogan, N., and Adanacioglu, H. (2024). Factors influencing farmers' decisions to produce geographical indication dry beans: a case study from Turkey. *Front. Sustain. Food Syst.* 8:1348090. doi: 10.3389/fsufs.2024.1348090

Duan, J., Ren, C., Wang, S., Zhang, X., Reis, S., Xu, J., et al. (2021). Consolidation of agricultural land can contribute to agricultural sustainability in China. *Nat. Food* 2, 1014–1022. doi: 10.1038/s43016-021-00415-5

Falsetti, B., Ridolfi, L., and Laio, F. (2022). Role of trade agreements in the global cereal market and implications for virtual water flows. *Sci. Rep.* 12:6790. doi: 10.1038/s41598-022-10815-7

Fan, P., Mishra, A. K., Feng, S., Su, M., and Hirsch, S. (2023). The impact of China's new agricultural subsidy policy on grain crop acreage. *Food Policy* 118:102472. doi: 10.1016/j.foodpol.2023.102472

Fei, R., Lin, Z., and Chunga, J. (2021). How land transfer affects agricultural land use efficiency: evidence from China's agricultural sector. *Land Use Policy* 103:105300. doi: 10.1016/j.landusepol.2021.105300

Ge, D., Long, H., Zhang, Y., and Tu, S. (2018). Analysis of the coupled relationship between grain yields and agricultural labor changes in China. *J. Geogr. Sci.* 28, 93–108. doi: 10.1007/s11442-018-1461-5

Global Times. (2021). China's grain production reaches new record at 685 billion kg in 2021 despite extreme weather—global times. Global Times. Available at: https://www.globaltimes.cn/page/202112/1240754.shtml

Habib-ur-Rahman, M., Ahmad, A., Raza, A., Hasnain, M. U., Alharby, H. F., Alzahrani, Y. M., et al. (2022). Impact of climate change on agricultural production; issues, challenges, and opportunities in Asia. *Front. Plant Sci.* 13:925548. doi: 10.3389/fpls.2022.925548

Hansen, B. E. (1999). Threshold effects in non-dynamic panels: estimation, testing, and inference. *J. Econ.* 93, 345–368. doi: 10.1016/S0304-4076(99)00025-1

Hao, W., Hu, X., Wang, J., Zhang, Z., Shi, Z., and Zhou, H. (2023). The impact of farmland fragmentation in China on agricultural productivity. *J. Clean. Prod.* 425:138962. doi: 10.1016/j.jclepro.2023.138962

Hasegawa, T., Wakatsuki, H., Ju, H., Vyas, S., Nelson, G. C., Farrell, A., et al. (2022). A global dataset for the projected impacts of climate change on four major crops. *Scient. Data* 9:58. doi: 10.1038/s41597-022-01150-7

Hu, T., Ju, Z., and Liu, X. (2023). Towards sustainable food security through regional grain supply and demand analysis in China. *Int. J. Environ. Res. Public Health* 20:3434. doi: 10.3390/ijerph20043434

Hu, Y., Zou, Z., Wu, J., and Meng, Z. (2024). Double-edged sword: China's free trade agreements reinforce embodied greenhouse gas transfers in agricultural products. Humanities and social sciences. *Communications* 11, 1–13. doi: 10.1057/s41599-024-01234-5

Huan, M., Li, Y., Chi, L., and Zhan, S. (2022). The effects of agricultural socialized services on sustainable agricultural practice adoption among smallholder farmers in China. *Agronomy* 12:9. doi: 10.3390/agronomy12092198

Huan, M., and Zhan, S. (2022). Agricultural production services, farm size and chemical fertilizer use in China's maize production. *Land* 11:11. doi: 10.3390/land11111931

Huang, J., Rozelle, S., Zhu, X., Zhao, S., and Sheng, Y. (2020). Agricultural and rural development in China during the past four decades: an introduction. *Aust. J. Agric. Resour. Econ.* 64, 1–13. doi: 10.1111/1467-8489.12352

Huo, Y., Ye, S., Wu, Z., Zhang, F., and Mi, G. (2022). Barriers to the development of agricultural mechanization in the north and Northeast China plains: A farmer survey. *Agriculture* 12:2. doi: 10.3390/agriculture12020287

Kuang, Y., Yang, J., and Abate, M.-C. (2021). Farmland transfer and agricultural economic growth nexus in China: agricultural TFP intermediary effect perspective. *China Agric. Econ. Rev.* 14, 184–201. doi: 10.1108/CAER-05-2020-0076

Kukal, M. S., and Irmak, S. (2018). Climate-driven crop yield and yield variability and climate change impacts on the U.S. Great Plains Agricultural Production. *Sci. Rep.* 8:3450. doi: 10.1038/s41598-018-21848-2

Li, Y., Han, X., Zhou, B., Lv, L., and Fan, Y. (2023). Farmland dynamics and its grain production efficiency and ecological security in China's major grain-producing regions between 2000 and 2020. *Land* 12:7. doi: 10.3390/land12071404

Li, T., Long, H., Zhang, Y., Tu, S., Ge, D., Li, Y., et al. (2017). Analysis of the spatial mismatch of grain production and farmland resources in China based on the potential crop rotation system. *Land Use Policy* 60, 26–36. doi: 10.1016/j.landusepol.2016.10.013

Li, Z., Luan, W., Zhang, Z., and Su, M. (2020). Relationship between urban construction land expansion and population/economic growth in Liaoning Province, China. *Land Use Policy* 99:105022. doi: 10.1016/j.landusepol.2020.105022

Li, Y., Zhang, W., Ma, L., Wu, L., Shen, J., Davies, W. J., et al. (2014). An analysis of China's grain production: looking back and looking forward. *Food Energy Secur.* 3, 19–32. doi: 10.1002/fes3.41

Liao, L., Long, H., Gao, X., and Ma, E. (2019). Effects of land use transitions and rural aging on agricultural production in China's farming area: A perspective from changing labor employing quantity in the planting industry. *Land Use Policy* 88:104152. doi: 10.1016/j.landusepol.2019.104152

Liu, Y., Wang, C., Tang, Z., and Nan, Z. (2018). Will farmland transfer reduce grain acreage? Evidence from Gansu province, China. *China Agric. Econ. Rev.* 10, 277–292. doi: 10.1108/CAER-04-2017-0072

Lu, H., and Huan, H. (2022). Does the transfer of agricultural labor reduce China's grain output? A substitution perspective of chemical fertilizer and agricultural machinery. *Front. Environ. Sci.* 10:961648. doi: 10.3389/fenvs.2022.961648

Ma, W., Liu, T., Li, W., and Yang, H. (2023). The role of agricultural machinery in improving green grain productivity in China: towards trans-regional operation and low-carbon practices. *Heliyon* 9:e20279. doi: 10.1016/j.heliyon.2023.e20279

Ma, L., Long, H., Tu, S., Zhang, Y., and Zheng, Y. (2020). Farmland transition in China and its policy implications. *Land Use Policy* 92:104470. doi: 10.1016/j.landusepol.2020.104470

Ma, L., Zhang, Y., Chen, S., Yu, L., and Zhu, Y. (2022). Environmental effects and their causes of agricultural production: evidence from the farming regions of China. *Ecol. Indic.* 144:109549. doi: 10.1016/j.ecolind.2022.109549

Miao, K., Li, K., and Su, L. (2020). Panel threshold models with interactive fixed effects. *J. Econ.* 219, 137–170. doi: 10.1016/j.jeconom.2020.05.018

Nayak, A. (2016). "Farmer producer organizations in India: policy, performance, and design issues" in *Organised retailing and Agri-business. India studies in business and economics*. eds. N. Rao, R. Radhakrishna, R. Mishra and V. Kata (New Delhi: Springer).

Niu, Y., Xie, G., Xiao, Y., Liu, J., Zou, H., Qin, K., et al. (2022). The story of grain self-sufficiency: China's food security and food for thought. *Food Energy Secur.* 11:e344. doi: 10.1002/fes3.344

Nolan, P. (1983). De-collectivisation of agriculture in China, 1979—82: A long-term perspective. *Camb. J. Econ.* 7, 381–403. doi: 10.1093/cje/7.3-4.381

Ou, M., and Gong, J. (2021). Farmland transfers in China: from theoretic framework to practice. *Int. J. Environ. Res. Public Health* 19:217. doi: 10.3390/ijerph19010217

Pan, J., Chen, Y., Zhang, Y., Chen, M., Fennell, S., Luan, B., et al. (2020). Spatial-temporal dynamics of grain yield and the potential driving factors at the county level in China. *J. Clean. Prod.* 255:120312. doi: 10.1016/j.jclepro.2020.120312

Peng, J., Zhao, Z., and Liu, D. (2022). Impact of agricultural mechanization on agricultural production, income, and mechanism: evidence from Hubei province, China. *Front. Environ. Sci.* 10:838686. doi: 10.3389/fenvs.2022.838686

Promkhambut, A., Yokying, P., Woods, K., Fisher, M., Yong, M. L., Manorom, K., et al. (2023). Rethinking agrarian transition in Southeast Asia through rice farming in Thailand. *World Dev.* 169:106309. doi: 10.1016/j.worlddev.2023.106309

Qiu, T., Boris Choy, S. T., Li, S., He, Q., and Luo, B. (2020). Does land renting-in reduce grain production? Evidence from rural China. *Land Use Policy* 90:104311. doi: 10.1016/j.landusepol.2019.104311

Ren, Z. (2023). Effects of risk perception and agricultural socialized services on farmers' organic fertilizer application behavior: Evidence from Shandong Province, China. *Front. Public Health* 11:1056678. doi: 10.3389/fpubh.2023.1056678

Ren, C., Liu, S., van Grinsven, H., Reis, S., Jin, S., Liu, H., et al. (2019). The impact of farm size on agricultural sustainability. *J. Clean. Prod.* 220, 357–367. doi: 10.1016/j.jclepro.2019.02.151

Reydon, B. P., Fernandes, V. B., and Telles, T. S. (2015). Land tenure in Brazil: the question of regulation and governance. *Land Use Policy* 42, 509–516. doi: 10.1016/j.landusepol.2014.09.007

Sahu, S., Bishnoi, S., Sharma, R., Satyapriya, S. M., Mahra, G. S., Burman, R. R., et al. (2024). Exploring popular information sources and determinants of farmers' access to agricultural extension services in the indo-Gangetic plains. *Front. Sustain. Food Syst.* 8:1339243. doi: 10.3389/fsufs.2024.1339243

Shen, W., Hu, Q., and Zhang, Z. (2024). Impacts of in situ urbanisation on grain production: evidence from the Yangtze River Delta, China. *Habitat Int.* 143:102989. doi: 10.1016/j.habitatint.2023.102989

Shi, F., Cai, B., Meseretchanie, A., Geremew, B., and Huang, Y. (2023). Agricultural socialized services to stimulate the green production behavior of smallholder farmers: the case of fertilization of rice production in South China. *Front. Environ. Sci.* 11:106176. doi: 10.3389/fenvs.2023.1169753

Song, X., Wang, X., Li, X., Zhang, W., and Scheffran, J. (2021). Policy-oriented versus market-induced: factors influencing crop diversity across China. *Ecol. Econ.* 190:107184. doi: 10.1016/j.ecolecon.2021.107184

Tong, W., Qin, G., Xu, Y., and Fu, C. (2023). Sustainable growth, input factors, and technological progress in agriculture: evidence from 1990 to 2020 in China. *Front. Environ. Sci.* 10:1040356. doi: 10.3389/fenvs.2022.1040356

Unger, J. (1985). The decollectivization of the Chinese countryside: A survey of twenty-eight villages. *Pac. Aff.* 58, 585–606. doi: 10.2307/2758470

Verburg, P. H., Chen, Y., and Veldkamp, T. (2000). Spatial explorations of land use change and grain production in China. *Agric. Ecosyst. Environ.* 82, 333–354. doi: 10.1016/S0167-8809(00)00236-X

Wang, S., Bai, X., Zhang, X., Reis, S., Chen, D., Xu, J., et al. (2021). Urbanization can benefit agricultural production with large-scale farming in China. *Nat. Food* 2, 183–191. doi: 10.1038/s43016-021-00228-6

Wang, X., Cai, D., Grant, C., Hoogmoed, W. B., and Oenema, O. (2015). Factors controlling regional grain yield in China over the last 20 years. *Agron. Sustain. Dev.* 35, 1127–1138. doi: 10.1007/s13593-015-0288-z

Wang, Y., and Huan, M. (2023). The effects of socialized agricultural services on rural collective action in the irrigation commons: evidence from China. *Agric. Water Manag.* 289:108519. doi: 10.1016/j.agwat.2023.108519

Wang, Y., Li, X., Lu, D., and Yan, J. (2020). Evaluating the impact of land fragmentation on the cost of agricultural operation in the southwest mountainous areas of China. *Land Use Policy* 99:105099. doi: 10.1016/j.landusepol.2020.105099

Wang, J., Xin, L., and Wang, Y. (2019). Economic growth, government policies, and forest transition in China. *Reg. Environ. Chang.* 19, 1023–1033. doi: 10.1007/s10113-018-1450-3

Wang, H., Zhang, M., and Cai, Y. (2009). Problems, challenges, and strategic options of grain security in China. *Adv. Agron.* 103, 101–147. doi: 10.1016/S0065-2113(09)03003-X

Westerlund, J. (2009). A note on the use of the LLC panel unit root test. *Empir. Econ.* 37, 517–531. doi: 10.1007/s00181-008-0244-8

Xie, X., Zhang, A., Cai, Y., and Zhang, Y. (2020). How government-led land consolidation efforts achieve grain production stability? An empirical analysis in Hubei Province, China. *Land Use Policy* 97:104756. doi: 10.1016/j.landusepol.2020.104756

Xu, F., Wang, Z., Chi, G., and Zhang, Z. (2020). The impacts of population and agglomeration development on land use intensity: new evidence behind urbanization in China. *Land Use Policy* 95:104639. doi: 10.1016/j.landusepol.2020.104639

Yang, C., Cheng, C., Cheng, N., and Zhang, Y. (2023). Research on the impact of internet use on farmers' adoption of agricultural socialized services. *Sustain. For.* 15, 1–17. doi: 10.3390/su15107823

Yang, S., and Li, W. (2022). The impact of socialized agricultural machinery services on land productivity: evidence from China. *Agriculture* 12:12. doi: 10.3390/agriculture12122072

Ye, J. (2015). Land transfer and the pursuit of agricultural modernization in China. *J. Agrar. Chang.* 15, 314–337. doi: 10.1111/joac.12117

Yi, S., and Xiao-li, A. (2018). Application of threshold regression analysis to study the impact of regional technological innovation level on sustainable development. *Renew. Sust. Energ. Rev.* 89, 27–32. doi: 10.1016/j.rser.2018.03.005

Yifulin, J., and Jameswen, G. (1995). China's regional grain self-sufficiency policy and its effect on land productivity. *J. Comp. Econ.* 21, 187–206. doi: 10.1006/jcec.1994.0003

You, H., Wu, S., Wu, X., Guo, X., and Song, Y. (2021). The underlying influencing factors of farmland transfer in urbanizing China: implications for sustainable land use goals. *Environ. Dev. Sustain.* 23, 8722–8745. doi: 10.1007/s10668-020-00990-w

Yu, H., Liu, K., Bai, Y., Luo, Y., Wang, T., Zhong, J., et al. (2021). The agricultural planting structure adjustment based on water footprint and multi-objective optimisation models in China. *J. Clean. Prod.* 297:126646. doi: 10.1016/j.jclepro.2021.126646

Yu, X., Sun, J. X., Sun, S. K., Yang, F., Lu, Y. J., Wang, Y. B., et al. (2019). A comprehensive analysis of regional grain production characteristics in China from the scale and efficiency perspectives. *J. Clean. Prod.* 212, 610–621. doi: 10.1016/j.jclepro.2018.12.063

Yu, J., and Wu, J. (2018). The sustainability of agricultural development in China: the agriculture–environment nexus. *Sustain. For.* 10:6. doi: 10.3390/su10061776

Zang, L., Wang, Y., Ke, J., and Su, Y. (2022). What drives smallholders to utilize socialized agricultural services for farmland scale management? Insights from the perspective of collective action. *Land* 11:930. doi: 10.3390/land11060930

Zhan, S. (2017). Riding on self-sufficiency: grain policy and the rise of agrarian capital in China. *J. Rural. Stud.* 54, 151–161. doi: 10.1016/j.jrurstud.2017.06.012

Zhang, S., Li, B., and Yang, Y. (2021). Efficiency analysis of scientific and technological innovation in grain production based on improved grey incidence analysis. *Agriculture* 11:1241. doi: 10.3390/agriculture11121241

Zhang, D., Wang, H., and Lou, S. (2021). Research on grain production efficiency in China's main grain-producing areas from the perspective of grain subsidy. *Environ. Technol. Innov.* 22:101530. doi: 10.1016/j.eti.2021.101530

Zhang, H., Zhang, J., and Song, J. (2022). Analysis of the threshold effect of agricultural industrial agglomeration and industrial structure upgrading on sustainable agricultural development in China. *J. Clean. Prod.* 341:130818. doi: 10.1016/j.jclepro.2022.130818

Zhou, C., Liang, Y., and Fuller, A. (2021). Tracing agricultural land transfer in China: some legal and policy issues. *Land* 10:1. doi: 10.3390/land10010058

Zhu, W., Qi, L., and Wang, R. (2022). The relationship between farm size and fertilizer use efficiency: evidence from China. *J. Integr. Agric.* 21, 273–281. doi: 10.1016/S2095-3119(21)63724-3

Zhu, Y., Waqas, M. A., Li, Y., Zou, X., Jiang, D., Wilkes, A., et al. (2018). Large-scale farming operations are win-win for grain production, soil carbon storage and mitigation of greenhouse gases. *J. Clean. Prod.* 172, 2143–2152. doi: 10.1016/j.jclepro.2017.11.205