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The impact of socialisation services in the whole process of agricultural production on food security—quasi-natural experimental evidence from China

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Food security (FS) is an important guarantee for world peace and development and the basis for building a community of human destiny, which has a bearing on the sustainable development and future destiny of humankind. This study empirically analysis the relationship between socialisation services in the whole process of agricultural production (ASS) and guaranteeing FS, as well as the path of their role, using provincial panel data from 2010 to 2022 in China as an example, using the double-difference method. The regression results show that ASS can have the ability to contribute to the level of FS, and the conclusion still holds after a series of robustness tests. The results of the heterogeneity analysis show that the role of ASS in guaranteeing FS receives the influence of the level of agricultural development in each region, while it plays a greater role in the main food-producing areas. The mechanism analysis analyses the mechanism of the role of ASS in the whole process of agricultural production in guaranteeing FS from the three links of pre-production, mid-production and post-production respectively, and finds that ASS in the whole process of agricultural production is able to guarantee FS by reducing the cost of purchasing means of production in the pre-production stage, fostering a new type of agricultural management main body in the mid-production stage, and increasing the income of farmers' household management in the post-production stage. Based on the above findings, this study proposes corresponding policy recommendations. This study can provide insights for ensuring world FS and contribute to maintaining social stability and development. The conclusions of the study are universally applicable, and all countries in the world can benefit from and draw lessons from it.

KEYWORDS

socialisation services in the whole process of agricultural production (ASS), food security (FS), means of agricultural production, new agricultural business entities, farmers' household income

1 Introduction

'Food is the God of the people', agriculture is part of the social, economic, cultural and environmental system and is an important part of the global economy and its driving force (Achterbosch et al., 2014). The gradual shortage of energy in the world, accompanied by an increase in the international price of crude oil (Vochozka et al., 2020a,b), indirectly leads to an increase in the cost of agricultural production. Against this background the costs of crude

agriculture are gradually rising, while the output is not able to sustain the national demand. In contrast, the advantages of sustainable agriculture with a higher return on investment are gradually emerging (Pavolova et al., 2021; Akbari et al., 2021). Although the development of sustainable agriculture accompanied by agro-technological innovations, such as the extraction of silica nanoparticles from the pith of coconut shells to improve seed germination (Maroušek et al., 2022), as well as energy innovations, such as the utilisation of renewable energy sources (Bencoova et al., 2021) can be effective in guaranteeing the conduct of the agricultural process, and consequently FS. However, with the continuous growth of the population, the problem of FS can still not be underestimated (Liu and Zhong, 2024). At the same time, due to the differences in the level of development of countries around the world, there are gaps in food production and security capacity. Taking China as an example, in 2020, the world's average yield level of rice is 4,609 kg/hm^2, and China's average yield level of rice is 7079.59 kg/hm^2, which is higher than the world's average; however, compared with developed countries, such as the United States, which has an average yield level of rice of 8,540 kg/hm^2, there is still a large gap in China (Song and Jiang, 2024).

In order to enhance farmers' motivation in land management, increase the scale of agricultural business, improve agricultural production capacity, reduce dependence on the international food market and guarantee FS, ASS has emerged. As an integral part of modern agriculture, ASS can effectively improve the efficiency of agricultural production and guarantee FS (Kong et al., 2009). On the one hand, ASS connects to the vast number of small farmers on the demand side, and through the services, it links up the scattered small farmers and improves the organisation of small farmers (Gao and Kong, 2013). On the other hand, ASS on the supply side connects diversified agricultural service subjects with higher degree of organisation, which can more economically and efficiently meet the diversified agricultural service demands of dispersed small farmers, and then realise the development drive of small farmers to integrate into modern agriculture (Guo and Wen, 2023). However, despite the development of ASS, there are still deficiencies; therefore, combining the current situation of China's FS and ASS, it is of great research value to study how to effectively improve the level of FS by relying on the guarantee of ASS.

2 Literature review

FS is a highly complex phenomenon that depends on social, cultural and political systems as well as environmental factors (Arezki and Bruckner, 2011). There is a distinction between FS in a narrow sense, which relates to the output of food crops, and a broader sense, which relates to agriculture as a whole, including fisheries. This study examines FS at the narrow level. Research on FS has focused on food security measurement, connotations, and influencing factors. The connotation of FS is: quantity sufficiency, that is, the sufficiency of food production and supply is the first condition for guaranteeing FS; second is quality safety, people should eat healthy and feel relieved. The third supply structure should be balanced, that is, the food supply should be comprehensive and focus on nutritional matching; finally, sustainable production should be carried out without destroying the ecological balance and wasting resources (Wang and Zhou, 2016). FS has many influencing factors. Some of the studies on the exploration of the factors affecting FS are also related to the measurement of FS. It has been pointed out that the sown area of grain (Chen et al., 2011), fertiliser inputs (Lv et al., 2022), effective irrigation coverage, germplasm resources (Xie and Li, 2021), and the construction of social safety nets (Khan et al., 2023), environmental tax (Samusevych et al., 2021) have a positive impact on FS, and in order to guarantee national FS, a long-term mechanism to promote stable and increased food production that is compatible with the market mechanism should be gradually established and improved (Liu, 2014). In addition, it was found through grey correlation method analysis that the equipping of agricultural machinery was equally important factor affecting FS (Wang et al., 2018). In terms of negative impacts, poor social governance (Khan et al., 2024a), population growth, low levels of agricultural production, and climate change, especially warming, can pose a threat to FS (Khan et al., 2024b).

ASS requires the use of various types of equipment, machinery and other services such as information input, land preparation for harvesting and other basic processes known as services and mechanisms (Manta and Aduba, 2013; Akinbamowo, 2013; Mrema et al., 2014). Existing studies on ASS mainly focus on the role of social services, problems, current situation, countermeasures and other qualitative theoretical analyses. It has been pointed out that ASS can further promote the reduction of chemical fertiliser application by upgrading plot size and promoting off-farm employment of labourers (Zhang M L, et al., 2023); and alleviate the phenomenon of farmers' land abandonment by alleviating the constraints of technology, labour force, and efficiency (Zeng and Shi, 2022; Yang, 2023). ASS can achieve high-quality development of agriculture by changing production participation, production scale and production mode, and can effectively improve agricultural production efficiency (Tang et al., 2022; Lin et al., 2022) and promote farmers' income (Yang, 2022). At present, although China's ASS has made great progress, there are still the following problems: low government management efficiency and lack of targeted policies (Tong, 2016), slow construction speed and low service level (Lin et al., 2016), imbalance in personnel structure and shortage of professionals (Sun et al., 2018), insufficient capacity and imbalance in the supply of services (Sun et al., 2019). Therefore, China's ASS still needs to make improvements in the management system, service system, talent training, and service capacity (Liu et al., 2022).

In summary, existing research on ASS and FS provides a good theoretical basis for this study and reveals the intrinsic interconnectedness of ASS to ensure FS. However, there are still certain shortcomings in the existing studies. Although it has been pointed out that ASS can effectively improve the eco-efficiency of arable land, the eco-efficiency of arable land as a comprehensive representation of the level of FS is one-sided. In contrast, there is a lack of empirical research evidence on the relationship between ASS and FS, and the mechanism of action that can provide causal identification of the connection. Therefore, this study makes an expansion in the following aspects: analysing the role of ASS in ensuring FS by means of empirical analysis; divide ASS into pre-production, mid-production and post-production segments, and explore the role of ASS in ensuring FS; based on the findings of the empirical analyses, targeted policy advice for FS is provided.

3 Theoretical analysis

In order to better understand the impact of ASS on safeguarding FS, so that scholars from all over the world can clearly sort out the mechanism of action, this study uses theoretical analysis to sort out the path of action of ASS in safeguarding FS. Based on the theoretical analysis, this study proposes corresponding research hypotheses and confirms them later. The ASS provides farmers with the opportunity to obtain better services with lower inputs by integrating the needs of dispersed farmers (Zeng and Shi, 2021), and its services cover the three stages of pre-production, mid-production and post-production. ASS can provide group-buying services in the pre-production period, obtain production materials at lower prices, save production costs, and stimulate farmers' motivation to increase production to ensure FS (Pang, 2006; Kong et al., 2009). In production, taking the application of agricultural mechanisation as an example, considering the nature of large-scale operations and input costs, more and more smallholders are choosing to outsource agricultural machinery services (Paudel et al., 2019), and for smallholders, the investment in agricultural machinery is a relatively large expenditure, while the sunk costs of machinery are relatively high. As a result, smallholders usually do not have the incentive to purchase their own machinery (Zhou et al., 2020), and in order to manage agricultural production more efficiently, smallholders prefer to outsource the labour-intensive production process to provide technical support services, and the outsourcing of the production process is mainly realised through service organisations such as new agricultural management entities (Belton et al., 2021). Services in the post-production chain are mainly based on processing, storage, transport and marketing. Compared to industrial products, initial agricultural products are of low value and difficult to sell at a good price. Socialised services enhance the added value of agricultural products through deep processing of agricultural products after production, while relying on service organisations to effectively safeguard the sales channels of agricultural products, which effectively promotes the stability and growth of farmers' income (Li and Cui, 2016). In summary, the following hypotheses were formulated for this study:

> *H*1. ASS can effectively guarantee FS.
>
> *H*2. ASS can guarantee FS by reducing the cost of purchasing agricultural production materials.
>
> *H*3. ASS can guarantee FS by fostering new agricultural management entities.
>
> *H*4. ASS can guarantee FS by increasing farmers' household income.

4 Research design

4.1 Model construction

This study aims to examine the impact of agricultural socialisation services on FS. The specific idea of this study is to take the pilot of ASS as an entry point and divide 30 regions in China into experimental and control groups. Pilot areas were the experimental group and non-pilot areas were the control group. The impact of agricultural socialisation services on FS is analysed by comparing pilot and non-pilot areas horizontally and adding a time factor to consider a longitudinal comparison of the time series. The specific design is as follows:

4.1.1 Differences in differences model construction

The pilot policy on ASS started in 2016 and the implementation area includes 17 provinces in China. Therefore, this study uses a differences in differences model to analysis the impact of ASS on ensuring FS by comparing the experimental group with the control group.

$$Y_{it} = \alpha_0 + \alpha_1 didd_{it} + \gamma X_{it} + \nu_i + \mu_t + \varepsilon_{it} \quad (1)$$

Where Y_{it} is the level of FS and $didd_{it}$ is the core explanatory variable, which refers to whether or not the ASS policy was implemented in a region in a given year. The core explanatory variables were obtained by multiplying the area dummy with the time dummy, with the area dummy set to 1 for the experimental group and 0 for the control group.

The time dummy variable is set to 0 before 2016 and 1 for 2016 and beyond. The model controls for time and area effects.

4.1.2 Parallel trend test model construction

$$Y_{it} = \alpha + A^{-5} + A_{it}^{-4} + \cdots + A_{it}^{3} + A_{it}^{4} + A_{it}^{5} + A_{it}^{6} + A_{it}^{7} + \gamma X_{it} + \nu_i + \mu_t + \varepsilon_{it} \quad (2)$$

The prerequisite for the use of the differences in differences model is to pass the parallel trend test, so this study constructs the parallel trend test model as above. In Equation 2, $didd_{it}$ is replaced by A_{it}, and 2010 is dropped as the base year to avoid multicollinearity.

4.2 Variable selection and data sources

4.2.1 Variable selection

1. Explained variables. According to the previous analysis, the present study is based on the combination of previous studies (Izraelov and Silber, 2019; Li and Wang, 2023; Cui and Nie, 2019). A system of indicators for evaluating the level of FS was constructed from four levels: quantitative security, environmental security, quality security and trade security, and was measured using the entropy method.

Quantitative security includes: grain output, *per capita* grain output, grain output per unit of arable land area, grain output volatility, and the area of agricultural natural disasters. Grain output volatility is calculated as $(Y_t\text{-}Y_t`)/Y_t`$, with Y_t being the grain output in year t and $Y_t`$ being the predicted output, which is calculated from the 5-year moving average (Zhang M L, et al., 2023).

Environmental security includes: fertiliser use, pesticide use, agricultural film use, and agricultural carbon emissions. It is important to note that while more effective carbon sequestration technologies have been innovated (Maroušek et al., 2023). Still, the generation of carbon emissions from agriculture cannot be ignored. Agricultural carbon emissions are calculated with reference to Zhu and Huo's way

of calculation (Zhu and Huo, 2022) calculated as shown in Equation 3, Car_{it} is the total amount of carbon emissions, E_{it} is the total amount of each carbon emission source, and α_{it} is the carbon emission coefficient of each carbon emission source. The table of carbon emission coefficients is shown in Table 1.

Quality security includes: *per capita* arable land area, effective irrigated area, financial expenditure on agricultural production, agricultural mechanisation level, grain replanting index.

Trade security includes: trade dependence, trade competition index. Trade dependence is measured by the ratio of food imports to total food imports and exports; the trade competition index is calculated as: food exports—food imports / food exports + food imports.

The specific construction method is shown in Table 2.

$$Car_{it} = \sum E_{it} \times \alpha_{it} \quad (3)$$

2. Core explanatory variables. $didd_{it}$ is the core explanatory variable, which refers to whether or not a region has implemented a policy on socialisation services for the whole process of agricultural production in a given year. It is generated as shown above.
3. Control variables. The control variables selected for this study include two categories, one of which is the variables reflecting the state of agricultural and rural development, including the level of labour input in the plantation industry (X1), measured by the ratio of the number of labourers in the plantation industry to the rural population; the level of rural electric power consumption (X2), measured by the total amount of rural electric power consumption; the status of rural outbound workers (X3), measured by the ratio of the number of rural outbound workers to the rural population; the level of land transfer (X4), measured by the ratio of the land transfer area to the total cultivated area; and the status of small farm economy (X5), measured by the number of farm households with an operating scale of less than 10 mu. (X3), measured by the ratio of the number of rural migrant workers to the rural population; the level of land transfer (X4), measured by the ratio of the area of land transferred to the total area of cultivated land; and the status of the small-farm economy (X5), measured by the ratio of the number of farm households with a business size of less than 10 mu to the total number of farm households. The other category responds to regional economic development, including: the level of financial development (X6), measured by the ratio of the balance of deposits in financial institutions to the balance of loans in financial institutions; and the level of domestic trade (X7), measured by the ratio of total domestic retail sales of consumer goods to GDP.
4. Mechanism variables. According to the previous analysis, the mechanism variables selected for this study are: agricultural production costs (M1), measured by the ratio of agricultural intermediate consumption to agricultural GDP; new agricultural business entities (M2), measured by the number of new agricultural business entities; and income from the sale of agricultural products (M3), measured by the average *per capita* income of farmers' family business, which refers to the income earned by farmers from the sale of agricultural products.

Descriptive statistics for each variable are shown in Table 3.

5 Analysis of empirical results

5.1 Analysis of regression results

Table 4 presents the regression results computed from Equation 1. Column (1) of Table 4 reports the results of the double difference model without the inclusion of control variables. Column (2) of Table 4 reports the results of the differences in differences model with the inclusion of control variables. In the regression approach, both control for time and region and both use robust standard errors. Based on the regression results, it can be seen that the relationship between the explanatory variables and the core explanatory variables is significantly positive regardless of whether control variables are added or not. This indicates that ASS can significantly guarantee FS. The benchmark regression validates hypothesis H1 of the study.

5.2 Robustness tests

5.2.1 Parallel trend test

The use of the differences in differences model presupposes that the model can pass the parallel trend test. If there is no significant difference between the explanatory variables of the control group and the experimental group before the implementation of the pilot policy of socialised production whole process services, it means that the model has passed the parallel trend test. For ease of understanding, this study uses a graphical presentation of the results of the parallel trend test, as shown in Figure 1. In Figure 1, if the blue line does not

TABLE 1 Carbon emission source coefficients.

Carbon emissions sources	Carbon emissions coefficient	Sources
Ploughing	312.6 kg C/km^2	School of Biology and Technology of China Agricultural University
Diesel fuel	0.5927 kg C/kg	IPCC United Nations Intergovernmental Committee of Experts on Climate Change
Agricultural film	5.18 kg C/kg	Institute of Agricultural Resources and Ecological Environment of Nanjing Agricultural University
Pesticide	4.934 kg C/kg	Oak Ridge National Laboratory of the United States
Fertiliser	0.8956 kg C/kg	Oak Ridge National Laboratory of the United States
Irrigation	25 kg C/km^2	Dubey and Lal, 2009

TABLE 2 Indicator system for evaluating the level of FS.

Indicator category	Indicator name	Description of indicators	property
Quantitative security	Grain output	Million tonnes	Positive
	Per capita grain output	Grain production/total population	Positive
	Grain output per unit of arable land area	Grain production/area of arable land	Positive
	Grain output volatility	–	Negative
Environmental security	The area of agricultural natural disasters	Million acres	Negative
	Fertiliser use	Million tonnes	Negative
	Pesticide use	Million tonnes	Negative
	Agricultural film use	Million tonnes	Negative
	Agricultural carbon emissions	Million tonnes	Negative
Qualitative security,	*Per capita* arable land area	Arable land/total population	Positive
	Effective irrigated area	Million acres	Positive
	Financial expenditure on Agricultural production	Million	Positive
	Agricultural mechanisation level	Million kilowatts	Positive
Trade security	Grain replanting index	Grain sown area/total sown area	Positive
	Trade dependence		Negative
	Trade competition index		Positive

TABLE 3 Descriptive statistics.

Variable category	VarName	Unit	Average value	Standard deviation
Explanatory variable	Level of FS	–	0.36	0.08
Core explanatory variables	$didd_{it}$	–	0.26	0.44
Control variable	X1	–	0.22	0.08
	X2	Billion kW/h	289.83	419.26
	X3	–	0.24	0.21
	X4	–	0.37	0.14
	X5	–	0.81	0.19
	X6	–	1.32	0.25
	X7	–	0.38	0.07
Mechanism variables	M1	–	0.42	0.07
	M2	individual	42446.30	37378.02
	M3	RMB/person	4402.53	1661.68

intersect with the 0 scale, it means that there is a significant difference between the experimental group and the control group. If they intersect, it means that there is no significant difference. For ease of viewing, the study intercepted parallel trend test plots for 4 years before the policy and 3 years after the policy. Figure 1 shows that before 2016, there is no difference between the experimental and control groups and after 2016, the difference exists. This indicates that the model passes the parallel trend test (Ye et al., 2023). The reason for this is that in 2016 there was no significant difference in the level of FS between pilot and non-pilot areas before the policy was implemented, significant differences in FS levels between pilot and non-pilot areas after policy implementation, therefore it can be judged to have a policy effect and the test passes.

5.2.2 Propensity score matching test

In order to reduce the impact of too much variation between the samples and thus on the regression results, this study examines the regression results by using a combination of propensity score matching with a differences in differences model. In this study, the variables of the control variables that can reflect the status of rural and agricultural development are used as matching variables. For the matching method, nearest neighbour matching (1:4) and kernel density matching were chosen. The matching results are shown in columns (3) and (4) of Table 4. The results show that no matter which matching method is used, the regression results are significantly positive after eliminating the unsuccessful matching variables, which verifies the correctness of the conclusions of this study.

After propensity score matching, the differences between the variables after matching need to be tested, and the deviation of each matching variable after matching should not exceed 10%. The deviation of each matching variable before and after matching is shown in Figure 2. According to Figure 2, it can be seen that the matching results of both matching methods are within the acceptable range, so the propensity score matching results can be used.

5.2.3 Placebo test

In order to avoid bias in the results due to omitted variables and unobservable problems between the experimental and control groups, this study conducted a placebo test on the regression results. Specifically, regression analyses were performed on different sample combinations by disrupting the experimental and control groups, and this process was carried out 1,000 times, and the results of the 1,000 regressions were presented by means of kernel density plots, and the results are shown in Figure 3. Figure 3 shows that the kernel density plot obeys normal distribution and the regression coefficients are all around 0, indicating that the placebo test is passed. Further proof of the correctness of the results.

TABLE 4 Benchmark regression result.

	(1)	(2)	(3)	(4)
	FS	FS	FS	FS
$didd_{it}$	0.069***	0.063***	0.070***	0.076***
	(0.010)	(0.010)	(0.010)	(0.011)
X1		0.091	0.055	0.052
		(0.037)	(0.054)	(0.059)
X2		0.225***	0.221***	0.353***
		(0.063)	(0.065)	(0.106)
X3		0.063**	0.157***	0.028
		(0.034)	(0.044)	(0.051)
X4		0.107**	0.041	0.036
		(0.046)	(0.044)	(0.036)
X5		−0.106***	−0.097**	−0.080
		(0.079)	(0.048)	(0.049)
X6		0.397***	0.018	0.018
		(0.039)	(0.037)	(0.038)
X7		0.192*** (0.147)	0.478***(0.147)	0.538***(0.147)
Region Time	Control Control	Control Control	Control Control	Control Control
_cons	0.298***	−0.092	−0.130	−0.173
	(0.004)	(0.116)	(0.116)	(0.113)
N	389.000	389.000	326.000	290.000
r2	0.939	0.943	0.948	0.950

Standard errors in parentheses. *$p<0.1$, **$p<0.05$, ***$p<0.01$.

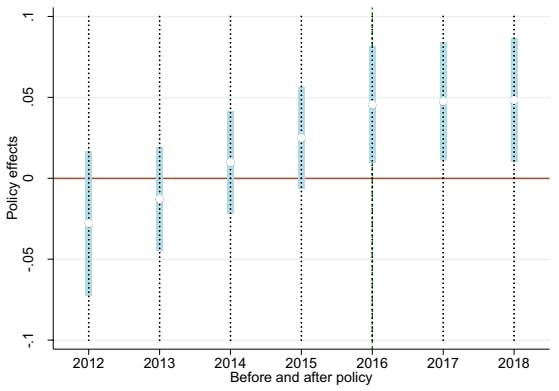

FIGURE 1
Parallel trend test.

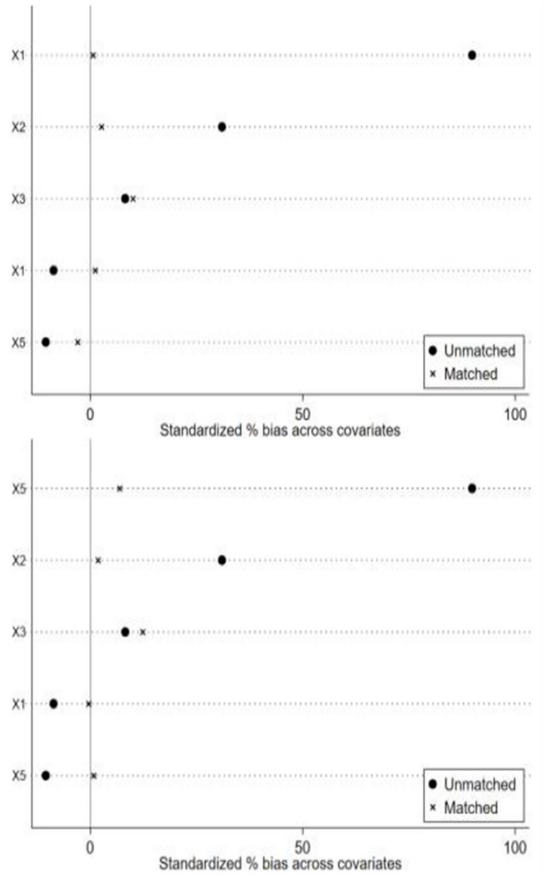

FIGURE 2
Balance test.

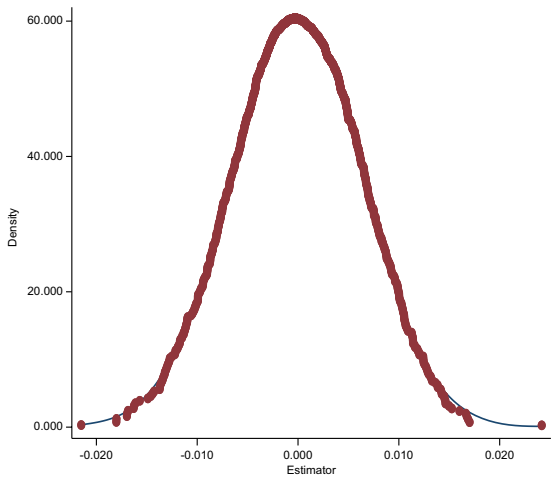

FIGURE 3
Placebo test.

6 Heterogeneity analysis

6.1 Differences in the level of agricultural development

This section analyse whether differences in the level of agricultural development affect the policy effect of ASS by creating an interaction term. By introducing the interaction term between the moderating variables and the core explanatory variables in Equation 1 is able to analyse the moderating effect, and if the interaction term is significant, it means that the moderating effect exists. The regression results are shown in column (1) of Table 5. The results show that the coefficient

of the interaction term is significantly positive, indicating that socialised services in the whole process of agricultural production can have a greater effect in areas with a higher level of agricultural development.

6.2 Heterogeneity analysis of the main food-producing regions

Based on the previous assumptions, this part aims to examine whether ASS in areas belonging to the main food-producing regions would have a more optimal role. The relevant operational methods can be group regression or interaction term regression. Since grouped regressions lead to a reduction in the overall sample size, which could potentially affect the regression results, this study used interaction term regressions. In this study, the areas belonging to the main food-producing regions were set to 1 and the rest to 0. Multiplying this with the time dummy and area dummy in Equation 1 yields the triple difference dummy (didd1). If the triple difference dummy variable is 1, it means that the region is both a major food-producing area and has implemented the ASS policy. If it is 0, then one of the two conditions is not satisfied. The regression results are shown in column (2) of Table 5. The results show that the triple difference dummy variables are significantly positive and the coefficients of the core explanatory variables have increased compared to the original regression equation's. This suggests that policies for ASS within the main food-producing regions are more effective.

TABLE 5 Heterogeneity analysis.

	(1)	(2)
	FS	FS
$didd_{it}$	0.069***	
	(0.01)	
Level of agricultural development	0.185**	
	(0.219)	
inter1	0.218***	
	(0.096)	
didd1		0.101*** (0.011)
Region Time	Control Control	Control Control
_cons	0.179	−0.075
	(0.063)	(0.080)
N	389.000	389.000
r2	0.956	0.953

Standard errors in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

7 Mechanism of action analysis

In this study, a three-step approach was used to analyse the mechanism of action. On the basis of the original regression equation, the mechanism variable m is used to replace the explanatory variables with the core explanatory variables in the regression, and if the result is significant, it indicates that the mechanism of action may exist. On this basis, the mechanism variable is added to the original regression equation, and if the mechanism variable is still significant and the significance of the core explanatory variable decreases or disappears, the mechanism of action exists. Table 6 reports the results of mechanism analysis. The results show that the relationship between each mechanism variable and the core explanatory variables is significant. After adding the original regression equation, the significance of the core explanatory variables decreased and the mechanism variables remained significant. This suggests that ASS can guarantee FS by reducing agricultural production costs before production, strengthening the cultivation of new management subjects during production, and increasing the selling price of agricultural products after production. Mechanistic analysis validated the research hypotheses H2, H3, and H4.

TABLE 6 Analysis of mechanisms.

	(1)	(2)	(3)	(4)	(5)	(6)
	M1	M2	M3	Food security	Food security	Food security
$didd_{it}$	−0.020**	0.112***	0.069***	0.060***	0.027***	0.053***
	(0.078)	(0.051)	(0.047)	(0.039)	(0.035)	(0.041)
M1				−0.140***		
				(0.044)		
M2					0.322***	
					(0.031)	
M3						0.143*** (0.055)
Region Tmie	Contorl Contorl	Contorl Contorl	Contorl Contorl	Contorl Contorl	Contorl Contorl	Contorl Contorl
_cons	0.407***	0.295***	0.569***	−0.035	−0.187**	−0.173**
	(0.112)	(0.089)	(0.109)	(0.074)	(0.072)	(0.087)
N	389.000	389.000	389.000	389.000	389.000	389.000
r2	0.935	0.893	0.948	0.951	0.961	0.951

Standard errors in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

8 Conclusion and policy recommendations

8.1 Conclusion

This study analysis the impact of ASS on safeguarding FS and the mechanism of its action using a differences in differences model. The study found that 1. ASS can effectively guarantee FS. 2. ASS can play a better role in major food-producing areas or areas with a higher level of agricultural development. 3. The mechanism of action found that ASS can guarantee FS by reducing the cost of agricultural production, fostering new agricultural business entities, and increasing farmers' income. It should be noted that the results of the mechanism of action analysis in this study corroborate the research hypotheses in the theoretical analysis section of this study. These conclusions are derived by means of an empirical study using Chinese provincial panel data for the years 2010-2022. However, from an international perspective, this study can provide valuable insights and lessons learned from China's experience in promoting ASS for FS in countries around the world.

Compared to existing studies, the present study reached similar conclusions to existing studies in ASS to secure FS. It has been shown that ASS can improve agro-ecological efficiency (Cheng, 2022; Leng, 2023). Compared with existing studies, the contributions of this study are as follows: 1. Existing studies have only analysed the role of ASS from the perspective of eco-efficiency, which does not adequately represent the level of FS. Based on the existing studies, this study incorporates economic and social variables to more comprehensively analyse the impact of ASS on ensuring FS, specifically including *per capita* arable land area, *per capita* food yields, food volatility, agricultural natural disasters, government financial expenditure and other factors, which is more comprehensive and scientific compared with the results of existing studies. 2. This study additionally analysis the heterogeneity factors of ASS to ensure FS. 3. This study analysis the mechanism of ASS to ensure FS from the perspectives of pre-production, mid-production and post-production, which have not been found in existing studies, and this study complements and improves the existing studies.

8.2 Policy recommendations

1. National level: Deepening the implementation of ASS. According to the natural, economic and social characteristics of each region, targeted implementation of ASS; focusing on promoting the promotion and implementation of ASS in the main food-producing regions, giving full play to the advantages of equipment, facilities, land and other resources in the main food-producing regions, and effectively guaranteeing FS; strengthening assistance and guidance for regions that are not the main food-producing regions, and providing support in terms of funding, technical personnel and so on; give full play to the role of the main grain-producing areas in driving non-main grain-producing areas in the neighbourhood, so as to make up for the shortcomings of non-main grain-producing area.
2. Regional level: Provinces should continue to implement direct subsidies for grain farmers, specify the target recipients of the subsidies, set reasonable standards, and provide subsidies for the purchase of farmers' means of production, so as to reduce the costs of purchasing and using means of production; strengthen the cultivation of new types of agricultural business entities such as leading enterprises and cooperatives, and give full play not only to their roles in technical training and production guidance during the process of production, but also to their roles of lowering the costs of purchasing means of production before the process of production and providing integrated services of processing, storage and marketing after production, thus increasing the selling price of grain.

8.3 Future prospects

There is still some scope for improvement in this study. Currently, the use of computers and artificial intelligence (Kliestik et al., 2023; Dvorský et al., 2023), digital technologies (Valaskova et al., 2024; Kliestik et al., 2024) plays an increasingly important role in economic development. In the future we believe that it can play a great role in the field of agricultural development and ensuring FS. In addition, technological innovations in agriculture are constantly taking place, which include not only aspects of grain production and processing, but also production and processing of other crops, for example, innovations in oil extraction technology can effectively increase the supply of oilseeds (Maroušek, 2014; Maroušek et al., 2015). Therefore, in the future, this study will refine the research object. In the choice of explanatory variables, this study is not limited to food crop production, but will take the production security situation of the whole agricultural crop plantation industry as the main object of study; in the choice of core explanatory variables, this study will analyse how to guarantee FS more effectively from the perspective of the combination of artificial intelligence technology, digital technology and ASS.

Data availability statement

Publicly available datasets were analysed in this study. This data can be found at: Data from China Statistical Bureau (https://www.stats.gov.cn/).

Author contributions

YT: Writing – original draft. CZ: Funding acquisition, Writing – review & editing.

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Conflict of interest

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

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