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Do agricultural productive services alleviate farmland abandonment? Evidence from China rural household panel survey data

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As an important means to solve "who will farm" and "how to farm" in the future, agricultural productive services change the allocation structure of agricultural factors and play an important role in alleviating farmland abandonment. This study uses the 2017 China Rural Household Panel Survey data and adopts the logistic model, the IV Tobit model, and the mediating effect model to investigate the impact of agricultural productive services on farmland abandonment. The results show: (1) Agricultural productive services significantly reduce farmland abandonment by 1.51% on average. (2) Mechanism analysis implies that agricultural labour substitution, land transfer effect, and technological adoption effect play important intermediary roles in alleviating farmland abandonment. (3) Moreover, compared with the eastern, central, and non-karst regions, agricultural productive services failed to reduce farmland abandonment in the western and karst regions with poor terrain conditions. Agricultural productive services could alleviate the farmland abandonment of small farmers and elderly farmers. Therefore, agricultural productive services contribute to the reuse of small-scale plots.

KEYWORDS

farmland abandonment, agricultural productive services, CRHPS data, China, mediating effects

1 Introduction

With the rapid development of industrialization and urbanization, the income gap between urban and rural areas continues to expand, and the income structure of rural households has experienced profound changes (Xu et al., 2017). A large number of the rural population chose to work in the city to obtain higher income, which led to the ageing of agricultural production. The outflow of the rural population and the ageing of the rural labour force have caused significant changes in land use, such as the abandonment of farmland (Chen et al., 2014). Moreover, Since the 1980s, the Household Contract Responsibility System (HCRS) has been implemented in China, dividing land property rights into ownership and tenure rights, redistributing the tenure right to individual households, and improving the farming enthusiasm of farmers. During the allocation of tenure rights, one household had more than one plot of land with different sizes and space divisions, which formed a land fragmentation management pattern. Small-scale and

fragmented land impedes the adoption of advanced technology and reduces the efficiency of agricultural factor allocation. Due to the low efficiency of agricultural production, many scattered and fragmented lands have been abandoned (Xu et al., 2019b). It can be found that with the rapid development of China's economy and society, the farmland abandonment phenomenon has become more serious. Land abandonment poses big challenges to safeguarding national food security and maintaining ecosystem diversity (Li and Li, 2017). The Chinese government has implemented a series of policies such as land system reform, land protection subsidies, and the development of land transfer markets to alleviate farmland abandonment, but the overall effect is not obvious.

Land abandonment belongs to the inefficient performance of agricultural production behaviour, resulting in land waste and other production factors. Therefore, how to solve the problem of abandoned land has become a concern of the central government, which is essential to safeguard food security and stick to the red line of 1.8 billion mu of cultivated land in China (Chen et al., 2022). The central government pointed out that alleviating farmland abandonment can be achieved by developing agricultural productive services (APS). In China, APS refer to professional service organizations such as agricultural service enterprises and farmers' cooperatives that provide grain farmers with land preparation service, sowing service, pest control service and harvesting service. APS could effectively improve agricultural production efficiency and compensate for the lack of agricultural labour force. On the one hand, APS optimizes the allocation structure of agricultural factors and improves agricultural productivity (Chen et al., 2022; Wang et al., 2022). The rapid development of the agricultural service market promotes the transformation and upgrading of land and labour factor markets. For example, service providers usually have advanced mechanical equipment and technology, which can change the traditional production mode of farmers and promote agricultural modernization, which may be conducive to reducing land abandonment. On the other hand, APS helps to reduce production costs and improves unit labour productivity, which increases farmers' enthusiasm for farming and reduces the probability of farmland abandonment (Cai et al., 2021). APS helps to promote continuous planting, thus reducing land abandonment caused by land fragmentation. In addition, APS is beneficial to the sustainability of the agriculture industry. Farmers relying on professional service organizations can achieve the scientific application of pesticides and fertilizers, which reduce agricultural non-point source pollution and improve soil fertility.

At present, many scholars have systematically discussed the driving factors of farmland abandonment from the micro level. Farmers, as the users and beneficiaries of cultivated land resources, play critical roles in the decision to abandon the land. Economic and social characteristics, biophysical factors, and political and regulatory factors are the important factors affecting the farmland abandonment behavior of farmers (Xu et al., 2019a; Subedi et al., 2021; Li and Lee, 2022). In terms of economic factors, due to technical and financial constraints, it is difficult for farmers to benefit from land cultivation, and they tend to choose to go out to work for better income, which leads to land abandonment (Deng et al., 2018a; Xu et al., 2019b; Ma and Zhu, 2020). There are three types of land management: owner-farmed land, transferred land, and abandoned land. Higher agricultural production costs and lower income make scattered and small-scale land difficult to transfer for profit, and the land that cannot be transferred out will be abandoned by farmers (Lieskovský et al., 2015; Cheng et al., 2022). Moreover, some farmers still have a "land complex", so they would rather abandon the cropland than transfer it out (Whalley and Zhang, 2007; Zhang et al., 2022; Xue et al., 2022). Regarding social factors, with the rapid development of urbanization and industrialization, the non-agricultural rural population has exceeded the first turning point of Lewis (Zhou, 2017; Zhao et al., 2022). The negative impact of rural population reduction has gradually become prominent, which leads to the ageing of the rural labour force, and no one cultivates rural land. Older farmers close to retirement are more likely to make decisions on land abandonment due to physical exhaustion (He et al., 2020). The New Rural Pension Scheme replaces the endowment insurance function of the land, which increases the probability of the elderly abandoning their farmland (Min et al., 2022). Internet use can reduce farm households' cropland abandonment by 43.20% (Deng et al., 2019).

Regarding biophysical factors, topography, soil type (Baumann et al., 2011), and land slope (Subedi et al., 2021) are the main factors affecting land abandonment. Poor topographic conditions tend to increase farmers' management and machine operation costs, making it difficult for farmers to obtain equal returns on agricultural production inputs, which leads to farmland abandonment (Xu et al., 2017; Deng et al., 2018b). This is also the reason for land abandonment in some mountainous and hilly areas. Land far away from each other could increase the costs of farming management, resulting in land abandonment (Sklenicka and Salek, 2008). Land abandonment occurs first in locations far from farmers' homes with bad irrigation conditions and poor land quality (He et al., 2020). The more fragmented the land, the greater the probability of being abandoned. In terms of political and regulatory factors, the resettlement policy, land rental market and the reform of land certification have a significant impact on the land abandonment of farmers. The resettlement policy makes farmers far away from cultivated land, and the increasing in agricultural operation cost leads to land abandonment (Wang et al., 2020). An imperfect land rental market, such as lower land transfer prices and less land transfer demand, increases the probability of abandoned land of farmers (Alcantara et al., 2013; Lieskovský et al., 2015). The reform of land certification helps prevent farmers from abandoning their farmland by improving soil fertility, promoting land transfer, and improving agricultural income (Zheng and Qian, 2021).

The above research mostly discusses the driving factors of farmland abandonment from biophysical factors, social and economic characteristics, political and regulatory factors. However, few studies have focused on the impact of APS on the land abandonment of farmers. APS embed modern machinery and green production technology into agricultural production, which could alleviate labour and technical constraints of farmers and improve farmers' farming ability (Liao et al., 2021). Farmers are less likely to abandon land when they can benefit from agricultural activity (Ma et al., 2022). Agricultural machinery services reduce the probability that small farmers exit from agricultural production through land abandonment but increase the probability through land renting out (Baiyegunhi et al., 2019; Qiu et al., 2021).

Agricultural machinery services promote the marketization of land transfer, and the rise of land rent increases the probability of the land transferred by small farmers. Pest control outsourcing services significantly decrease the size of land abandonment (Zhang et al., 2022). Machinery harvesting service has a significant negative impact on land abandonment (Xue et al., 2022). A few studies explore the impact of agricultural services on land abandonment, which only focus on the mechanical services in a certain link and the issues discussed need to be more comprehensive. Different links of services have different impact mechanisms on land abandonment. The existing research needs more theoretical analysis and empirical testing on the specific impact mechanism between APS and land abandonment. Moreover, Existing research ignored the constraint analysis of the application effect of APS. China is a vast country with abundant resources. There are significant differences in resource endowments and terrain conditions in different regions. An area with a high incidence of landslides also has a high incidence of cropland abandonment (Deng et al., 2018b). The steep terrain not only increases land management costs (Yang et al., 2022), but also seriously affects APS's application effect (Lu et al., 2022). Steep mountain areas are unsuitable for crop farming, and applying APS requires a large amount of human and capital investments, which increases the difficulty of mechanized operation and reduces the economic benefits of service providers (Sklenicka, 2016). In many cases, despite considerable investments, there might not be satisfactory returns, and the land with poor terrain conditions is likely to be abandoned. The small-scale machinery service system is not mature in the mountainous and hilly areas, which is difficult to meet the diversified needs of farmers and may increase the probability of land abandonment (Rahman and Rahman, 2009). Therefore, the impact mechanism of APS on land abandonment under different terrain conditions will be discussed in this paper.

In detail, this study makes four main contributions. First, this paper empirically investigates the relationship between APS and land abandonment using representative micro-survey data and provides further empirical evidence in the literature on abandoned land. While the driving factors of land abandonment have been a popular topic for researchers, little is known about what roles APS plays in reducing farmland abandonment. In considering the universal application of APS, APS in this study includes all production links such as cultivating, sowing, fertilizing, spraying insecticide, and harvesting, which is useful for understanding the multiple effects of APS on land abandonment. Second, previous studies fail to conduct rigorous empirical tests of the impact mechanisms of APS on land abandonment. This paper conducts a systematic theoretical analysis and empirical test of the impact mechanisms of APS on land abandonment. This study confirms that the impact mechanisms mainly include the land transfer effect, agricultural labour substitution effect, and technology adoption effect, which provides a useful supplement to the previous research conclusion that APS alleviates land abandonment. Third, this study explores the heterogeneity analysis of APS on farmland abandonment by farmers of different sizes and ages. This study found that APS could alleviate the land abandonment of small farmers and elderly farmers, which imply the small-scale land abandoned can be solved by developing agricultural services. The problem of no one farming in the future can be alleviated through developing APS. Fourth, this study found APS failed to alleviate the land abandonment in the Western region and Karst region with poor soil quality and steep slopes. We may conclude that APS contributes to the exit of lands unsuitable for crop cultivation. In addition, this study used the national micro survey data from 1428 villages of 29 provinces, which allows for a more comprehensive understanding of the regional disparities of APS on land abandonment in China.

The remainder of this paper is organized as follows. Section 2 proposes three theoretical hypotheses; Section 3 describes the methodology and data; Section 4 discusses the benchmark regression and robustness test results and conducts the impact mechanism identification and heterogeneity analysis; Section 5 presents the discussion and the main conclusions.

2 Theoretical analysis and research hypotheses

2.1 Agricultural labor substitution effect

The new labour migration economics argue that farmers are rational. They will measure the gap between agricultural and non-agricultural income based on the maximization of household income to rationally allocate labour resources, such as working outside, farming at home or starting their own businesses (Barkley, 1990; Larson and Mundlak, 1997). Some studies have confirmed that non-agricultural employment opportunities attract a large number of rural labour outflow, resulting in land abandonment (Xu et al., 2017; Deng et al., 2020). During the busy season, agricultural employment expenses tend to be high, and higher agricultural production costs and lower agricultural income force farmers to abandon their land. Based on the theory of division of labour by Adam Smith, the APS provides better choices for farmers. The theory argues that the division of labour promotes the invention of advanced technology, and reduces the conversion cost and learning the cost of different links (Feenstra and Hanson, 1996; Smith, 1776). The division of labor aims to increase the resources that could be invested into the core business, improving productivity (Hamel and Prahalad, 1989). APS belongs to the process of deepening the agricultural division of labour. With the massive transfer of rural population and the improvement of agricultural mechanization, the division of labor in labor-intensive links such as land preparation, sowing and harvesting is constantly increasing. The substitution effect of APS on the labour force has been enhanced. Farmers usually outsource some difficult production links to professional service organizations, which can alleviate the labour pressure (Li et al., 2021; Min et al., 2022). With the rapid development of urbanization, APS could optimize household labour allocation and promote part of labour to engage in non-agricultural industries, which not only improves family welfare but also reduce land abandonment. Moreover, APS make up for the problem of delay in pest management caused by the labour shortage, which strengthens farmers' profitability. Therefore, APS reduce land abandonment through the labour substitution effect.

2.2 Technological adoption effect

In the 1930s, Hicks put forward the theory of induced technological innovation for the first time, believing that the high price of production factors can stimulate invention, especially technical inventions that directly save relatively expensive elements (Hicks, 1963). The theory of agricultural-induced technological innovation points out that agricultural technology progress could be divided into mechanical technology progress, dominated by labour substitution and biochemical technology progress, dominated by land substitution (Hayami and Ruttan, 1971). APS is an effective carrier for providing mechanical technology and biochemical technology, which can improve the technology application level of farmers (Chen et al., 2022). Farmers often miss opportunities related to advanced technology adoption because they lack enough financial support. Based on the comparative advantage theory, service providers have more capital than farmers, and they help farmers overcome the constraints of the capital endowment. Farmers could obtain various technologies, including organic fertilizer, pest control, and certified DTM seed technologies, at low costs by purchasing APS (Makate et al., 2019; Yu et al., 2021). Advanced technology prevents farmers from overusing pesticides and fertilizers and produces agricultural products with higher market value. High-value agricultural products improve agricultural output and farmers' income, which reduces the probability of abandoned farmland by farmers (Heider et al., 2021). Moreover, farmers could receive targeted guidance and technical training provided by service organizations. Therefore, the APS could reduce land abandonment through the technology adoption effect.

2.3 Land transfer effect

Based on the scale economy theory of Adam Smith, it is emphasized that the division of labor significantly promotes productivity. Market capacity and operation scale restrain the economic effect of the division of labor, and expanding operation scale could produce more significant economies of scale (Smith, 1776). APS could achieve external economies of scale through vertical division of labor, and expanding land scale could achieve internal economies of scale. There is an interactive correlation mechanism between APS and the expansion of land scale (Yu et al., 2021). Agricultural machinery services relieve the financial, technical, and labour constraints in agricultural production, promoting farmers to rent in the land and gain economies of scale. Large-scale farmers make full use of APS to gain economies of scale and reduce investment costs and sunk costs (Zhou, 2017; Hu et al., 2019). Therefore, service organizations are more willing to cooperate with large-scale households. For small farmers, the development of APS may encourage them to rent out their farmland to obtain higher land rents, which helps alleviate land abandonment of small farmers (Qiu et al., 2021). The agricultural service market promotes the development of the land transfer market, and the land rents tend to be market-oriented. The rise of land transaction value promotes different farmers to participate in the land transfer market. Renting in or out of the land could increase land use efficiency and reduce land abandonment. Therefore, the APS reduce land abandonment through the land transfer effect. The theoretical mechanism is shown in Figure 1.

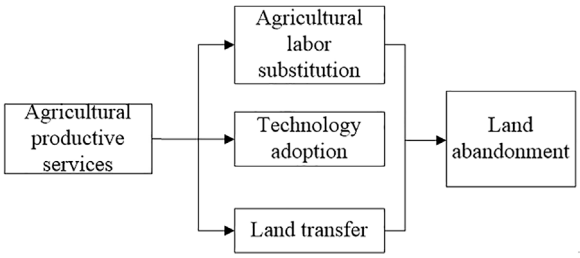

FIGURE 1
Theoretical analysis framework.

Drawing upon the above mechanism analysis, we propose the following two hypotheses.

Hypothesis 1: APS is conducive to the reduction of land abandonment.

Hypothesis 2: APS reduces land abandonment through three channels: agricultural labour substitution effect, land transfer effect, and technology adoption effect.

3 Data sources and research methods

3.1 Data sources

In view to verifying our hypotheses, the data used in the paper was the China Rural Household Panel Survey data (CRHPS) conducted by Zhejiang University and Southwestern University of Finance and Economics in 2017, which mainly investigated the individual characteristics, family characteristics, and village characteristics in 1428 villages (communities) of 29 provinces by stratified sampling and three-stage proportional sampling methods. According to the research theme, the individual, family, and village data were matched to obtain complete information about the sample. On this basis, 3631 samples were obtained by excluding the samples living in cities, working in non-agricultural industries, and the missing data for key variables.

In Table 1, the proportion of farmers who abandoned land was 10.63%, and the proportion of abandoned farmland area in the total land area was 4.95%. The average expenditure of farmers on purchasing APS was 1009.1105 yuan per hectare. The average age of the household head was 56 years old, and 9.2% of the household heads were male. The average education level of farmers was a primary school. 57.47% of the families were married, and 16.24% of the household heads had migrant experiences. For the family characteristic, the proportion of non-agricultural income in the total income was 69.72%. The average agricultural subsidy was about 626.56 yuan per hectare. The average value of the fixed assets was 3481.635 yuan. The total land area was 0.57 per hectare, and the average land area rented out by households was 0.0516 per hectare. The distance between

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TABLE 1 Definition and statistical results.

Variables	Definition	Mean	S.D.
Land Abandonment Incidence	Yes = 1; No = 0	0.1063	0.3083
Land Abandonment Area	The proportion of land abandonment area in the total land area	0.0495	0.2412
Agricultural Productive Services (APS)	Total expenditure of households on purchasing agricultural productive services (CNY/hm^2)	1009.1105	1306.7150
Mechanism Variables			
Proportion of Agricultural Labor	Proportion of agricultural labor in total household labor	0.7485	0.3167
Application of Agricultural Technology	Whether to apply organic fertilizer technology in agricultural production (Yes = 1; No = 0)	0.1864	0.3895
Land Transfer	Whether land transfer occurs (Yes = 1; No = 0)	0.4379	0.3591
Control Variables			
Head Age	Household head's age (year)	56.3263	11.2124
Head Gender	The gender of household head (0 = female; 1 = male)	0.9160	0.2774
Head Education	No school = 1; Primary school = 2; Junior high school = 3; High school = 4; Technical secondary school = 5; Junior college = 6; Bachelor degree or above = 7	2.5070	0.9044
Head Marriage	Married = 1; Unmarried = 0(Yes = 1; No = 0)	0.5747	0.0295
Head Health	Health status of the head (very bad = 1; bad = 2; general = 3; good = 4; very good = 5)	2.8738	1.0535
Migrant Work Experience	Whether farmers have migrant work experiences (Yes = 1; No = 0)	0.1624	0.3689
Proportion of Non-farm Income	The proportion of off-farm income in total income	0.6972	0.2615
Agricultural Subsidies	The agricultural subsidies received by households in 2016(CNY)	626.5661	2781.5880
Farm Asset	Value of own machinery (CNY)	3481.6350	40,686.6800
Land scale	Total farmland area in a household (hm^2)	0.5777	2.1748
Number of plot	The number of farmland plots	5.4802	6.1123
Rent Out	The land rented out (hm^2)	0.0516	0.3243
Distance to Township Government	Distance between village committee and township government (km)	6.9027	5.9890
Traffic Conditions	Number of roads from the village to the county Center	2.6549	0.7661

the village committee and the township government was 6.9027 km.

3.2 Variable selection

3.2.1 Dependent variable

Existing research used the proportion of abandoned farmland in the total farmland to measure land abandonment (Deng et al., 2020; Jiang and Song, 2022). Land abandonment, including the land abandonment behaviour and land abandonment area, is the dependent variable concerned in this study. Among them, farmers who have abandoned their land are recorded as 1. Otherwise, it is 0. Land abandonment area is defined as the proportion of abandoned farmland area in the total farmland area. Land abandonment in this study mainly refers to plots where households did not have any factors input, and agricultural production activities have completely stopped throughout the entire year, which means permanent abandonment.

3.2.2 Independent variables

APS was the independent variable in this paper. Consistent with previous studies of Qian et al. (2022) (Qian et al., 2022), this study adopts the expenditure of APS purchased by households in 2016 as a proxy for APS. APS include a wide range of specific activities that contribute to the agricultural production, such as land preparation service, sowing service, pest control service and harvesting service. Land preparation service involves clearing, leveling, and tilling the land to prepare it for planting crops. Sowing service refers to evenly distributing the ratio of seed and fertilizer and flexibly changing the density of row and plant spacing, which mainly includes sowing, mulching, and suppression. Pest control service includes chemical control using pesticides and physical control using light or rays, which help to prevent pests from harming crops. Harvesting service refers to the machinery service that helps farmers to harvest their crops in time during the busy season. Compared with the adoption behaviour of agricultural services or the number of agricultural service links, the expenditure of APS purchased by households could better reflect the level of vertical division of labour.

3.2.3 Mechanism variables

(1) Agricultural labour substitution (ALS). APS could replace agricultural labour to complete agricultural production efficiently. Therefore, the proportion of agricultural labour in total household labour is used to measure the variable of ALS.

(2) Technological adoption effects (TAE). Existing studies use straw-returning technology, no-tillage technology, and UAV plant protection technology to measure technological adoption (Sims and Kienzle, 2017; Makate et al., 2019). However, these indicators still belong to the category of labour-intensive technology, which has been widely used. Technology-intensive services such as organic fertilizer, soil testing, and formula fertilization need urgently be strengthened. Therefore, this study uses organic fertilizer technology as a measure.

(3) Land transfer effects (LTE). APS could reduce land abandonment through land transfer. Hence, we use the land transfer action to measure the LTE.

The second category was the other control variables. This study drew on the existing literature on land abandonment and agricultural services and selected other exogenous explanatory variables (Min et al., 2022). As presented in Table 1, these variables include individual, family, and village characteristics.

3.2.4 Control variables

(1) Individual characteristics. Farmers' personal characteristics include age, gender, education level, marital status, health status, and the experience of migrant workers. Existing studies have shown the probability of abandoned land increases when farmers' age increases (Jiang and Song, 2022). Compared with the elderly farmers, the young farmers are healthier, and the physical and intellectual input in agricultural production is sufficient. The variable of age is expected to have a positive impact on land abandonment. Female households are more likely to abandon the land, and this study expected a significant impact of the gender variable on land abandonment (Ding et al., 2022). Educated farmers have rich knowledge and learning ability, increasing farmland use efficiency and reducing land abandonment. Hence, the education level of farmers has a negative effect on land abandonment.

(2) Family characteristics. The family characteristics mainly include non-farm employment, agricultural subsidies, fixed assets, the total land area, and the number of land plots (Ou and Gong, 2022). Most studies found the increasing proportion of non-agricultural employment of farmers may weaken comparative agricultural advantages, which increases the probability of land abandonment. As the proportion of off-farm income increases, farmers will abandon more plots (Lu and Wu, 2022). Hence, non-agricultural employment has a positive effect on land abandonment. Agricultural subsidies effectively ease financial constraints and increase agricultural income, reducing the probability of land abandonment (Ding et al., 2022). The variable of agricultural subsidy is expected to have a negative impact on land abandonment. Agricultural mechanizations help to expand the land scale and reduce land abandonment. Full-mechanized farming significantly decreases the likelihood of cropland abandonment by 50% (Yu et al., 2021). Hence, the farm asset is expected to have a negative effect on land abandonment. Farm size significantly negatively affects land abandonment (Bao et al., 2019; Li et al., 2021; Ojha et al., 2022). The large land scale helps to realize agricultural mechanization, which increases agricultural income and reduces land abandonment. The land scale is expected to have a negative impact on land abandonment. Many studies found that land fragmentation will increase production and transaction costs, leading to land marginalization and even land abandonment (Cheng et al., 2022; Yu et al., 2022). Hence, the number of plots has a positive effect on land abandonment.

(3) Village characteristics. The village characteristics mainly include the distance between the village committee and the township government and the village traffic conditions (Liu and Zhou,

2018). The distance between the village committee and the township government could easily reduce land abandonment (Min et al., 2022). The remoteness of villages reduces the probability of farmers going out to work, and farmers mainly rely on farming to maintain their livelihood, which reduces land abandonment. Hence, the distance between the village committee and the township government is expected to have a negative effect on land abandonment. The higher the proportion of hardened pavement, the lower the proportion of abandoned land (Chen et al., 2022). Road traffic conditions in villages affect the efficiency of agricultural machinery operation, and better road facilities can help ease labour constraints and reduce land abandonment (Baumann et al., 2011; Terres et al., 2015). Hence, the traffic conditions are expected to have a negative effect on land abandonment.

3.3 Method

3.3.1 Logistic model and tobit model

In this paper, the Logistic model and Tobit model were used to explore the impact of APS on land abandonment. Land abandonment includes two parts, the incidence of land abandonment and the land abandonment area. This study intends to analyze the impact of APS on the incidence of land abandonment with the Logistic model and the impact of APS on the land abandonment area with the Tobit model. Thus, the basic formulas of the econometric model constructed are as follow:

$$\boldsymbol{Y_i = \beta_0 + \beta_1 S_i + \beta_2 X_i + \eta_i} \quad (1)$$

$$\boldsymbol{LP_i = \alpha_0 + \alpha_1 S_i + \alpha_2 X_i + \varepsilon_i} \quad (2)$$

In Eq. (1), the subscript i represents the farmer household. Y_i is a dummy variable in which a value of one represents that the farmer has abandoned farmland and a value of 0 represents the farmer has not abandoned farmland. In Eq. (2), LP_i is a continuous variable representing the proportion of the abandoned land area in total land area. S_i is the core independent variable, expressed as the expenditure of APS purchased by farmers. X_i refers to the control variables representing individual, family, and village characteristics, which are expected to affect land abandonment. Both β_0 and a_0 are constant terms. β_1, a_1, β_2, and a_2 are estimated parameters for the related variables. η_i and ε_i represent the residual of the models.

3.3.2 IV tobit model

While there may be a causal relationship between APS and land abandonment, the APS of this study may be endogenous. It is shown in the following two aspects. First, reverse causality exists in the relationship between APS and land abandonment because the farmers who have abandoned land may withdraw from agricultural production or engage in non-agricultural industries, which have little need for APS; Second, although we control for individual, family, and village characteristic variables, the problem of omitted variables including psychological or cognition of farmers may confound our analysis. Missing some important variables may easily lead to biased estimated results. Thus, the core independent variables may be endogenous variables. In order to solve the possible endogenous problems, this study refers to a similar setting of Xue et al. (2022). This study selected the average expenditure of APS purchased by farmers in the same village except for the surveyed farmers as the instrument variable, which is $IVS_i = (S_1 + S_2 + \ldots + S_{n-1})/(n-1)$. The reason for choosing IVS_i is that the average expenditure of APS purchased by other farmers in the same village has a significant impact on the expenditure of APS purchased by the surveyed farmers, but it has no direct impact on the land abandonment of the surveyed farmers, which meets the two assumptions of relevance and exogenous of the instrument variable settings. The IV-Tobit model was used to estimate the impact on the land abandonment area. The model formulas are as follows:

$$\boldsymbol{S_i = \delta_0 + \delta_1 IVS_i + \delta_2 X_i + \theta_i} \quad (3)$$

$$\boldsymbol{LP_i = \alpha_0 + \alpha_1 S_i + \alpha_2 X_i + \varepsilon_i} \quad (4)$$

In Eq. (3), IVS_i represents the instrument variable**.** The δ_1 is the impact coefficient for the instrumental variable on APS in Eq. (3). The a_1 is the coefficient for the impact of APS on land abandonment after adding tool variables in Eq. (4). The entire process of this research was conducted *via* Stata 15.

3.3.3 Mediating effect model

The study uses the mediating effect model to explore the impact mechanism of APS on land abandonment. Mediation analysis involves statistical methods used to respond to how an independent variable of APS transmits its effect on a dependent variable of land abandonment, and this effect is "mediated" by other variables of agricultural labour input, technology adoption, and land transfer. The estimation process can be represented as Eqs (5)–(8). According to the references by Judd and Kenny (Judd and Kenny, 1981), in Stage 1, the effects of APS on potential mechanism variables, including agricultural labour input, technology adoption, and land transfer, are examined based on Eqs (5)–(7). In Stage 2, the effect of every mechanism variable on land abandonment is examined based on Eq. (8). The LPi is the dependent variable that denotes the proportion of the abandoned land area in the total land area. The labori, techi, and landi are the mediators representing the agricultural labour input, technology adoption, and land transfer. φ_1, φ_2, φ_3 are the coefficients for the mediating effect of APS on agricultural labour input, technology adoption, and land transfer in Eqs (5)–(7). K_2, k_3, and k_4 are the coefficients for the intermediary variables on land abandonment in Eq. (8). The k_1 is the coefficient for the direct effect of APS on land abandonment after controlling the impact of intermediary variables. φ_0 and k_0 are the intercepts, and τ_i, ρ_i, ω_i and χ_i are random errors that exist in the normal distribution.

If the regression coefficients satisfy the conditions: 1) φ_1, φ_2, φ_3, k_2, k_3, and k_4 regression coefficients are significant, and the value k_1 decreases compared to the a_1 regression coefficient, there is a partial mediating effect; 2) The above conditions are satisfied, and the k_1 regression coefficient is not significant, then there is a full mediating effect. Finally, the intermediary effect of APS on land abandonment should be compared and show the largest intermediary effect mechanism.

TABLE 2 Estimated results of APS on land abandonment.

Variables	Logit models for land abandonment incidence				Tobit models for land abandonment area		IV tobit model for land abandonment area	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
APS	−0.1055***	−0.1094***	−0.0094***	−0.0901***	−0.0946***	−0.0151***	—	−0.1020***
	(0.0191)	(0.0198)	(0.0017)	(0.0109)	(0.0114)	(0.0018)		(0.0195)
Rural APS	—	—	—	—	—	—	0.6170***	—
							(0.0255)	
Head Age	—	0.4302	0.0370	—	0.1694	0.0271	0.4185*	0.2185*
		(0.3350)	(0.0287)		(0.1554)	(0.0248)	(0.2440)	(0.1240)
Head Gender	—	0.2385	0.0205	—	0.0342	0.0054	0.2440	0.0500
		(0.1992)	(0.0171)		(0.1104)	(0.0176)	(0.1828)	(0.8720)
Head Education	—	0.0301	0.0025	—	0.0047	0.0007	0.2054***	0.0192***
		(0.0709)	(0.0061)		(0.0358)	(0.0057)	(0.0558)	(0.0285)
Head Marriage	—	0.0234	0.0020	—	0.0078	0.0013	−0.0205	−0.0012
		(0.0552)	(0.0047)		(0.0302)	(0.0048)	(0.0488)	(0.0243)
Head Health	—	0.0570	0.0049	—	0.0207	0.0033	−0.0676	0.0198
		(0.0575)	(0.0050)		(0.0305)	(0.0048)	(0.0462)	(0.0242)
Migrant Work Experience	—	0.2265	0.0195	—	0.0938	0.0150	−0.2265*	0.0560
		(0.1677)	(0.0144)		(0.0855)	(0.0136)	(0.1283)	(0.0679)
Proportion of Non-farm Income	—	0.1979	0.0170	—	0.1510	0.0241	−0.3534*	0.1186
		(0.2339)	(0.0201)		(0.1232)	(0.0197)	(0.1905)	(0.0982)
Agricultural Subsidies	—	−0.0509**	−0.0043**	—	−0.2229***	−0.2019***	0.1003***	−0.0072
		(0.0203)	(0.0017)		(0.0908)	(-0.0717)	(0.0170)	(0.0090)
Farm Asset	—	−0.0819***	−0.0071***	—	−0.0304***	−0.0048***	−0.1033***	−0.0382***
		(0.0177)	(0.0015)		(0.0090)	(0.0014)	(0.0131)	(0.0076)
Land Area	—	−0.2822***	−0.0243***	—	−0.1502***	−0.0240**	−0.4776***	−0.2338***
		(0.0995)	(0.0085)		(0.0527)	(0.0084)	(0.0810)	(0.0453)
Number of plot	—	0.0244***	0.0021***	—	0.0099**	0.0015**	0.0162**	0.0093***

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TABLE 2 (*Continued*) Estimated results of APS on land abandonment.

Variables	Logit models for land abandonment incidence				Tobit models for land abandonment area		IV tobit model for land abandonment area	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
		(0.0086)	(0.0007)		(0.0044)	(0.0007)	(0.0082)	(0.0034)
Rent Out	—	0.0716	0.0061	—	0.0273	0.0043	−0.0260*	0.0275
		(0.0638)	(0.0051)		(0.0241)	(0.0032)	(0.0147)	(0.0212)
Distance to Township Government	—	−0.0070	−0.0006	—	0.0014	−0.0002	−0.0209**	−0.0043
		(0.0097)	(0.0008)		(0.0051)	(0.0008)	(0.0083)	(0.0042)
Traffic Conditions	—	0.1041	0.0090	—	0.0910**	0.0145**	0.1011***	0.0676**
		(0.0788)	(0.0068)		(0.0405)	(0.0064)	(0.0633)	(0.0329)
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−3.3365*** (1.2318)	−4.2066***	—	−0.6671***	−2.1525***	—	0.0940	−1.5776***
		(1.4378)		(0.0845)	(0.7019)		(1.0947)	(0.5617)
Wald Chi Square Test	212.99***	276.63***	—	—	—	—	—	—
LR Chi Square Test	—	—	—	295.99***	336.81***	—	—	—
Pseudo R2/Wald Exogenous Test	0.1077	0.1355	—	0.1092	0.1245	—	—	5.54**
								(0.0186)
F Value/Endogenous Wald χ^2	—	—	—	—	—	—	42.29***	12.42***
Observations	3631	3631	3631	3631	3631	3631	3631	3631

Note: Robust standard errors in parentheses: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

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TABLE 3 Robustness test results.

Variables	Robustness check models for replacing dependent variable		Robustness check models for replacing core independent variable		Robustness check models for replacing sample data	
	Model 9	Model 10	Model 11	Model 12	Model 13 (act)	Model 14 (area)
APS	−0.0333**	−0.0351**	—	—	−0.1146*	−0.0472***
	(0.0132)	(0.0156)			(0.0602)	(0.0176)
Adoption Behavior of APS	—	—	−0.5291***	−0.5459***	—	—
			(0.0691)	(0.0718)		
Control Variables	No	Yes	No	Yes	Yes	Yes
Constant	0.4149***	−2.0352**	−0.6669***	−2.1366***	−3.9732***	−1.0567***
	(0.0522)	(0.8367)	(0.0851)	(0.7009)	(1.0671)	(0.2903)
F Value	7.39***	3.18***	—	—	—	—
Pseudo R2	0.0229	0.0555	0.1045	0.1191	—	0.1547
LR Chi Square Test	—	—	283.26***	322.15***	—	218.2***
Wald Chi Square Test	—	—	—	—	189.35***	—
Province	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3631	3631	3631	3631	8937	8937

Note: Robust standard errors in parentheses: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

$$labor_i = \varphi_0 + \varphi_1 S_i + \gamma X_i + \tau_i \quad (5)$$

$$tech_i = \varphi_0 + \varphi_2 S_i + \gamma X_i + \rho_i \quad (6)$$

$$land_i = \varphi_0 + \varphi_3 S_i + \gamma X_i + \omega_i \quad (7)$$

$$LP_i = \kappa_0 + \kappa_1 S_i + \kappa_2 labor_i + \kappa_3 tech_i + \kappa_4 land_i + \gamma X_i + \chi_i \quad (8)$$

4 Results and analyses

4.1 Baseline regression analysis

Table 2 presents the estimation results of the impact of APS on land abandonment. Models (1) to (3) in Table 3 are based on Eq. 1, which aims to explore the impact of APS on land abandonment. More specifically, in Table 3, Model (1) adds the focus variable for APS and the variables for province dummies; Model (2) adds the individual, household, and village variables based on Model (1); Model (3) reports the marginal effect estimation results. Model (1) to Model (3) are estimated by the Logistic model. Model (4) to Model (6) shows the estimation results of the impact of APS on the land abandonment area with the Tobit model. Among them, Model (4) adds the focus variable for APS and the variables for province dummies; Model (5) adds the individual, household, and village variables based on Model (4); Model (6) reports the marginal effect of estimation results. Model (7) and Model (8) report the results that are estimated by the IV Tobit method.

The estimation results in Table 2 show that APS can reduce land abandonment. As shown in the models included in Table 2, APS was significantly negative ($p < 0.01$) for nearly all models, which indicates that APS has a negative impact on land abandonment. The results were in line with theoretical hypothesis 1. The coefficient of APS is −0.0151 and significant at the level of 1% in Model (6), which indicates with every 1% increase in APS, the land abandonment area will drop by 1.51 percentage points. Thus, Hypothesis one is verified. APS not only embeds advanced elements into agricultural production but also improves soil fertility and farmers' management ability, reducing land abandonment.

In addition, the coefficients of agricultural subsidies, farm assets, and land scale are all significantly negative at a 1% level. And the coefficients of the number of plots and traffic conditions are all significantly positive at a 5% level in Model (6). Preliminarily, the increase in agricultural subsidies, farm assets, and land scale reduces land abandonment. The variable of agricultural subsidy is an effective incentive to prevent farmers from abandoning farmland by increasing agricultural income. The larger the land scale, the lower the probability of abandoned farmland, which is consistent with Yan et al. (2016) (Yan et al., 2016) and Deininger et al. (2012) (Deininger et al., 2012). The number of plots and the traffic conditions may increase land abandonment. The result is in line with Li et al. (Li et al., 2018), who found that smaller plots are more likely to be abandoned. Farmers in villages with convenient transportation conditions tend to engage in non-agricultural employment and abandon their land, proving that urbanization has accelerated land abandonment (Xie and Lu, 2017).

The estimation results of Endogenous Wald $\chi 2$ are shown in Model 7 and Model 8 ($p < 0.01$), which indicate that APS is an endogenous variable. This paper found that rural APS in the first stage has a significant positive impact on the APS. The F value in the first stage is larger than the empirical value of 10, which rejected the

TABLE 4 Estimated results of the impact mechanism of APS on land abandonment.

Variables	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20	Model 21	Model 22
APS	−0.0946***	−0.0128***	0.0245*	0.0194***	−0.0912***	−0.0891***	−0.0859***	−0.0872***
	(0.0114)	(0.0017)	(0.0133)	(0.0042)	(0.0115)	(0.0110)	(0.0111)	(0.0016)
ALS	—	—	—	—	0.2390**	—	—	0.2542**
					(0.1043)			(0.1047)
TAE	—	—	—	—	—	−0.0331**	—	−0.0423**
						(0.0148)		(0.0150)
LTE	—	—	—	—	—	—	−0.2773***	−0.2545***
							(0.0800)	(0.0794)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−2.1525***	0.6963***	−4.8343**	0.3496	−2.3164	1.5435	1.9590	−2.1237**
	(0.7019)	(0.1229)	(2.2652)	(1.0246)	(0.7085)	(1.6470)	(1.6824)	(0.7071)
Adjusted R^2	—	0.0714	0.0664	0.1437	—	—	—	—
F Value	—	—	5.33***	7.31***	—	—	—	—
LR Chi Square Test	336.81***	—	—	—	342.22***	336.65***	346.49***	363.17***
Pseudo R^2	0.1245	—	—	—	0.1265	0.1241	0.1278	0.1342
Observations	3631	3,631	3631	3,631	3,631	3631	3,631	3631

Note: Robust standard errors in parentheses: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

TABLE 5 Estimated results of individual heterogeneity.

Variables	Elderly group	Non-elderly group	Large scale group	Small scale group
	Model 23	Model 24	Model 25	Model 26
APS	−0.1300*** (0.0218)	−0.0885*** (0.0165)	−0.0470*** (0.0133)	−0.0969*** (0.0140)
Control Variables	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes
Constant	−1.1831***	−1.7166	1.6142	1.4675
	(0.4366)	(0.6055)	(3.9889)	(1.8208)
LR Chi Square Test	213.4***	164.11***	114.53***	252.38***
Pseudo R^2	0.1343	0.1287	0.2275	0.1160
Observations	1,783	1,848	927	2,704

Note: Robust standard errors in parentheses: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

hypothesis of weak instrumental variables. The estimation results in the second stage show that the estimated coefficient of APS is significantly less than 0, indicating that APS reduce land abandonment effectively. Compared with the results of benchmark regression in Model 5, the coefficient slightly increases after considering the endogenous problem in Model 7. It indicates that if the endogenous problem was ignored, the result above might underestimate the impact of APS on land abandonment.

4.2 Estimated results of robustness tests

Considering that the impact of APS on land abandonment may not be very robust, three strategies for robustness tests are applied in this study. First, referring to the study of Jiang et al., the size of land abandonment replaces the dependent variable. Second, the independent variable is replaced by the adoption behaviour of APS. Third, the survey database is replaced with the data of the China Labor Force Dynamic Survey of Sun Yat Sen University in

TABLE 6 Estimated results of regional heterogeneity.

Variables	Major grain producing areas	Main grain sales area	Production and marketing balance area	Eastern	Central	Western	Karst area	Non-karst area
	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32	Model 33	Model 34
APS	−0.1268***	−0.0836***	−0.0510***	−0.0643***	−0.1976***	−0.0313	−0.0112	−0.1256***
	(0.0216)	(0.0230)	(0.0130)	(0.0173)	(0.0325)	(0.0418)	(0.0152)	(0.0150)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.6495	−4.6897	7.6778	−5.6417 (5.2534)	0.9089	5.5906	−1.7541**	−2.9372***
	(4.3407)	(5.9874)	(2.6418)		(8.4468)	(1.9270)	(0.8719)	(0.9886)
LR Chi Square Test	185.65***	53.55***	107.57***	151.87***	127.51***	100.18***	54.71***	298.25***
Pseudo R^2	0.1535	0.1090	0.1161	0.1914	0.1531	0.0994	0.0851	0.1484
Observations	1,975	567	1,089	1,302	1,126	1,203	704	2927

Note: Robust standard errors in parentheses: $^{**}p < 0.05$, $^{***}p < 0.01$.

2016, and the impact of APS on land abandonment is analyzed from the village level. Model 9, model 10, model 13, and model 14 are estimated by the OLS model. Model 11 and model 12 are estimated by the Tobit model. The estimation results are presented in Table 3.

As shown in Table 3, in terms of the impact of APS on land abandonment, whether this study replaced the core independent variable, the dependent variable, and the survey data, the direction and significance of the coefficients are all consistent with the benchmark regression. The only difference lies in the sizes of estimation coefficients. The estimation results confirm that the inhibition effect of APS on land abandonment is still significant and robust.

4.3 Mechanism identification

According to the previous analysis, APS could reduce land abandonment through three channels: agricultural labour substitution (ALS), technology adoption effect (TAE), and land transfer effect (LTE). To empirically identify these mechanisms, the two-stage mediating effect model is constructed. As shown in Table 4, the dependent variable of Model (15), Model (19) to Model (22) is land abandonment area; the dependent variable of Model (16) is the proportion of agricultural labour in the total number of households, the dependent variables of Model (17) is agricultural technology adoption, the dependent variables of Model (18) is land transfer behaviour. Model (15) is estimated by Eq. 2, and Model (16), Model (17), and Model (18) are estimated by Eqs 5–7, respectively. And Model (22) is estimated by Eq. 8. All models are estimated by the OLS method.

The results of Models (16), (17), and (18) in Table 4 show that the direct effects of APS are significant, at least at a 1% level and 10% level, and their signs are consistent with our expectations. In Models (16), the direct effects of APS are significantly negative, indicating that increases in APS can reduce the proportion of agricultural labour. In Models (17) and (18), the direct effects of APS are significantly positive, suggesting that APS help improve farmers' technology application level and promote land transfer. The results of Models (19), (20), and (21) in Table 4 show that the direct effects of ALS, TAE, and LTE are all significant, at least at a 5% level and 1% level. The direct effects of ALS are significantly positive, and the direct effects of TAE and LAE are significantly negative. These findings confirm that APS reduce land abandonment *via* the channels of agricultural labour substitution, technology adoption effect, and land transfer effect. Thus, Hypothesis two is verified. The Sobel test method is used to verify the significance of the intermediary mechanism. The Sobel method includes two steps, first, the standard errors of $\varphi_1 k_2$, $\varphi_1 k_3$, and$\varphi_1 k_4$ should be calculated based on the estimation results in Table 4; Second, the Z statistics of$\varphi_1 k_2$, $\varphi_1 k_3$, and$\varphi_1 k_4$ should be calculated. We can get $Z_{\varphi_1\kappa_2} = -2.6447$, $Z_{\varphi_1\kappa_3} = -2.3881$ and $Z_{\varphi_1\kappa_4} = -2.5091$, at a significance level of 1%. These results show that APS reduces land abandonment by replacing agricultural labor, improving technology application level, and promoting land transfer. In addition, the sizes of the three channel effects of ALS, TAE, and LTE could be compared. The calculation method is the proportion of the channel effect in the total effect, $E_{labor} = \varphi_1\kappa_2/\kappa_1$, $E_{tec} = \varphi_1\kappa_3/\kappa_1$, $E_{land} = \varphi_1\kappa_4/\kappa_1$, and we can get $E_{labor} = 0.0493$,$E_{tec} = 0.0091$ and $E_{land} = 0.0526$. The channel effect of LTE is the largest, ALS is the second, and TAE is the last. Overall, APS is beneficial for reducing land abandonment.

4.4 Heterogeneity analysis results

According to the results of Table 2, the variables of age and land scale significantly impact land abandonment. Thus, this study further analyzed the heterogeneity of APS on land abandonment

across different land scales and ages of farmers. In the study, the age of farmers above 65 years old is defined as the elderly group, and the age of farmers below or equal to 65 years old is defined as the non-elderly group. The land scale larger than the average value of 0.578 h m^2 are defined as large farmers, and the land scale less than or equal to the average value of 0.578 h m^2 are defined as small farmers. The results are shown in Table 5. For different age groups, APS significantly reduces land abandonment in both the elderly and the non-elderly groups, and the effects in the elderly group are higher than in the non-elderly group. This showed that the elderly group has few opportunities for non-agricultural employment and most farming at home. APS makes up for the poor health of elderly farmers by reducing land abandonment. For the different land scales, the effect of APS on land abandonment is greater in small-scale groups than in large-scale groups. It indicates that APS promote the full use of small-scale land and avoids small-scale fragmented land being abandoned. The result confirmed that APS is an important channel for promoting the organic connection between small farmers and modern agriculture.

China's vastness determines many noticeable differences among regions, such as geographic location, resource endowments, and farming conditions. Therefore, the heterogeneity across different regions, including the eastern, western, and central regions, needs to be analyzed. The heterogeneity across different resource endowments, including the main grain-selling areas, the balanced production and marketing areas, and the main grain-producing areas, are analyzed. The heterogeneity across different farming conditions, including karst and non-karst area, are analyzed. Areas with complex terrain and many slopes (Guizhou, Guangxi, Yunnan, Sichuan, Chongqing) are considered karst areas. Table 6 reports the estimation results for the heterogeneity analysis. Regarding geographic location, compared with the western region, the effect of APS on land abandonment is significantly negative at a 1% level in the eastern and central regions. It indicates that the western region is mostly mountainous and hilly, which weakened the inhibition effect of APS on land abandonment. Regarding resource endowments, the effect of APS on land abandonment in major grain-producing areas is greater than in the main grain sales and production and marketing balance areas. It indicates that the agricultural mechanization in the main grain-producing areas is high, which causes a large demand for agricultural services and reduces land abandonment. Regarding farming conditions, compared with the non-karst area, APS failed to reduce the land abandonment in the karst area, indicating that the steep terrain increases the cost of agricultural service operation and reduces the benefits of service providers. The effect of APS on land abandonment is limited by complex terrain.

5 Discussion

Based on the 2017 China Rural Household Panel Survey data across 29 provinces, this study explores the impact of APS on land abandonment and explains the impact mechanism. Furthermore, a series of robustness tests are performed. Finally, the heterogeneity analysis with different regions and individual characteristics is conducted. The results will help provide research support for the effective implementation of land abandonment policies in China and other countries.

Our main finding is that APS could reduce land abandonment. After controlling for other variables, every 1% increase in APS and the proportion of land abandonment area will drop by 1.51 percentage points. It is consistent with the conclusions of (Yu et al., 2021; Zhang et al., 2022; Xue et al., 2022), which believe that APS plays an important role in the effective allocation of farmland resources. Farmers not only obtain green production technology and planting information by purchasing APS but also gain economies of scale (Qian et al., 2022); Especially for the farmers who have "land attachment", the emotional sustenance of the land makes the farmers unwilling to abandon the land (Zhang et al., 2022; Liu et al., 2022). Purchasing APS meet the need for deep attachment to the land of farmers. Previous studies have discussed the driving factors affecting the land abandonment of farmers, and they found that labour migration would promote the land abandonment (Deng et al., 2018a; Xu et al., 2019a; Castro et al., 2020; Lorenzen et al., 2020). A large number of labour force migrants driven by economic interests and poor quality of cultivated land were abandoned (Xu et al., 2020). We find that APS could help farmers manage land in the context of labour scarcity and stimulate the labour substitution effect, which consistent with Belton et al. (Belton et al., 2021) and Fang et al. (Fang et al., 2022a). In our study, we analyze the intermediary role of land circulation in APS affecting the land abandonment of farmers and find that APS reduce land abandonment by promoting land transfer, which enriches the existing research. The conclusion is consistent with Xu et al. (Xu et al., 2022). They confirmed that APS significantly affects land transfer and mitigates the constraints on the resource endowment of farmers. Moreover, our study discussed the role of agricultural technology adoption in the impact of APS on land abandonment, and previous studies have not paid much attention to the issue. Most studies have found APS have a positive impact on the adoption of conservation tillage and green production technology among farmers (Zhang et al., 2022). Few studies have discussed the relationship between APS, technology application and farmland abandonment. The results of our study show that APS reduce farmland abandonment by promoting technology adoption. But the technology adoption effect is the lowest. There is improvement room in the effect of technological progress promoted by APS. It is suggested that the government should provide financial support and preferential tax policies for technical service organizations. Strengthen the supervision over the technical service contracts and the quality of technical services.

Agricultural services providers emerged under the background of deepening division of labor and advancing technological innovation. Agricultural services providers make great contributions to improve crop yields and the value of agricultural products. Agricultural service providers introduce advanced mechanical and digital technologies into agricultural production, and provide guidance and training for farmers, which enhances the livelihood ability of farmers and agricultural production efficiency. Services providers reduce agricultural production costs and learning costs of farmers through unified supply of services, which improved the agricultural operating income. Importantly, professional service providers have reduced service risks and guaranteed service quality

by building a mutual trust mechanism through the village acquaintance society, which plays an important role in releasing rural labor force and promoting urbanization.

This study found that APS has a more significant effect on alleviating land abandonment of small farmers and elderly farmers. The result is consistent with the study of Qiu et al. (Qiu et al., 2021), which found that the APS increases the probability of renting out the land of smallholder farmers and reduces land abandonment. When the farmland is smaller than a certain scale, the agricultural operation cannot reach the optimal scale. The threshold for farmers to exit agricultural production is lower and the probability of small-scale land being abandoned is higher. With the increasing of non-farm employment opportunities and wage income, the decline in comparative agricultural interest drives smallholder farmers to transfer out the land or abandon the land. Small-scale plots are difficult to be transferred out due to the higher management costs and land consolidation costs (Heider et al., 2021; Wang et al., 2022). Differences in crop varieties, soil conditions and tillage arrangements make it difficult for smallholders to cooperate on farmland scale management, resulting in the abandonment of small-scale land. This study found that APS play an important role in alleviating the abandonment of small-scale land and provides a new perspective for the management strategy of small scale land abandoned. APS not only avoid adverse factors such as a high transfer cost and an uncertain transfer period, but also obtain agricultural economies of scale by integrating small-scale land. It is suggested to carry out land trusteeship service projects in small plots, which promote the organic connection between small farmers and modern agriculture. The leading role of village collective economic organizations in the development of APS should be emphasized, which promotes small farmers to participate in the agricultural service market. This study also found that APS failed to reduce land abandonment in the Western and Karst regions. The results reflected the complexity of developing APS in the Western region and Karst region with poor terrain conditions. Most Western and Karst regions are mountainous and hilly. Land fragmentation and steep terrain make farming conditions more difficult (Deininger et al., 2012; Zhou et al., 2020). APS operates on steep land increases the transaction and machinery use costs, and the service quality provided by service organizations is difficult to guarantee. Therefore, the study proves that developing agricultural services in the western region and karst areas faces more challenges. Differentiated agricultural service models should be developed suitable for different terrain conditions. The result is consistent with the study of Zhang et al. (Zhang et al., 2022), which found that the special mountainous terrain places higher demands on agricultural service providers and service supply model. In the future, we should pay attention to the innovation of the APS model in the western region and karst region. The joint service model of village collectives and cooperatives, and the service model of agricultural trust center should be developed in the western region and karst region, which contribute to land reclamation and unify supply services. The government should cultivate professional agricultural service organizations who provide agricultural socialized services suitable for steep mountainous areas. Services providers in western regions and karst areas should be given subsidies support to enhance the operation ability in hilly and mountainous areas. Services providers should be encouraged to research and manufacturing small machinery and equipment suitable for mountainous and hilly areas.

The main difference between this study and similar studies is that we have made a theoretical analysis and empirical test of the impact mechanism of APS on land abandonment and found three mediation paths. Among them, the land transfer effect is the largest, agricultural labour substitution is the second, and the technology adoption effect is the last, which implies that APS alleviate farmland abandonment caused by the constraint of the farmers' resource endowment. APS not only helps farmers manage land and expand the land scale but also eases labour and technology constraints (Lu et al., 2022; Li et al., 2022). Moreover, we find APS has a more significant effect on alleviating the land abandonment of elderly farmers, which is different from the study of Xue et al. (Xue et al., 2022). They find harvesting service has no significant impact on the abandoned farmland of households with seniors. The main reason for the difference is that the contents of agricultural services and the grouping criteria are different between the two studies. Agricultural services include the land preparation service, sowing service, pest control service and harvesting service in our study, and agricultural service includes only harvesting service in their study. Grouping criteria in our study are based on the age of the head of the household, and grouping criteria in their study are based on whether they are households with seniors. Therefore, the conclusions are different.

In addition, this study has some shortcomings, which can be further enriched in future studies. First, China is in a stage of rapid urbanization, and the development of the agricultural service market is still a long-term trend and dynamic process. Whether the APS would impact farmland abandonment in China need panel data to reveal, while this study is only based on cross-section data. Future studies can further investigate the driving mechanism of land abandonment from the perspective of spatial and temporal dynamic changes. Second, the study only discusses the behavior of land abandonment and the proportion of land abandonment area without considering the potential threat caused by invisible land abandonment due to the reduction of farming time. In the future, we can further explore the impact mechanism of APS on invisible land abandonment and explicit land abandonment, respectively. Third, with the development of the agricultural services market, the service supply covers many links, such as pre-production, mid-production, and post-production. In the future, we can explore the heterogeneity analysis of different link services on farmland abandonment.

6 Conclusion and implications

Based on the China Rural Household Panel Survey data across 29 provinces in 2017, this study focuses on the theoretical analysis and the empirical impact of APS on land abandonment. The main results can be summarized as follows.

(1) APS reduce land abandonment. More specifically, after controlling for other variables, the proportion of land

abandonment area will drop by 1.51 percentage points for every unit increase in APS.

(2) The agricultural labour substitution, technology adoption effect, and land transfer effect are the three main channels of APS affecting land abandonment. Among them, the land transfer effect is the largest, agricultural labour substitution is the second, and the technology adoption effect is the last.
(3) APS has heterogeneous impacts on land abandonment: APS failed to reduce the land abandonment in the Western and Karst areas, indicating it is difficult for APS to alleviate land abandonment with poor terrain conditions. APS has a more significant effect on alleviating the land abandonment of small farmers and elderly farmers. It shows that APS has become an important channel for promoting the organic connection between small farmers and modern agriculture, which promotes the reuse of small-scale land.

The study proves APS plays an important role in alleviating land abandonment. According to the above findings, we can also derive some policy implications. First of all, APS is conducive to allocating land resources and promoting the reuse of small-scale land. Hence, the government should encourage the construction of the agricultural services integration platform and strengthen the effective supply of APS. Strengthen the project support or subsidy support for professional organizations serving for small farmers. In addition, APS failed to reduce land abandonment in the Western and Karst areas. Therefore, the government should improve rural infrastructure construction and carry out a land renovation project in the Western and Karst areas. Differentiated agricultural service models should be developed suitable for different terrain conditions. For the land with poor terrain conditions, agricultural enterprises and other service organizations should be encouraged to independently develop small-scale agricultural machinery, which can meet the diversified needs of farmers in the Western region and Karst areas.

Data availability statement

The datasets presented in this article are not readily available because Data used in the paper is the China Rural Household Panel Survey data (CRHPS) conducted by Zhejiang University and Southwestern University of Finance and Economics in 2017. Scientific researchers who use the data need to submit a written application to the "China Family Database" of Zhejiang University. Those who pass the application can obtain the account and password for operating on the virtual machine platform. I also operated on the virtual machine platform and I am not qualified to download the original data. I am sorry that I could not provide the original data, but I can provide the process of how to apply for the data. I hope it can help readers in need. Requests to access the datasets should be directed to http://ssec.zju.edu.cn/sites/main/template/news.aspx?id=51026.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1072005/full#supplementary-material

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