Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-025-05254-4 OPEN

Differential analysis of the impact of adopting outsourced machinery services on land transfer between contracted and outsourced land-holding

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The use of outsourced machinery services has significantly transformed agricultural production methods, leading to varying impacts on farmers' land transfer behaviors. This study investigates the influence of outsourced machinery services on land transfer across different land ownership categories in China. Using data from the China Land Economic Survey (CLES), this research employs a two-way fixed-effects model. To address potential endogeneity, Propensity Score Matching (PSM) is applied, supplemented by validation through fixed and random-effects models. The results showed that the use of outsourced machinery services significantly reduces land transfer out by contracted land-holding farmers but has no substantial effect on land transferred in. Conversely, these services inhibit land transfer out by outsourced land-holding farmers while encouraging land transfer in. Furthermore, as the stages of outsourced machinery services increase, their adoption by contracted land-holding farmers significantly promotes land transfer in, whereas their impact on land transfer out for outsourced land-holding farmers becomes insignificant. This study offers valuable insights into how outsourced machinery services can be leveraged to facilitate land transfer and, consequently, advance agricultural development.

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Introduction

Accelerating land transfer to promote appropriately scaled agricultural operations is one of the key issues widely discussed in global agricultural policy and academia. Outsourced machinery services are recognized as a critical support mechanism for this process (Brümmer et al., 2006). Agricultural outsourced machinery services involve agricultural producers leasing mechanized operation services from specialized service providers through market transactions, rather than purchasing or owning agricultural machinery themselves. At its core, this model relies on a specialized division of labor, separating machinery investment and operational technology from individual farmers and creating a third-party service market.

In recent years, China has prioritized fostering and developing the outsourced machinery services market while actively encouraging smallholder farmers to adopt these services. In 2021, the Ministry of Agriculture and Rural Affairs of China issued the Guiding Opinions on Accelerating the Development of Agricultural Socialized Services, explicitly advocating for large-scale mechanized operations within socialized services. At the Third Plenary Session of the 20th Central Committee of the Communist Party of China in 2024, the country further emphasized the need to "improve a convenient and efficient system of agricultural socialized services."

Official statistics show that by the end of 2023, China had approximately 1.094 million entities engaged in agricultural socialized services, covering an annual service area of 2.14 billion mu. Over 94 million smallholder farmers benefited from these services, accounting for 47% of all agricultural operators nationwide. Simultaneously, the scale of rural land transfer in China has continued to expand, with the transfer rate steadily increasing. By 2022, the proportion of transferred farmland had risen to 36.73% nationwide.

Outsourced machinery services address the indivisibility constraints of traditional agricultural machinery factors (Zhang et al., 2022), providing farmers with a viable means to substitute labor with machinery and thereby alleviating their resource endowment constraints. The relaxation of these constraints enables farmers to optimize the allocation between external and self-owned production factors, potentially altering their agricultural input allocation and land transfer decisions (Bellemare, 2018). With the development of China's agricultural machinery socialized services, researchers have gradually shifted their focus to the relationship between such services and land scale. Existing studies primarily emphasize agricultural efficiency from an input perspective, exploring topics such as the substitution relationship between machinery and labor (Qian et al., 2022), and complementary effect between machinery and land (Yang et al., 2016). However, there is no academic focus regarding the impact of outsourced machinery services on land transfer.

Some scholars argue that outsourced machinery services inhibit land transfer, as they introduce mechanized production factors that ease labor constraints in agricultural production (Zhang et al., 2017). This effect may delay the exit of smallholder farmers from agricultural operations, reducing their willingness to transfer land and thereby hindering farmland transfer and the advancement of large-scale farming (Kang et al., 2020; Qiu et al., 2021a, 2021b). Conversely, other scholars contend that outsourced machinery services promote land transfer by alleviating labor and technical constraints in farmland operations. This leads smallholders to reduce land transfers out (Yang et al., 2019), while large-scale operators increase land transfers in (Olmstead and Rhode, 2001). This dynamic alters the supply-demand balance of farmland, creating a shortage and accelerating land transfer by driving up land rents (Li and Lee, 2022; Qian et al., 2022). Additionally, some studies suggest that the impact of outsourced machinery services on land transfer is not a simple linear relationship but is influenced by complex moderating factors, including the type of outsourcing services, the scale of farmland operations, and farmland location conditions (Qiu et al., 2021a, 2021b; Hong, 2019; Zhang et al., 2022).

Evidently, the impact of outsourced machinery services on land transfer remains inconclusive, necessitating further theoretical analysis and empirical evidence to clarify how these services influence land transfer. Notably, existing research primarily focuses on how farmland management characteristics mediate the impact of outsourced machinery services on farmers' land transfer decisions, with limited attention given to the heterogeneous effects induced by different types of farmland ownership.

In the case of China, farmland can be categorized into two types based on ownership: (1) Contracted land-holding, which refers to farmland initially allocated through contracting, typically characterized by small-scale plots, fragmented distribution, and a high degree of off-farm employment among farmers (Xu, 2019); and (2) Outsourced land-holding, which denotes farmland acquired by farmers through land transfer, usually featuring larger-scale farmland, concentrated distribution, and a lower degree of off-farm employment (Ren et al., 2018). The distinct characteristic of contracted and outsourced land-holding results in different cost-benefit changes when exposed to outsourced machinery services, which leads to heterogeneous land transfer decisions. Therefore, failing to distinguish between farmland ownership types hinders the scientific understanding of the impact of outsourced machinery services on the land transfer.

In developed countries, outsourced machinery services have become a crucial means of promoting large-scale farming and agricultural modernization. The widespread application of intelligent agricultural machinery and technological innovations has significantly enhanced the efficiency and sustainability of these services. They operate efficiently through cooperative organizations or socialized service networks, which optimize resource allocation. However, in developing countries, inadequate infrastructure, shortages of technology and skilled labor, immature markets, and information asymmetry have hindered the promotion of outsourced machinery services. As a large developing country with a vast agricultural population, China faces structural challenges such as the transformation of smallholder agriculture, the non-farm employment of rural labor, and land fragmentation. In this scenario, an in-depth investigation into the impact of outsourced machinery services on land transfer in China will not only help to understand its underlying mechanisms but also provide insights for other countries facing similar challenges.

In view of this, this paper systematically analyzes the differential impacts of outsourced machinery services on land transfer across different farmland tenure types from three perspectives: (1) the alleviation of farmers' factor constraints through machinery outsourcing services, (2) the farmland rent effect that drives up land rents, and (3) the non-farm part-time effect that promotes farmers' non-farm employment. The analysis is based on data from the China Land Economy Survey (CLES) database.

The marginal contributions of this study are twofold. First, by analyzing the heterogeneous impact of outsourced machinery services on land transfer from the perspective of different farmland ownership types, this study deepens the understanding of the intrinsic link between the outsourcing service market and the land transfer market and addresses gaps in the existing literature. Second, by comprehensively examining the effects of outsourced machinery services on contracted and outsourced land-holding farmers—specifically their alleviation of production factor constraints, farmland rent effects, and non-farm employment effects—this study systematically clarifies the behavioral logic and constraint differences in land transfer decisions which enhances the depth and coherence of understanding regarding the mechanisms through which outsourced machinery services influence land transfer.

Research hypotheses

In this study, we assume that farmers are rational economic agents aiming to maximize their profits. Therefore, for farmers managing different types of farmland ownership, their land transfer decisions will be dynamically adjusted based on changes in their comparative advantages in agricultural operations before and after adopting outsourced machinery services. Within this framework, the introduction of outsourced machinery services will subject both contracted land-holding and outsourced land-holding farmers to the following cost-benefit shocks:

First, outsourced machinery services replace traditional labor with mechanized operations, enabling farmers to effectively alleviate constraints related to labor, technology, and other production factors. Compared to purchasing agricultural machinery, outsourced machinery services offer a cost advantage by avoiding the high expenses of machine acquisition and maintenance while allowing farmers to conveniently and promptly access advanced agricultural technology carried by large-scale machinery (Yang et al., 2019).

Second, given the constraint of a relatively fixed total farmland area, the expansion of outsourced machinery services has a dual impact on the supply-demand structure of the land transfer market. On the one hand, it reduces smallholder farmers' willingness to exit agricultural production, which leads to fewer land transfers out. On the other hand, it increases land demand among large-scale farmers, resulting in more land transfers (Zhang et al., 2022). This supply-demand imbalance intensifies tensions in the farmland market, creating a pattern of increasing demand and decreasing supply in the land transfer market, which, ultimately, drives up farmland rents (Qiu et al., 2021a, 2021b).

Third, the expansion of agricultural mechanization reduces dependence on human labor in agricultural production, which allows part of the labor force to shift from intensive farming activities to non-agricultural employment. In this process, farmers gain more non-farm employment opportunities, increasing the opportunity cost of agricultural production (Nolte and Ostermeier, 2017).

Based on these three effects, this study systematically analyzes the changes in comparative advantage for farmers managing different types of farmland ownership after adopting outsourced machinery services and further explores how these changes influence their land transfer decisions.

During the Household Responsibility System reform in China in the 1980s, farmers were granted fair access to contracted land-holding distributed by collective economic organizations. This institutional arrangement established the foundation for China's current agricultural structure, which is primarily characterized by smallholder and fragmented farming (Gong and Elahi, 2022). However, as China's agricultural production reaches the Lewis turning point, the traditional smallholder farming model has shown its limitations in improving agricultural productivity (Liu and Zhang, 2014). Specifically, contracted land-holding farmers generally face constraints in labor, technology, and capital. In this context, they can be inclined to transfer out of land, exit agricultural production, and shift to non-agricultural employment for higher returns.

With the introduction of outsourced machinery services, the production factor constraints faced by contracted land-holding farmers are significantly alleviated. First, outsourced machinery services provide a mechanism to replace expensive and scarce labor with relatively inexpensive and abundant mechanized inputs, effectively reducing dependence on human labor in agricultural production. By easing the constraints on agricultural labor time, farmers can balance agricultural production while freeing up more time for non-agricultural employment, thereby earning higher incomes. Second, outsourced machinery services introduce advanced agricultural technologies and equipment, such as mechanical rice transplanting, deep plowing, soil testing-based fertilization, and unmanned plant protection drones (Lowenberg-DeBoer et al., 2021). The widespread application of these technologies enables contracted land-holding farmers to access and utilize modern agricultural technology more conveniently, thereby effectively alleviating technological constraints in agricultural production. Under the combined effect of alleviating these production factor constraints, the agricultural operating cost of contracted land-holding farmers decreases, productivity improves, and profitability increases, which weakens their motivation to transfer out land.

However, while outsourced machinery services alleviate production factor constraints for contracted land-holding farmers, their adoption does not directly increase farmland demand or lead to the expansion of contracted land-holding operations. This is primarily reflected in two aspects: First, as outsourced machinery services become widely adopted, the land transfer market experiences supply shortages and increases farmland rents (Cheng et al., 2022). With rising rental costs, the willingness of contracted land-holding farmers to expand their operations is restrained and limiting their operational growth. Second, expanding agricultural operations requires contracted land-holding farmers to invest more time in farming, reducing their available time for non-agricultural employment and increasing the opportunity cost of acquiring additional farmland (Wang et al., 2020). Since non-agricultural employment often offers higher income returns, the increase in opportunity costs makes contracted land-holding farmers more inclined to maintain their current scale rather than expanding their operations through land transfers.

In summary, under the influence of outsourced machinery services, contracted land-holding farmers can reduce agricultural production costs and increase profitability. However, due to rising farmland rents and increased opportunity costs of non-agricultural employment, their demand for additional farmland remains constrained, making it difficult to expand their operational scale. Based on the above analysis, the following research hypotheses are posited:

H1: Contracted land-holding utilizing outsourced machinery services impede the transfer out of lands managed by farmers.

H2: Contracted land-holding employing outsourced machinery services exerts an insignificant influence on farmers' willingness to acquire others' lands.

Unlike contracted land-holding farmers, outsourced land-holding farmers constitute a major demand-side force in the farmland transfer market (Zhang et al., 2022). They primarily lease land for specialized production and large-scale operations, managing larger farmland areas. This results in higher demand for agricultural inputs and technical services, as well as a greater need for labor. Moreover, as outsourced land-holding farmers typically operate farmland in contiguous plots, this scale-based characteristic allows service providers to achieve economies of scale more easily, thereby reducing service supply costs. Therefore, compared to the dispersed operations of contracted land-holding farmers, outsourced land-holding farmers get a more significant cost advantage in purchasing outsourced machinery services, and form a comparative price advantage (Qian et al., 2022). Against this backdrop, after adopting outsourced machinery services, outsourced land-holding farmers experience a stronger alleviation of constraints related to labor, technology, and capital inputs, thereby reducing the likelihood of transferring out leased land.

However, it is important to note that the total supply of farmland in the transfer market remains relatively fixed. Thus, a reduction in farmland being transferred out (i.e., supply contraction) will inevitably increase the farmland rents and leasing costs for outsourced land-holding farmers (Kang et al., 2020). Nevertheless, compared to contracted land-holding farmers, outsourced land-holding farmers face significantly different cost-benefit conditions in the land transfer process, which can be observed in two key aspects:

First, as the operational scale of outsourced land-holding farmers expands, they face increasing constraints related to labor, technology, and capital, making it increasingly urgent to alleviate these limitations (Valtiala et al., 2023). In this context, the role of outsourced machinery services in mitigating input constraints becomes more pronounced. Compared to the rising rent effect, the role of these services in facilitating the expansion of the operational scale of outsourced land-holding farmers grows stronger. Therefore, despite increasing farmland rents, farmers continue to expand their operations due to cost efficiencies and productivity improvement provided by outsourced machinery services.

Second, outsourced land-holding farmers generally operate on a larger scale, with their income structure primarily reliant on agricultural activities. Compared to contracted land-holding farmers, they are less involved in non-agricultural employment, resulting in a relatively lower opportunity cost for acquiring additional farmland. As a result, they are more inclined to expand their land holdings to achieve economies of scale (Prager et al., 2016).

In summary, although rising farmland rents increase cost pressures on outsourced land-holding farmers, the benefits of outsourced machinery services in reducing input constraints—along with the relatively low opportunity cost of non-agricultural employment—collectively enhance their demand for farmland. This, in turn, drives their efforts to acquire more land. Based on the analysis above, the following research hypotheses are posited:

H3: Outsourced land-holding utilizing outsourced machinery services limits the transfer out of lands managed by farmers.

H4: Outsourced land-holding utilizing outsourced machinery services facilitates farmers' acquisition of others' lands.

Material and methods

Data sources and variable selection. This study used micro-level data from the China Land Economic Survey (CLES) database, established in 2020 with the support of Jinshanbao Institute of Agricultural Modernization Research at Nanjing Agricultural University. The sampling process employed the Probability Proportional to Size (PPS) method, selecting two townships from each of the 26 districts and counties across 13 prefecture-level cities in Jiangsu Province. Subsequently, one administrative village was randomly selected from each township, and 50 households from each village were surveyed. Based on the initial 2020 survey conducted in Jiangsu Province, CLES carried out a follow-up survey in 2021. Currently, tracking data is available for the years 2020, 2021, and 2022. The specific research areas are illustrated in Fig. 1.

Dependent variable. The study focuses on the land transfer variable, which encompasses both incoming (trans-in) and outgoing (trans-out) transfers. Outgoing transfers are measured using the "cultivated land area transferred out" variable from the household data. Incoming transfers, on the other hand, are represented by the combined value of two variables: "motorized land transferred within the village" and "land transferred to the household."

Core independent variable. The central independent variable in this study is the utilization of outsourced machinery services. This is specifically measured using a question from the household data: "Which of the following tasks have you outsourced (plowing, seedling cultivation, planting, pesticide spraying, harvesting, straw returning)?" If none of these tasks were outsourced, the variable was coded as 0; if some tasks were outsourced, it was coded as 1.

Control variables. To mitigate potential biases arising from omitted variables, this study controls for a comprehensive set of variables, including household characteristics (such as the gender, age, educational level, and health status of the household head), family characteristics (including total household income, household size, whether household members are cadres or party members, the number of individuals engaged in agricultural labor, total household savings, and the household's borrowing situation), and village characteristics (such as terrain features, road conditions, and village size). The assignment details for these variables, along with descriptive statistics, are provided in Table 1.

After organizing the data, a total of 5889 valid samples were obtained. Among these, 1792 samples (30.4%) involved contracted land-holding households utilizing outsourced machinery services, while 4097 samples (69.6%) did not utilize such services. For outsourced land-holding households, 410 samples (7%) utilized outsourced machinery services, whereas 5479 samples (93%) did not.

Model selection. Using panel data, this study conducts an empirical analysis by constructing a two-way fixed-effects model that incorporates both regional fixed-effects and time fixed-effects. This approach captures individual characteristics that remain constant over time and the trends that are consistent across individuals, thereby reducing omitted variable bias and yielding more accurate and reliable estimation results. The regression equation is specified as follows:

$$lnLandTrans = \beta_0 + \beta_1 OMS + \beta_2 X' + \eta_j + \nu_t + \mu_{it} \quad (1)$$

Equation (1) outlines the theoretical model, where land transfer serves as the dependent variable. OMS represents outsourced machinery services X' represents a set of control variables. These control variables include gender, age, education level, health status, total household income, cadre status, party membership, total household population, agricultural labor force, total deposit amount, borrowing situation, terrain features, road conditions, and village size. η_j represents regional fixed-effects ν_t denotes time fixed-effects, and μ_{it} represents individual random disturbance terms.

Results and analysis

Baseline regression results. Table 2 reports the impact of adopting outsourced machinery services on outgoing (trans-out) and incoming (trans-in) land transfers for contracted land-holding. Models (1) and (4) present results with only explanatory variables, Models (2) and (5) include control variables, and Models (3) and (6) incorporate individual and time fixed-effects. The regression results indicate that adopting outsourced machinery services significantly reduces land transferred out but has no significant impact on land transferred in for contracted land-holding, confirming Hypotheses 1 and 2. This outcome can be attributed to the fact that outsourced services compensate for insufficient household labor, enabling contracted land-holding

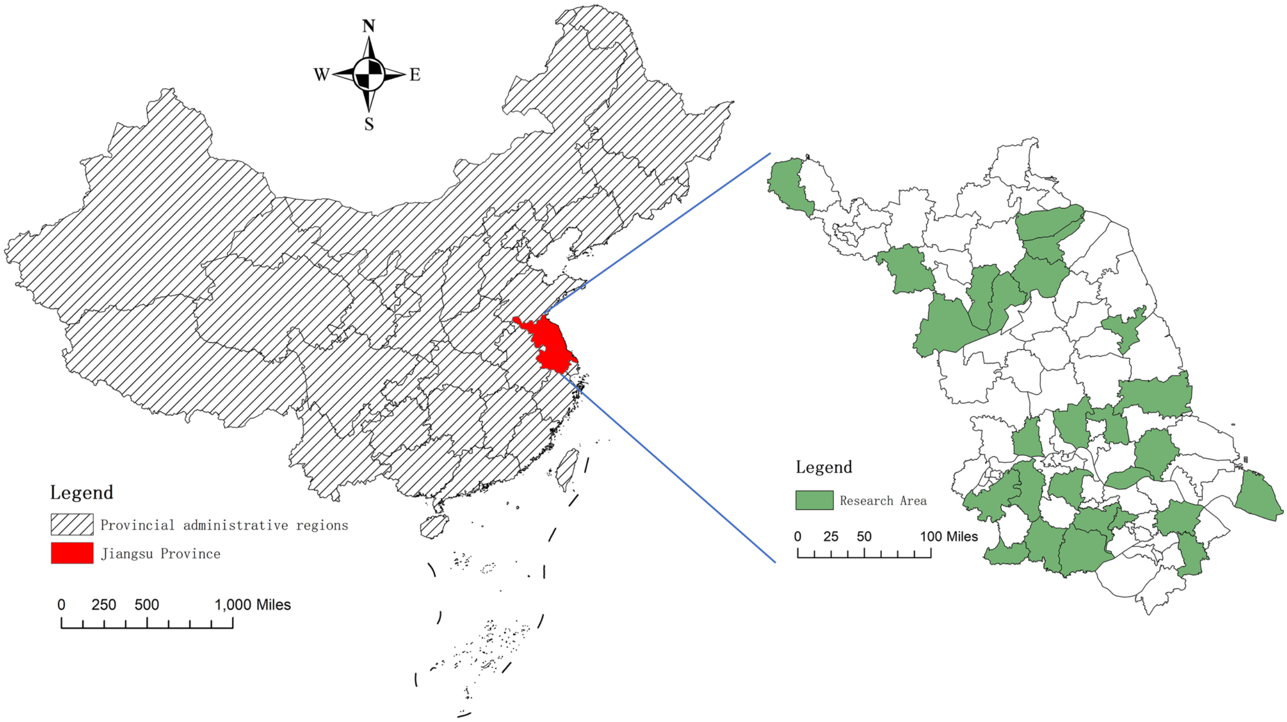

Fig. 1 Research areas in Jiangsu Province, China.

farmers to sustain cultivation. By enhancing efficiency without the risks and costs associated with machinery acquisition, outsourcing supports mechanization and reduces the amount of land required. However, it does not significantly promote land transfer in, likely because expanding operational scale requires continuous investment, which limits off-farm work opportunities and increases costs. As Lowder et al. (2021) suggest, economies of scale primarily benefit larger farms, and small-scale transfers may not achieve sufficient scale. Additionally, an underdeveloped outsourcing market compels farmers to limit land use to control costs (Hendricks, 2022). Thus, while outsourcing helps sustain land use, it does not significantly drive land expansion.

Table 3 presents the impact of adopting outsourced machinery services on trans-out and trans-in for outsourced land-holding. The model specifications are identical to those in Table 2. The regression results show that outsourcing adoption significantly reduces trans-out while promoting trans-in for this group, confirming Hypotheses 3 and 4. Similar to contracted farmers, outsourcing alleviates labor, technology, and capital constraints for outsourced land-holding farmers, reducing land transferred out. However, unlike contracted farmers, outsourced land-holding farmers operate on a larger scale, making expansion more feasible and enhancing cost efficiency and output. Driven by profit potential, they increase land demand, leading to more land being transferred in and less being transferred out. In summary, outsourcing enables outsourced land-holding farmers to optimize cultivation practices and facilitates the expansion of their operational scale.

Endogeneity test. To address the endogeneity issue arising from sample self-selection, this study employs the Propensity Score Matching (PSM) method to mitigate bias. PSM is widely used in counterfactual causal analysis to create quasi-randomized groups without experimental methods, which distinguish between treatment and control groups. In this study, the PSM method identifies samples that did not adopt outsourced machinery services but have similar matching scores as the control group for estimation purposes. Within the PSM framework, households are classified into treatment and control groups. If a household adopts outsourced machinery services, it is denoted as 1; otherwise, it is denoted as 0. $Y_i(1)$ and $Y_i(0)$ represent the outcomes of land transfer, depending on whether outsourced machinery services were adopted.

This study uses PSM to match the treatment group (households adopting outsourced machinery services) with the control group (households not adopting outsourced machinery services). By controlling for external conditions to ensure consistency, the study examines the impact of adopting outsourced machinery services on land transfer. The research steps are as follows:

Firstly, utilize the Logit or Probit model to estimate the conditional probability of fitted values of households adopting outsourced machinery services. The calculated Propensity Score (PS) is:

$$PS_i = Pr\left[OMS_i = 1|X_i\right] = E\left[OMS_i = 0|X_i\right] = \frac{exp\left(X_i^{'}\beta\right)}{1 + exp\left(X_i^{'}\beta\right)} \tag{2}$$

where $OMS_i = 1$ indicates the adoption of outsourced machinery services, while $OMS_i = 0$ signifies non-adoption of outsourced machinery services, and X_i represents observable covariates.

Secondly, match the treatment group and the control group. This study employs the Logit or Probit model to estimate propensity scores and utilizes the caliper nearest-neighbor matching method to process the data.

Finally, evaluate the net effect produced by the adoption of outsourced machinery services on land transfer. The "net effect" can be expressed as the Average Treatment Effect of the Treated (ATT):

$$\begin{aligned} ATT &= E\left(LandTrans_{1i}|OMS_i = 1\right) - E\left(LandTrans_{0i}|OMS_i = 1\right) \\ &= E\left(LandTrans_{1i} - LandTrans_{0i}|OMS_i = 1\right) \end{aligned} \tag{3}$$

Here $LandTrans_{1i}$ represents the land transfer scenario when outsourced machinery services are adopted, while $LandTrans_{0i}$

Table 1 Definitions of variables and descriptive statistics.

Variables	Definitions of variables	Mean value	Standard error	Minimum	Maximum
OMS_c	Which of the following aspects of the contracted land-holding have been purchased as outsourced services (plowing, seedling production, planting, pesticide spraying, harvesting, straw return)?	0.304	0.460	0	1
OMS_o	Which of the following aspects of the outsourced land-holding have been purchased as outsourced services (plowing, seedling production, planting, pesticide spraying, harvesting, straw return)?	0.070	0.255	0	1
$Land_{out}$	farmland area transferred out	2.490	3.688	0	83
$Land_{in}$	the sum of "motorized farmland transferred within the village" and "farmland transferred to the household."	14.322	100.356	0	2993
Gender	1 = male; 0 = female	0.921	0.270	0	1
Age	Age (years)	62.991	10.196	18	98
Education	Educational level (years in school) (years)	7.209	3.662	0	20
Health	Self-identified health status (1 = incapacitated; 2 = poor; 3 = medium; 4 = good; 5 = excellent)	3.939	1.101	1	5
Income	Annual income	14,912.05	92,760.53	0	3,644,000
Cadre	Is there anyone who is a cadre?	0.154	0.361	0	1
CCPM	Is there any member of your household who is a member of the Chinese Communist Party?	0.303	0.460	0	1
Population	How many permanent residents (living in your household for 6 months or more of the year) are there in your household?	3.129	1.625	1	11
Labor force	How many people in your household have worked in agriculture? (persons)	0.267	0.719	0	6
Deposit	Total deposits at year-end	49,721.13	148,778.3	0	5,000,000
Borrow	Total borrowings at the end of the year	30,073.53	225,357.6	0	10,000,000
Terrain	Topographical features of the village (1 = plain; 2 = hilly; 3 = mountainous; 4 = other, please specify)	1.150	0.357	1	2
Road	Does the village have a hardened road that conveniently connects to any of the neighboring routes, such as national or provincial roads or county and township roads?	0.528	0.499	0	1
Village	Year-end resident population	3426.409	1949.342	650	16,052

represents the land transfer situation when these services are not adopted. The expected value $E(LandTrans_{1i}|OMS_i = 1)$ is observable, whereas $E(LandTrans_{0i}|OMS_i = 1)$ is unobservable. To address this, PSM is applied to construct a substitute indicator for $E(LandTrans_{1i} - LandTrans_{0i}|OMS_i = 1)$.

First, propensity scores are calculated using matching variables. For outsourcing's influence on contracted land-holding transfers, Logit models are used to estimate propensity scores. A caliper nearest-neighbor one-to-four matching method with replacement is employed, with a caliper value of 0.01 (ε). Similarly, for outsourced land transfers, Logit models are applied to estimate propensity scores, using a caliper nearest-neighbor one-to-two matching method with replacement and a caliper value of 0.01 (ε). However, when analyzing outsourced land-holding transfers, Probit models are utilized to estimate propensity scores, with a caliper nearest-neighbor one-to-four approach with replacement and a caliper value of 0.01 (ε). The results of the PSM are presented in Table 4. The significant 1% LR chi-square statistic indicates that the model is a well-estimated model, with most variables also showing significance at the 1% level.

Inspection of matching quality

Matching balance tests. To validate the reliability of the matching results, the covariate balance was examined post-matching. The analysis revealed no significant differences between the control and treatment groups for any covariates. As shown in Table 5, all covariate standardized biases post-matching were below 10%. Additionally, the *P*-values from the covariate *t*-tests are exceeded 10% post-matching, which indicate that the group means were relatively similar without significant differences. This confirms that balance was achieved and implying the successful matching.

The PSM effectively balanced the groups across different types of land transfer, thereby strengthening the causal analysis. Specifically, for contracted land transfer out, matching eliminated significant pre-matching differences in variables such as age, income, and population. This shows the impact of outsourcing on contracted land-holding transfer out. For outsourced land-holding transfer in, matching addressed the pre-matching differences in variables such as gender and age, which validates the analysis of the effects of outsourcing adoption on outsourced land-holding transfer in. For outsourced land-holding transfer out, matching removed pre-matching differences in variables such as terrain and others, which enhanced the credibility of the outsourcing analysis for outsourced land-holding transfer out.

Overlapping hypothesis test. After confirming the conditional independence assumption, the next step involves conducting the PSM overlap hypothesis test. This test examines the common support between the two sample groups, as illustrated in Fig. 2. Panels 1 and 2 of Fig. 2 depict the kernel density functions before and after matching. This shows the impact of adopting outsourced machinery services on land transferred out in contracted land-holding. Similarly, Panels 3 and 4 of Fig. 2 show the kernel density functions before and after matching, highlighting the impact on land transferred in outsourced land-holding. Additionally, Panels 5 and 6 of Fig. 2 present the kernel density functions before and after matching, focusing on the impact of adopting outsourced machinery services on land transferred in outsourced land-holding.

After applying caliper-based nearest-neighbor matching, the model evaluating the impact of adopting outsourced machinery services on land transferred out in contracted land-holding retains 5870 matched samples for both the treatment and control

Table 2 Benchmark regression results on the adoption of outsourced mechanical services by contracted land-holding.

Variables	(1) $Land_{out}$	(2) $Land_{out}$	(3) $Land_{out}$	(4) $Land_{in}$	(5) $Land_{in}$	(6) $Land_{in}$
OMS_c	−1.677*** (−16.82)	−1.597*** (−15.89)	−1.130*** (−6.04)	0.555 (0.22)	2.967 (1.19)	−0.216 (−0.06)
Gender		0.233 (1.28)	−0.410 (−1.28)		10.289** (2.31)	0.926 (0.27)
Age		0.026*** (4.67)	0.019 (1.54)		−0.485*** (−3.59)	−0.410 (−1.21)
Education		−0.004 (−0.24)	0.007 (0.21)		−0.195 (−0.52)	0.236 (0.43)
Health		−0.095** (−2.14)	−0.101 (−1.35)		2.797** (2.55)	4.140** (2.55)
Income		−1.26e-06** (−2.56)	−1.77e-06* (−1.72)		0.0002*** (14.04)	−0.00002 (−1.11)
Cadre		0.556*** (4.02)	0.486** (2.00)		3.596 (1.04)	2.143 (0.58)
CCPM		0.149 (1.25)	0.446 (1.20)		−4.220 (−1.45)	−5.768 (−1.02)
Population		0.038 (1.28)	−0.006 (−0.10)		1.186 (1.60)	1.570 (0.98)
Labor force		0.036 (0.59)	−0.127 (−1.04)		−1.382 (−0.90)	−7.085 (−1.64)
Deposit		−1.79e-07 (−0.59)	−;2.87e-07 (−0.62)		7.53e-06 (0.99)	2.19e-06 (0.25)
Borrow		−;9.73e-08 (−0.48)	6.11e-08 (0.40)		0.0001*** (21.22)	4.81e-07 (0.05)
Terrain		0.391*** (2.68)	0.160 (0.58)		0.723 (0.20)	−;1.839 (−1.16)
Road		0.383*** (4.60)	0.453** (2.39)		2.320 (1.09)	10.189 (0.69)
Village		−;0.0001*** (−5.18)	0.00008 (1.49)		0.002*** (3.22)	0.006 (1.33)
Constant term	2.989*** (47.65)	1.131** (2.20)	1.570 (1.50)	13.162*** (8.04)	6.080 (0.48)	−;0.919 (−0.03)
R^2	0.0278	0.0397	0.0487	0.0000	0.0000	0.0182
Wald chi^2	282.81***	423.32***	7.57***	0.05	826.62***	1.11
Control variable	No	Yes	Yes	No	Yes	Yes
Bidirectional Fixed-Effects	No	No	Yes	No	No	Yes
N	5889	5889	5889	5889	5889	5889

*, **, and *** indicate significance at the 10%, 5% and 1% levels of statistical significance, respectively; values in parentheses in models (1) (2) (4) (5) are *Z*-values, and values in parentheses in models (3) (6) are *T*-values.

Table 3 Benchmark regression results on the adoption of outsourced mechanical services by outsourced land-holding.

Variables	(1) $Land_{out}$	(2) $Land_{out}$	(3) $Land_{out}$	(4) $Land_{in}$	(5) $Land_{in}$	(6) $Land_{in}$
OMS_o	−;1.015*** (−5.45)	−;0.829*** (−4.45)	−;0.407* (−1.75)	66.971*** (14.55)	66.420*** (14.81)	34.911*** (3.52)
Gender		0.238 (1.29)	−;0.366 (−1.11)		8.320** (1.90)	1.754 (0.47)
Age		0.027*** (4.85)	0.019 (1.49)		−;0.324** (−2.45)	−;0.401 (−1.20)
Education		0.0005 (0.03)	0.005 (0.15)		−;0.154 (−0.42)	0.167 (0.31)
Health		−;0.073 (−1.63)	−;0.081 (−1.08)		2.643** (2.45)	4.151** (2.53)
Income		−;1.12e-06** (−2.24)	−;1.77e-06* (−1.72)		0.0002*** (14.71)	−;0.00003 (−1.18)
Cadre		0.531*** (3.76)	0.471* (1.93)		2.783 (0.82)	1.595 (0.45)
CCPM		0.230* (1.90)	0.470 (1.27)		−;3.127 (−1.10)	−;4.382 (−0.82)
Population		0.031 (1.01)	−;0.004 (−0.06)		0.669 (0.92)	1.449 (0.90)
Labor force		−;0.053 (−0.86)	−;0.133 (−1.08)		−;0.271 (−0.18)	5.353 (−1.22)
Deposit		−;6.56e-08 (−0.21)	−;2.97e-07 (−0.62)		9.67e-06 (1.29)	1.93e-06 (0.23)
Borrow		4.57e-08 (0.22)	1.65e-07 (1.11)		0.0001*** (21.61)	−;2.23e-07 (−0.02)
Terrain		0.496*** (3.33)	0.201 (0.74)		2.355 (0.67)	−;2.606 (−1.59)
Road		0.526*** (6.26)	0.629*** (3.34)		3.639* (1.73)	11.577 (0.77)
Village		−;0.0001*** (−5.41)	0.00005 (1.07)		0.002*** (3.64)	0.005 (1.22)
Constant term	2.552*** (44.09)	0.333 (0.64)	1.152 (1.10)	8.911*** (6.18)	−;7.801 (−0.64)	−;2.374 (−0.08)
R^2	0.0018	0.0177	0.0258	0.0151	0.0032	0.0308
Wald chi^2	29.75***	183.36***	3.48***	211.65***	1117.81***	1.70**
control variable	No	Yes	Yes	No	Yes	Yes
Bidirectional Fixed-Effects	No	No	Yes	No	No	Yes
N	5889	5889	5889	5889	5889	5889

*, **, and *** indicate significance at the 10%, 5%, and 1% levels of statistical significance, respectively; values in parentheses in models (1) (2) (4) (5) are *Z*-values, and values in parentheses in models (3) (6) are *T*-values.

Table 4 PSM estimation.

Variables	Contracted land-holding ($Land_{out}$)		Outsourced land-holding ($Land_{in}$)		Outsourced land-holding ($Land_{out}$)	
	Regression coefficient	*Z*-value	Regression coefficient	*Z*-value	Regression coefficient	*Z*-value
Gender	0.112	1.01	0.936***	3.33	0.936***	3.33
Age	−;0.012***	−;3.76	−;0.043***	−;7.79	−;0.043***	−;7.79
Education	−;0.020**	−;2.17	−;0.019	−;1.13	−;0.019	−;1.13
Health	−;0.039	−;1.40	0.034	0.66	0.034	0.66
Income	−;2.13e-06**	−;2.23	−;4.80e-07	−;0.64	−;4.80e-07	−;0.64
Cadre	0.160*	1.81	0.253	1.62	0.253	1.62
CCPM	−;0.331***	−;4.58	−;0.280**	−;2.04	−;0.280**	−;2.04
Population	0.055***	3.04	0.146***	4.77	0.146***	4.77
Labor force	0.344***	8.23	−;0.020	−;0.25	−;0.020	−;0.25
Deposit	−;1.07e-06***	−;3.27	−;1.32e-06**	−;2.07	−;1.32e-06**	−;2.07
Borrow	−;7.23e-07***	−;2.71	2.93e-07**	2.06	2.93e-07**	2.06
Terrain	−;0.574***	−;6.22	−;0.784***	−;3.88	−;0.784***	−;3.88
Road	−;0.570***	−;9.00	−;0.472***	−;4.08	−;0.472***	−;4.08
Village	0.00003	1.62	−;0.0001***	−;3.45	−;0.0001***	−;3.45
Constant term	0.868***	2.87	0.246	0.43	0.246	0.43
LR chi^2	266.01***		205.19***		205190***	
Pseudo R^2	0.0368		0.0690		0.0690	
N	5889		5889		5889	

*, **, and *** indicate statistically significant at the 10 per cent, 5 per cent and 1 per cent levels, respectively.

Table 5 Balance test.

Variables	Treatment	Contracted land-holding ($Land_{out}$)		Outsourced land-holding ($Land_{in}$)		Outsourced land-holding ($Land_{out}$)	
		Standard error (%)	Probability	Standard error (%)	Probability	Standard error (%)	Probability
Gender	Unmatched	1.3	0.637	20.7	0.000	20.7	0.000
	Matched	−1.9	0.566	−1.0	0.845	0.8	0.887
Age	Unmatched	−8.9	0.002	−52.8	0.000	−52.8	0.000
	Matched	0.4	0.908	−0.5	0.940	1.8	0.804
Education	Unmatched	−7.1	0.013	12.2	0.024	12.3	0.024
	Matched	1.6	0.640	1.1	0.877	0.2	0.975
Health	Unmatched	−5.7	0.044	13.7	0.009	13.7	0.009
	Matched	2.7	0.431	3.2	0.647	0.9	0.895
Income	Unmatched	−8.8	0.006	−2.9	0.627	−2.9	0.627
	Matched	−1.3	0.389	3.3	0.473	1.4	0.773
Cadre	Unmatched	−1.9	0.500	6.9	0.169	6.9	0.169
	Matched	−2.0	0.557	3.6	0.611	1.5	0.837
CCPM	Unmatched	−16.2	0.000	−13.1	0.013	−13.1	0.013
	Matched	2.5	0.431	−1.1	0.872	−0.4	0.952
Population	Unmatched	10.7	0.000	30.9	0.000	30.9	0.000
	Matched	−3.0	0.393	−1.7	0.819	0.8	0.912
Labor force	Unmatched	14.8	0.000	−4.9	0.331	−4.9	0.331
	Matched	0.0	0.990	3.4	0.611	0.3	0.971
Deposit	Unmatched	−11.6	0.000	−9.2	0.137	−9.2	0.137
	Matched	−1.0	0.689	0.9	0.836	−0.3	0.945
Borrow	Unmatched	−7.6	0.019	16.2	0.000	16.2	0.000
	Matched	−2.1	0.327	9.7	0.173	10.6	0.119
Terrain	Unmatched	−19.4	0.000	−26.2	0.000	−26.2	0.000
	Matched	−1.2	0.694	0.8	0.893	−0.2	0.973
Road	Unmatched	−22.1	0.000	−25.6	0.000	−25.6	0.000
	Matched	−0.8	0.814	−0.2	0.972	0.7	0.915
Village	Unmatched	−2.7	0.349	−23.8	0.000	−23.8	0.000
	Matched	−1.7	0.612	1.8	0.756	2.3	0.689

groups, with a loss of 19 samples. Similarly, the model examining the impact on land transferred in outsourced land-holding retains 5721 samples after a loss of 168 samples. Additionally, the model analyzing the effects on land transferred out in outsourced land-holding also retains 5721 samples, with a reduction of 168 samples (Table 6). Furthermore, Panels 1, 2, and 3 of Fig. 3 illustrate the common range of PSM values for land transferred out in contracted land-holding, land transferred out in outsourced land-holding with outsourced machinery services, and land transferred in with outsourced machinery services, respectively. The majority of samples fall within this common range, indicating a robust matching effect.

Results of PSM method. After conducting counterfactual estimation using PSM, the results show a net effect of −2.000 for the

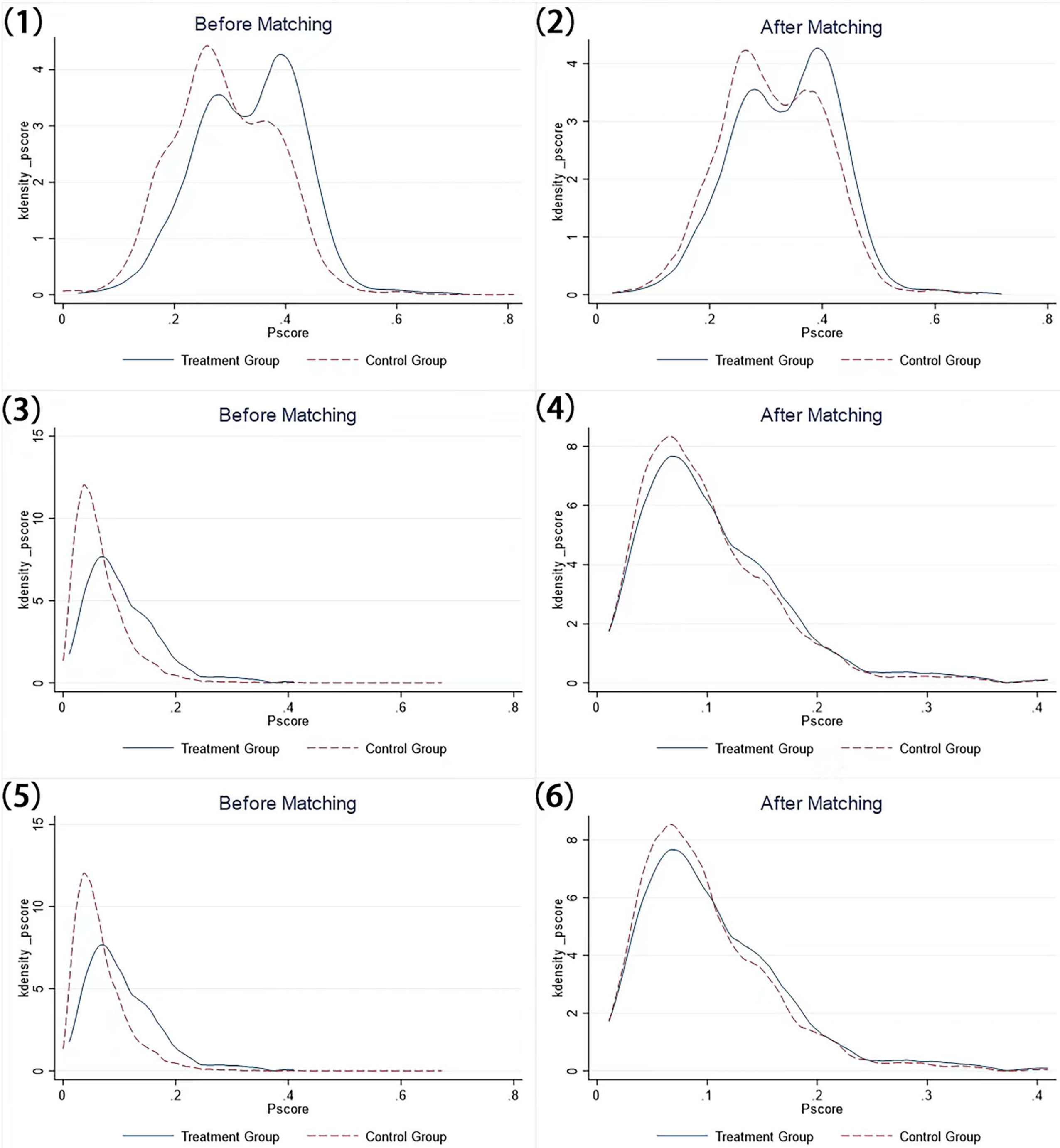

Fig. 2 Propensity score kernel density before and after matching.

impact of adopting outsourced machinery services on land transfers among contracted land-holding, which is statistically significant at the 1% level. This implies that, after accounting for selective bias among farmers, the adoption of outsourced machinery services significantly reduces the land transfers from contracted land-holding households. Conversely, the net effect of adopting outsourced machinery services on land transfers among outsourced land-holding is 80.214, also significant at the 1% level, while the net effect on land transferred out is −1.030, similarly significant at the 1% level. These findings fail to reject the null hypotheses (H1, H3, and H4).

To address the potential measurement bias arising from the application of different matching methods to the same sample data, robustness checks were conducted using the caliper values of 0.05 and 0.1 in the PSM based on caliper-based nearest-neighbor matching. The results consistently demonstrated the same direction and magnitude of the impact, confirming the robustness of the research findings. Detailed results are presented in Table 7.

Re-examination of results after the implementation of the PSM method. A regression analysis was conducted using panel data, excluding samples outside the common support range, as specified in Formula (1). The regression results are shown in Table 8. For contracted land-holding areas, the Hausman test suggests selecting a fixed-effects model to determine the impact

Table 6 Results of PSM matching.

	Contracted land-holding ($Land_{out}$)			Outsourced land-holding ($Land_{out}$)			Outsourced land-holding ($Land_{in}$)		
	Unmatched samples	Matched samples	Total	Unmatched samples	Matched samples	Total	Unmatched samples	Matched samples	Total
Treatment group	17	4080	4097	168	5311	5479	168	5311	5479
Control group	2	1790	1792	0	410	410	0	410	410
Total	19	5870	5889	168	5721	5889	168	5721	5889

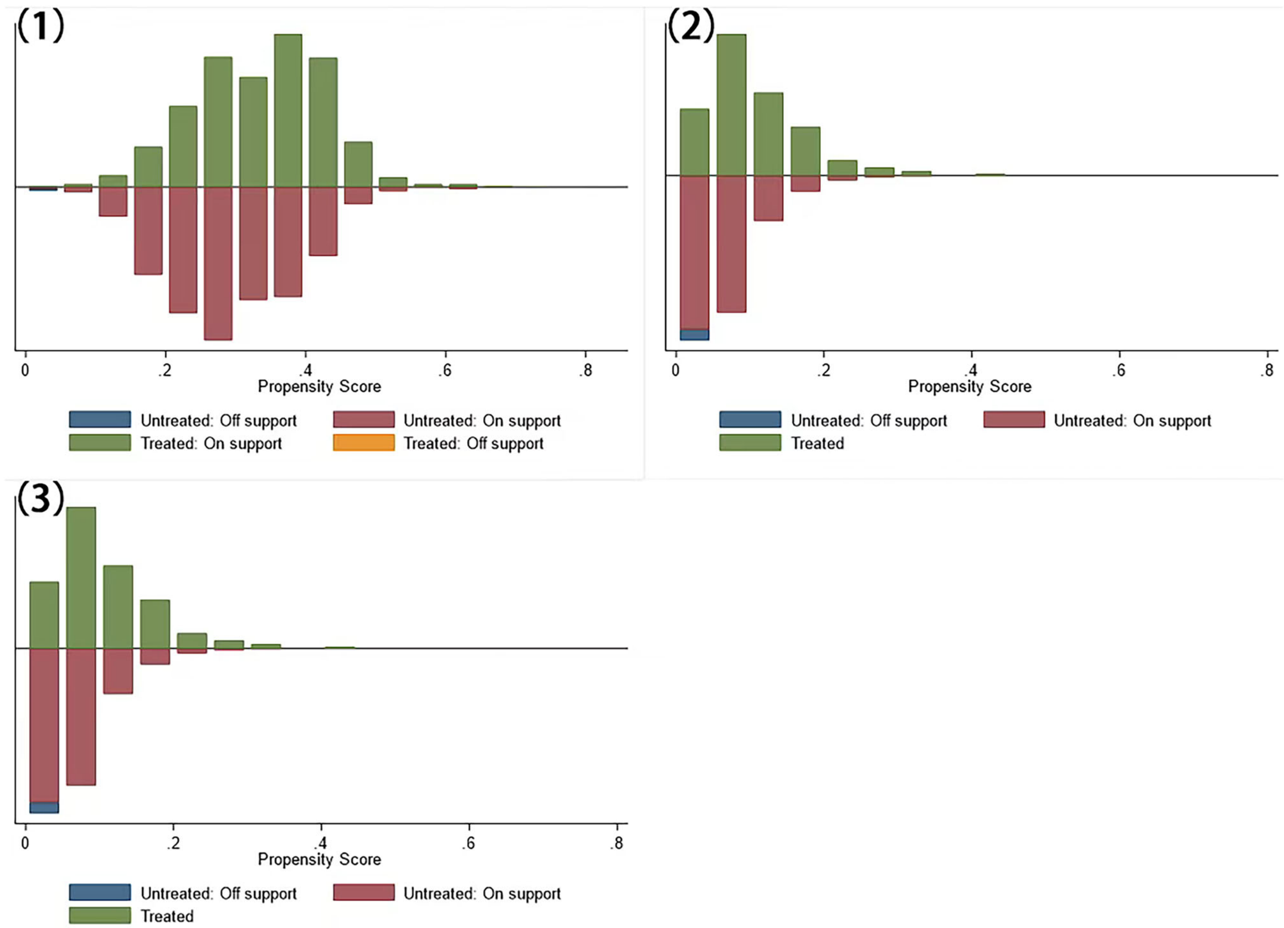

Fig. 3 Common range of values for propensity score matching.

of adopting outsourced machinery services on land transferred out. The *F*-values indicate that the results from the fixed-effects model are statistically significant at the 1% level. The coefficient for the main explanatory variable affecting the land transferred out is −1.126, which is statistically significant at the 1% level. This suggests that the adoption of outsourced machinery services in contracted land-holding significantly reduces the land transferred out from farming households. As demonstrated in the baseline regression, machinery outsourcing lowers operating costs and improves efficiency for contracted land-holding farmers, alleviating labor and technology constraints and thereby reducing land transfers out.

For outsourced land-holding areas, the Hausman test indicates that fixed-effects models for both land transfers in and transfers out are superior to random-effects models. The *F*-values confirm the statistical significance of the fixed-effects models in estimating the impact of adopting outsourced machinery services on land transferred in outsourced land-holding, with significance at the 5% level. Similarly, the overall results of the fixed-effects model estimating the impact of land transferred out in outsourced land-holding are significant at the 1% level. This implies that the adoption of outsourced machinery services in outsourced land-holding encourages farmers to acquire additional land. The coefficient representing the impact of adopting outsourced machinery services on land transferred out in outsourced land-holding is −0.404, significant at the 10% level. As previously analyzed, machinery outsourcing enhances agricultural efficiency by addressing labor shortages and introducing advanced technologies, improving farmland operations and discouraging land transfers out. At the same time, it facilitates the land expansion by easing financial constraints for incoming farmers, who are aware that their pursuit of economies of scale (Miller et al., 2019).

Table 7 Treatment effects of propensity score matching.

Variables	Matching method	Treatment group	Control group	ATT	*T*-value
Contracted land-holding ($Land_{out}$)	Pre-match	1.155	3.075	−1.920	−18.93
	caliper nearest-neighbor matching (Logit estimate, $n = 4$, $\varepsilon = 0.01$)	1.153	3.153	−2.000	−17.29
	caliper nearest-neighbor matching (Logit estimate, $n = 4$, $\varepsilon = 0.05$)	1.155	3.159	−2.005	−17.35
	caliper nearest-neighbor matching (Logit estimate, $n = 4$, $\varepsilon = 0.1$)	1.155	3.158	−2.003	−17.34
Outsourced land-holding ($Land_{in}$)	Pre-match	90.958	8.588	82.370	16.39
	caliper nearest-neighbor matching (Logit estimate, $n = 2$, $\varepsilon = 0.01$)	90.958	10.744	80.214	8.52
	caliper nearest-neighbor matching (Logit estimate, $n = 2$, $\varepsilon = 0.05$)	90.958	10.744	80.214	8.52
	caliper nearest-neighbor matching (Logit estimate, $n = 2$, $\varepsilon = 0.1$)	90.958	10.171	81.787	8.59
Outsourced land-holding ($Land_{out}$)	Pre-match	1.412	2.571	−1.159	−6.16
	caliper nearest-neighbor matching (Probit estimate, $n = 4$, $\varepsilon = 0.01$)	1.412	2.443	−1.030	−5.10
	caliper nearest-neighbor matching (Probit estimate, $n = 4$, $\varepsilon = 0.05$)	1.412	2.448	−1.035	−5.13
	caliper nearest-neighbor matching (Probit estimate, $n = 4$, $\varepsilon = 0.1$)	1.412	2.407	−0.995	−4.93

Table 8 Results of benchmark regression.

Variables	Contracted land-holding ($Land_{out}$)	Outsourced land-holding ($Land_{in}$)	Outsourced land-holding ($Land_{out}$)
OMS_c	−1.126*** (−5.95)		
OMS_o		35.314*** (3.50)	−0.404* (−1.71)
Gender	−0.390 (−1.22)	2.164 (0.54)	−0.382 (−1.12)
Age	0.018 (1.48)	−0.428 (−1.17)	0.019 (1.43)
Education	0.011 (0.35)	0.289 (0.49)	0.018 (0.57)
Health	−0.115 (−1.54)	4.176 (2.48)	−0.109 (−1.46)
Income	−6.26e-07 (−0.53)	−0.00005 (−1.36)	−2.63e-06*** (−2.71)
Cadre	0.487** (2.02)	1.681 (0.45)	0.425* (1.73)
CCPM	0.440 (1.18)	−4.946 (−0.86)	0.562 (1.49)
Population	−0.008 (−0.14)	1.335 (0.73)	−0.057 (−1.07)
Labor force	0.053 (0.70)	−0.163 (−0.05)	0.047 (0.60)
Deposit	−3.20e-07 (−0.46)	−1.59e-06 (−0.09)	4.44e-07 (0.53)
Borrow	−2.93e-07 (−0.89)	6.72e-08 (0.00)	1.16e-07 (0.51)
Terrain	0.131(0.49)	−3.235 (−1.63)	0.191 (0.64)
Road	0.350*** (3.72)	5.196 (1.39)	0.520*** (5.44)
Village	0.00008 (1.56)	0.008 (1.23)	0.0001** (2.20)
Constant term	1.624 (1.54)	−8.393 (−0.23)	1.015 (0.93)
F-value	7.81***	1.82**	4.96***
R^2	0.0444	0.0340	0.0330
Hausman test	75.22***	32.75***	66.58***
N	5870	5889	5889

*, **, and *** indicate significance at the 10%, 5% and 1% levels of statistical significance, respectively. Values in () represent *T*-values of the parameters.

Robustness checks. To estimate the robustness of the results, the kernel matching method with a bandwidth of 0.05 was employed to re-match data on the impact of adopting outsourced machinery services on land transferred out in contracted land-holding. This analysis showed a net effect of −1.868, which was significant at the 1% level. Similarly, using the nearest-neighbor one-to-three with replacement matching method, a significant net effect of 81.325 was observed for land transferred out in outsourced land-holding, while a net effect of −1.036 was found for land transferred in the same region, also significant at the 1% level. Subsequent panel regression analyses, as given in Table 9, showed the robustness of the research findings.

The Hausman test results indicated that fixed-effects models were selected for both contracted and outsourced land-holding analyses. Specifically, in contracted land-holding, the adoption of outsourced machinery services reduced land transferred out by farmers. Conversely, in outsourced land-holding, such adoption encouraged land transferred in and reduced land transferred out. These results, consistent with the baseline regression findings, reinforce the robustness of the models and enhance the credibility of the research outcomes.

Further analysis. To better illustrate the influence of varying degrees of outsourced machinery service adoption in agricultural production on land transfer, we assigned values from 0 to 6 to represent the extent of adoption across production stages. A value of 0 indicates no adoption, 1 signifies adoption in a stage, 2 reflects adoption in two stages, and so on, up to 6, which represents adoption across all stages. This approach allows us to examine how the adoption of outsourced machinery services affects land transfer. The impact of adopting different levels of outsourced machinery services on land transferred in contracted land-holding is presented in Table 10.

Based on the Hausman test results, a fixed-effects model is used to assess the impact of adopting outsourced machinery services in contracted land-holding on land transferred out. The results show a significantly negative impact, with a coefficient of −0.228, statistically significant at the 1% level. A subsequent two-way fixed-effects model yields a similar coefficient of −0.223, also significant at the 1% level. These consistent findings demonstrate that adopting outsourced machinery services in contracted land-holding significantly reduces land transferred out by farmers, which is aligned with the baseline regression analysis.

Table 9 Results of robustness test.

Variables	Contracted land-holding ($Land_{out}$)	Outsourced land-holding ($Land_{out}$)	Outsourced land-holding ($Land_{in}$)
OMS_c	−1.126*** (−5.95)		
OMS_o		−0.404* (−1.71)	66.418*** (8.05)
Gender	−0.390 (−1.22)	−0.382 (−1.12)	6.401** (2.50)
Age	0.018 (1.49)	0.019 (1.43)	−0.290* (−1.96)
Education	0.011 (0.35)	0.018 (0.57)	−0.186 (−0.80)
Health	−0.115 (−1.54)	−0.109 (−1.46)	2.77** (2.50)
Income	−6.26e-07 (−0.53)	−2.63e-06*** (−2.71)	0.0003* (1.76)
Cadre	0.488** (2.02)	0.425* (1.73)	2.576 (0.63)
CCPM	0.440 (1.18)	0.562 (1.49)	−2.824 (−1.18)
Population	−0.008 (−0.14)	−0.057 (−1.07)	0.224 (0.29)
Labor force	0.053 (0.71)	0.047 (0.60)	−0.313 (−0.16)
Deposit	−3.20e-07 (−0.46)	4.44e-07 (0.53)	7.61e-06 (0.33)
Borrow	−2.93e-07 (−0.89)	1.16e-07 (0.51)	0.0002*** (2.74)
Terrain	0.131 (0.49)	0.191 (0.64)	1.083 (0.22)
Road	0.350*** (3.72)	0.520***(5.44)	5.275 (1.60)
Village	0.00008 (1.57)	0.0001**(2.20)	0.003 (1.34)
Constant term	1.623 (1.54)	1.015 (0.93)	−11.580 (−0.89)
F-value/Wald chi^2	7.81***	4.96***	129.70***
Hausman test	74.30***	58.18***	30.49**
N	5873	5721	5721

*, **, and *** indicate significance at the 10%, 5% and 1% levels of statistical significance, respectively. Values in () represent *T*-values of the parameters.

Table 10 Impact of the adoption of different outsourced machinery services on land transfer in contracted land-holding.

Variables	$Land_{out}$		$Land_{in}$
	Fixed-effects	Two-way fixed-effects	Random-effects
OMS_c	−0.228*** (−3.86)	−0.223*** (−3.95)	1.495* (1.93)
Gender	−0.433 (−1.34)	−0.414 (−1.28)	10.308*** (3.36)
Age	0.018 (1.45)	0.018 (1.47)	−0.480*** (−3.32)
Education	0.005 (0.16)	0.004 (0.11)	−0.186 (−0.83)
Health	−0.101 (−1.35)	−0.094 (−1.25)	2.833** (2.39)
Income	−1.74e-06* (−1.71)	−1.78e-06* (−1.73)	0.00017 (1.35)
Cadre	0.489** (2.04)	0.489** (2.05)	3.435 (0.86)
CCPM	0.443 (1.18)	0.440 (1.18)	−4.052 (−1.60)
Population	−0.006 (−0.11)	−0.007 (−0.12)	1.184 (1.57)
Labor force	0.053 (0.71)	−0.110 (−0.90)	−1.544 (−0.90)
Deposit	−2.81e-07 (−0.60)	−2.88e-07 (−0.62)	7.68e-06 (0.48)
Borrow	6.27e-08 (0.42)	6.34e-08 (0.43)	0.0001*** (2.89)
Terrain	0.180 (0.67)	0.205 (0.75)	0.735 (0.15)
Road	0.372*** (3.89)	0.568*** (3.01)	2.633 (0.92)
Village	0.00006 (1.14)	0.00007 (1.25)	0.002 (1.12)
Constant term	1.554 (1.45)	1.469 (1.37)	4.896 (0.42)
F-value	6.94***	6.29***	78.66***
R^2	0.0389	0.0399	0.0000
Hausman test	73.52***		19.74
N	5889	5889	5889

*, **, and *** indicate significance at the 10%, 5%, and 1% levels of statistical significance, respectively. Values in the fixed-effects and two-way fixed-effects models () are *T*-values, and values in the random-effects model () are *Z*-values.

According to the Hausman test results, a random-effects model is selected to assess the impact of outsourced machinery services in contracted land-holding on land transferred in, without further re-examination using a two-way fixed-effects model. The adoption of these services has a significantly positive impact on land transferred in, as evidenced by a coefficient of 1.495, statistically significant at the 10% level. This suggests that mechanical outsourcing in contracted land-holding significantly promotes land transfer in. Using outsourcing in a single production stage may not fully address farming complexities, leading some farmers to transfer land for non-agricultural opportunities (Nolte and Ostermeier, 2017). However, as outsourcing expands across more stages, machinery gradually replaces labor and also enhances production efficiency. Larger cultivation scales further boost income and encourage farmers to acquire more land for higher returns.

Table 11 shows the impact of adopting different levels of outsourced machinery services on land transfer in outsourced land-holding. Based on the Hausman test results, fixed-effects models were selected to analyze the impact of adopting outsourced machinery services in outsourced land-holding on both land transferred in and transferred out, with further validation using two-way fixed-effects models. The adoption of these services has a significantly positive effect on land transferred in, with a coefficient of 10.748, statistically significant at the 1% level. The two-way fixed-

Table 11 Impact of the adoption of different outsourced machinery services on land transfer in outsourced land-holding.

Variables	$Land_{out}$		$Land_{in}$	
	Fixed-effects	Two-way fixed-effects	Fixed-effects	Two-way fixed-effects
OMS_o	−0.060 (−0.97)	−0.062 (−1.00)	10.748***(3.11)	10.686*** (3.09)
Gender	−0.377 (−1.14)	−0.359 (−1.08)	0.621 (0.17)	1.250 (0.33)
Age	0.019 (1.47)	0.019 (1.49)	−0.412 (−1.24)	−0.406 (−1.22)
Education	0.006 (0.18)	0.004 (0.14)	0.194 (0.35)	0.151 (0.27)
Health	−0.087 (−1.16)	−0.081(−1.07)	3.836** (2.41)	4.043** (2.46)
Income	−1.75e-06* (−1.71)	−1.78e-06* (−1.73)	−0.00002 (−1.15)	−0.00003 (−1.18)
Cadre	0.459* (1.90)	0.466* (1.91)	1.597 (0.45)	1.837 (0.52)
CCPM	0.477 (1.29)	0.475 (1.29)	−3.756 (−0.72)	−3.841(−0.73)
Population	−0.004 (−0.06)	−0.004 (−0.07)	1.474 (0.88)	1.448 (0.90)
Labor force	0.017 (0.23)	−0.120 (−0.98)	−1.108 (−0.40)	−5.823 (−1.34)
Deposit	−2.89e-07 (−0.60)	−2.95e-07 (−0.62)	1.47e-06 (0.18)	1.27e-06 (0.16)
Borrow	1.55e-07 (1.03)	1.57e-07 (1.04)	4.47e-07 (0.05)	4.99e-07 (0.06)
Terrain	0.178 (0.67)	0.199 (0.73)	−3.784** (−2.16)	−3.057* (−1.81)
Road	0.449*** (4.73)	0.639*** (3.40)	4.055 (1.42)	11.095 (0.74)
Village	0.00005 (0.92)	0.00005(1.00)	0.005 (1.23)	0.005 (1.24)
Constant term	1.210 (1.15)	1.136 (1.08)	1.576 (0.05)	−0.957 (−0.03)
F-value	3.47***	3.24***	1.50*	1.40
R^2	0.0245	0.0252	0.0335	0.0351
Hausman test	61.04***		32.00***	
N	5889	5889	5889	5889

*, **, and *** indicate significance at the 10%, 5%, and 1% levels of statistical significance, respectively. Values in () represent *T*-values of the parameters.

effects model yields a similar coefficient of 10.686, also significant at the 1% level. This indicates that adopting outsourced machinery services in outsourced land-holding significantly encourages land transferred in by farmers, with the effect becoming more pronounced as the number of adoption stages increases.

The effect on land transferred out is negative but lacks statistical significance, which deviates from the expectation that advancements in the mechanical outsourcing market would further constrain land transferred out. This paradox may arise from the concurrent expansion of the services sector, which increases transaction costs (Cai and Wang, 2016) and agricultural production costs. As a result, some farmers may use outsourced services for scaled operations while also purchasing machinery to mitigate high transaction costs in certain stages. Large-scale farmers often integrate self-owned machinery with outsourced services to achieve mechanization (Qiu et al., 2021a, 2021b), reducing the significant effect on land transferred out.

Additionally, imbalanced supply and demand in land transfer markets, driven by advancements in outsourced services, can elevate land rents (Kang et al., 2020). With abundant land availability, farmers in outsourced land-holding may adjust their decisions on land transferred out as local rent increases, opting to capitalize on higher rents. Therefore, as the adoption of outsourced machinery services progresses, the inhibitory impact on land transferred out diminishes.

Conclusion and policy implications

This study investigated the impact of adopting outsourced machinery services on land transfer behaviors across different land ownership categories in China. Using panel data from the China Land Economic Survey (CLES), the analysis employs PSM and fixed-effects models to examine this relationship. The findings reveal several key insights. For contracted land-holding farmers, adopting outsourced machinery services significantly reduces land transferred out but does not substantially affect land transferred in. By substituting labor and enhancing efficiency, these services enable sustained cultivation on contracted land-holding despite limitations in scale and resources. For outsourced land-holding farmers, outsourced machinery services significantly constrain land transferred out while facilitating land transferred in. These services alleviate labor, technology, and capital constraints, allowing farmers to maintain operational scale and expand profitably through additional land acquisition. However, as outsourced land-holding farmers deepen their involvement in outsourced services, the impact on land transferred out diminishes. This is likely due to the substitution of some services with self-owned machinery and rising land rents, which attenuate decisions to transfer land out.

The research findings highlight important policy implications. First, improve the market for outsourced machinery services. The government should establish a standardized market system for outsourced machinery services to ensure its healthy and orderly development. Through favorable policy, foster and develop professional agricultural machinery service providers, such as machinery cooperatives and service companies, to enhance the professionalism and scale of services. Conduct regular training for agricultural machinery service personnel to improve their operational skills and service levels, ensuring the quality and efficiency of outsourced machinery services. By addressing supply-demand imbalances in the agricultural machinery service market, alleviating constraints on farmers' resource endowments (e.g., labor), and promoting the application of agricultural technology at the grassroots level, these measures can facilitate large-scale farmland management, enhance agricultural productivity, and advance agricultural modernization.

Second, increase subsidies for agricultural machinery. Increase subsidies for agricultural machinery to reduce the cost of purchasing and using machinery for farmers. Implement differentiated subsidy policies for farmers of different scales. For example, provide outsourced machinery service subsidies for poor farmers and self-purchase machinery subsidies for large-scale operators to meet diverse farming needs. Promote the development of machinery-sharing platforms, encouraging farmers to access machinery services through shared models, thereby reducing redundant purchases and idle waste.

Third, promote the standardization of the land transfer market. Establish a unified land transfer platform at the national or regional level by offering one-stop services such as information release, transaction matching, and contract signing to reduce transaction costs and improve transfer efficiency. Introduce tax incentives for land transfers to reduce the tax burden and encourage farmers to participate actively in land transfers. Improve the legal framework for land transfers by clarifying the rights and obligations of both parties, protecting farmers' land rights, and increasing their confidence in participating in land transfers.

Fourth, encourage diversified agricultural business models. Develop moderate-scale farming by encouraging farmers to achieve scale operations through land transfers, thereby improving agricultural productivity and economic benefits. Support the development of family farms and cooperatives by providing policy support, including financial assistance, technical guidance, and market connections, to enhance their operational capacity and market competitiveness.

Data availability

The data that support the findings of this study are openly available at https://doi.org/10.19788/j.issn.2096-6369.230418.

Received: 12 March 2024; Accepted: 9 June 2025;
Published online: 16 June 2025

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Acknowledgements

This study is sponsored by the National Social Science Fund of China (NO. 20BJY118), and the Natural Science Foundation of Shandong Province (NO. ZR2020MG045).

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MG: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, visualization, roles/writing—original draft, writing—review & editing; FH: formal analysis, software, roles/writing—original draft, writing—review & editing; SC: writing—review & editing; TL: conceptualization, data curation, formal analysis, investigation, methodology, software, roles/writing—original draft, writing—review & editing.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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