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Mechanization services, farm productivity and institutional innovation in China

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Abstract
Purpose – The purpose of this paper is to investigate the impact of mechanization services on farm productivity in Northern China from an empirical perspective, with the aim to identify the underlying market and institutional barriers.
Design/methodology/approach – The authors apply the regression method with the control of village fixed effects to examining the relationship between capital–labor ratio, mechanization service ratio and farm productivity, using the panel data collected in 2013 and 2015 by CCAP.
Findings – Mechanization services improve farm productivity through substituting labor, but it may generate a less positive impact on farms who do not have self-owned capital equipment.
Originality/value – It is the first study to investigate how mechanization services affect farm productivity for grain producers in Northern China.

Keywords Total factor productivity, Farm survey, Mechanization service, Small household farms

Paper type Research paper

1. Introduction
The past four decades have witnessed a significant change in China's agricultural development and rural transformation, underlying which a rapid growth in agricultural productivity plays an important role. Between 1978 and 2008, agricultural total factor productivity (TFP) of the crop and livestock industry in China has grown at the rate of 2.4 percent a year, which is around twice of the world average for the same period of time (Fuglie and Rada, 2015; Sheng *et al.*, 2019). The rapid increase in agricultural productivity offsets negative effects of constrained supply of inputs and adverse seasonal conditions and contributes to improve China's food security. Since the late 1970s, the real gross output value of Chinese agriculture has grown at an average rate of 5.4 percent a year, while annual growth of total input was 2.5 percent a year (Huang and Rozelle, 2018), and agricultural production becomes more diversified. Increased agricultural productivity

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has also helped to release rural labor, facilitating rapid urbanization and industrialization in China. Since the early 1990s, there has been a strong rise in off-farm employment, providing additional labor supply to support the industrialization process and urban development (Meng and Zhang, 2010).

While accomplishments are impressive, agricultural productivity growth in China shows a slowing-down pattern since 2008. Over the past decade, the estimated agricultural TFP has fallen at the rate of 1.2 percent a year, which has been much lower than its historical trend (Sheng *et al.*, 2019). Underlying such a change in agricultural productivity growth, there are both previous remained issues and newly emerged challenges. For example, overuse of fertiliser and crop chemicals has gradually caused land degradation and slowed the yield growth of major crops (Zhang *et al.*, 2013; Lu *et al.*, 2015), while changing climate conditions also threaten agricultural productivity growth.

Other than those constraints listed above, a more critical issue is that small farm size (in terms of land area operated), as a consequence of the "equalitarianism" in land allocation system in history (Chen, 2018), has restricted farmers from utilizing labor-augmented techniques (such as precision seeding and micro-spray irrigation) (Sheng and Chancellor, 2018). Although over the last four decades, the farmland institutional reform in China has focused on "stabilizing the land property rights" and "promote the farmland transfer" (Luo, 2018), the farm size still small. Estimates based on annual rural household surveys by the Chinese Ministry of Agriculture and Rural Affairs (MARA) show that the average size of farms in China declined from 0.73 hectare in the early 1980s to 0.57 hectare in 2003. As most of these small household farms rely on labor-intensive technologies (Huang, 2013; Han, 2015), rising wages and rural labor shortages have caused them to lose competitiveness and profitability in market (Shi, 2018). Farmer input choice between labor and capital is likely to smooth the non-linear farm size–productivity relationship (Sheng *et al.*, 2019).

Mechanization services, including plant and machinery hire and technical/management services, have long been regarded as a complementary to self-owned machinery in agricultural production of OECD countries. Between 1973 and 2011, the proportion of expenditure on plant and machinery hire in total intermediate costs of the US farm sectors have increased by 40 percent. A similar growing trend was also observed in Australia and Canada as well as in the EU countries. For decades, farms in OECD countries gradually increase the percentage usage of mechanization services to save the sunk costs associated with investing in newly invented capital equipment, which become more expensive over time. This helps to facilitate the diffusion of technologies embodied, in particular for those professional farms which hope to increase asset liquidity and shorten investment cycles. Although mechanization services also become popular recently in China, little is known about whether and how mechanization services may change the way of production of small household farms. In particular, one would like to know whether small household farms could increase their productivity performance through outsourcing plant and machinery services.

To answer these questions, this paper examines the impact of mechisation services on production efficiency of small household farms from an empirical perspective, by using the farm-level panel data in Northern China collected by China Centre for Agricultural Policy (CCAP), Peking University, in 2013 and 2015. With the control of the village fixed effects, we show that switching toward capital-intensive technology tends to improve small household farms' TFP and profitability but not the yield. In this sense, mechanization services play a similar role in affecting farmers' productivity performance as self-owned investment and will significantly improve the productivity performance of those farms with no equipment. However, we also show that majority mechanization service providers provide only basic capital services to substitute labor, which is different from what we have observed in OECD countries, and thus it becomes a barrier to the development of modern agricultural production.

This implies that there could be some market failure that restricts high-quality mechanization services to be provided, calling for additional institutional arrangements.

The remainder of the paper organizes as below. Section 2 first describes the farm survey data used in this paper, followed by a brief discussion on the relationship between institutional arrangement, farm size and the development of mechanization services in China in Section 3. Section 4 provides the model specification. Section 5 presents the analytical results on how mechanization services may affect household farms' yield, profits and TFP relative to self-owned investment in machinery. Section 6 makes the concluding remarks.

2. Data source and variable description

The data sets used in this paper come from a two-wave repetitive farm survey conducted by CCAP, Peking University, in 2013 and 2015. This survey focuses on collecting the farm-level and the plot-level data on agricultural production and household consumption in two major cropping regions in Northern China: Northeast and North China.

In terms of survey methodology, we employed a stratified random sampling approach to choose household farms in two provinces (including Heilongjiang and Jilin) in Northeast and two provinces (including Shandong and Henan) in North China in 2013 and traced these selected samples in 2015. Two rice-dominated counties and two maize-dominated counties were randomly selected from each province in Northeast China, while three counties, mainly producing wheat and maize, were randomly chosen from each province in North China. We then randomly chose two towns in every selected county and two villages in every sample township. In total, ten household farms were selected as follow: we divided all household farms in each village into two groups, small and large farms, and chose seven household farms from the small farm group and three household farms from the large farm group randomly. If the large farm households were less than three, then we added the number of small farm households to make up a total of ten household farms from every village.

We surveyed 560 households in 2013 in Northeast and North China, and got 506 tracked-samples and 57 new samples in 2015. Because farmers could grow more than one crop for each year and the production of different crop may need different inputs and production technology, we treat the production of each type of crop as separate observation. So we got 1,494 observations from sampled households. We eliminated 110 observations in total, due to incomplete data, outliers and other statistical problems. Following this procedure, the total number of observations is 1,384, and 728 in 2013, 656 in 2015 (Figure 1).

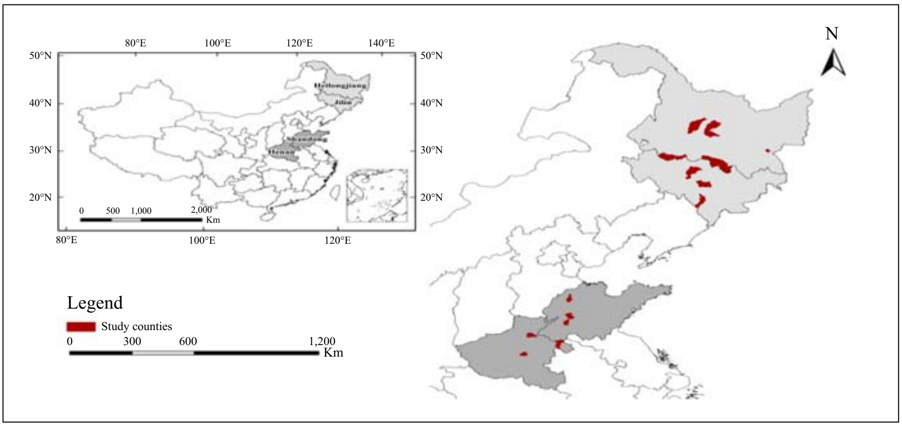


Figure 1.
Geographical distribution of sample farms in Northern China: 2013, 2015

To examine the impact of mechanization services on farm productivity, we define seven variables at the farm level. These variables include crop yield, benefit-cost ratio, LnTFP index, capital–labor ratio, the ratio of custom service over self-owned capital, a dummy variable used to identify household farms which do not own capital equipment but use custom services as capital inputs.

The crop yield is defined as total output of major grain crops (i.e. maize, wheat and rice) produced by each farm divided by the sowing area of the same grain crop each year. The benefit-cost ratio is defined as total value of the main grain crops (estimated by multiplying total output by the farm-gate price of the corresponding crop) divided by the total production costs which include land rent, labor costs, capital service costs (including both self-owned and custom services) and intermediate inputs such as fertilizers and chemicals. The farm-level TFP is defined as the residual that gross output minus the contributions of each input It is estimated by using the regression method based on the assumption of a Cobb–Douglas production function.

The capital–labor ratio is defined as real total costs related to the use of capital equipment (including the opportunity costs of using self-owned machinery and the costs of using custom services) divided by the total number of hours worked. The ratio of custom service over self-owned capital is then defined as the area of land cropped using the customized service divided by the area using the own machinery. To be noted, for those who own no capital equipment, there will be no value for this variable. We assume that, under this situation, the ratio of custom service over self-owned capital takes the value of zero. Finally, a dummy variable is used to identify household farms which do not own capital equipment but use custom services as inputs, and it takes 1 if the hypothesis is true and 0 otherwise.

Other variables used in the paper also include the intermediate input, the share of land adjoining, the share of land irrigated, the share of high-quality land, the share of farmers who aged over 65, the share of nonfarm labor, farmers' education, the share of male farming labor, family wealth and so on[1]. Table I provides the descriptive statistics for major variables.

Variable	Obs	NE&NC Mean	SD
Yield of wheat (t/ha)	405	7.3	1.0
Yield of maize (t/ha)	679	8.2	2.1
Yield of rice (t/ha)	300	7.5	1.6
The LnTFP index	1,384	−5.5	0.32
Benefit-cost ratio	1,384	1.2	0.2
Capital–labor ratio	1,384	2.7	3.6
The ratio of custom service over self-owned capital	1,384	1.7	2.9
Dummy for only using custom service (0 = No; 1 = Yes)	1,384	0.4	0.5
Intermediate input (yuan/ha)	1,384	291.8	90.2
The share of high-quality land (%)	1,384	28.4	41.1
The share of land irrigated (%)	1,384	84.8	35.5
The share of land adjoining (%)	1,384	11.2	26.6
The mean age of farming labor (%)	1,384	49.3	8.9
The maximum of farmer's education year	1,384	8.5	2.5
The share of nonfarm labor (%)	1,384	61.0	34.1
Family wealth (1,000 yuan)	1,384	202.9	270.3
Farmers only do manual work	15	–	–
Farmers only use self-owned capital	179	–	–
Farmers only use custom service	552	–	–
Farmers use self-owned capital and custom service	638	–	–
In 2013	728		
In 2015	656		

Note: The total number of observations is 1,384, and 728 in 2013, 656 in 2015
Source: Authors' estimation by using the CCAP farm survey data

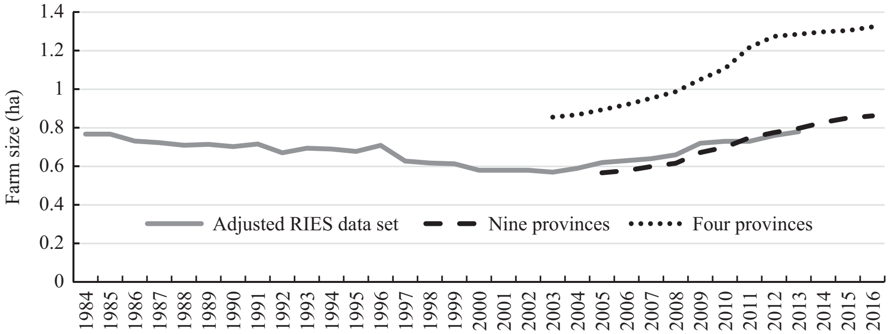
Table I. A descriptive statistics on key variables

3. Farm size, institutional arrangement and custom services in China

Agricultural productivity in China was heavily influenced by institutional innovation and its induced technological adoption over the past four decades. For the decade immediately after the implementation of household responsibility (HRS) reform 1978–1984, farm productivity in China experienced rapid growth. Between 1978 and 1985, the annual farm TFP for rice, wheat and maize grew at the rate of 6.9 percent a year, 7.3 percent a year and 5.6 percent a year, respectively, which were around twice of that for the USA and four times of the world average TFP over the same period of time (Huang and Rozelle, 1996; Jin *et al.*, 2002; Jin and Deininger, 2009). Efficiency gain obtained from incentiveness change, when the HRS reform dismantled the people's communes and contracted cultivated land to individual households equally, accounted for around 30–50 percent of output rise (Fan, 1991; Lin, 1992; Huang and Rozelle, 2018) and around 90 percent of TFP growth (Jin *et al.*, 2002).

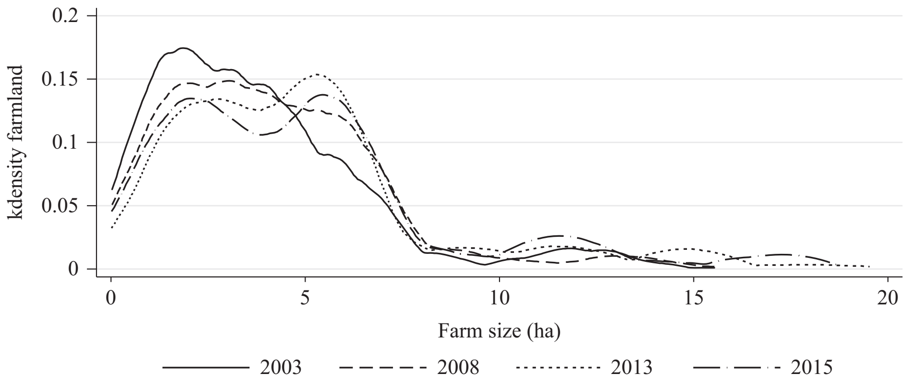
Although the HRS reform succeeded to promote farm productivity growth through stabilizing farmers' control of income from land contract rights (e.g. extending tenureship from 15 to 30 years), equitable distribution of land between farmers leads to the small-size farm issue (or the land fragmentation problem). Figure 2 shows that average farm size (in terms of land owned) declined from 0.73 hectare in 1984 to 0.57 hectare in 2004. Although ongoing land reforms, such as township land right transfers and "San-Quan-Fen-Zhi," facilitate land consolidation throughout the country since the mid-2000s (Huang and Ding, 2016), it is not until recent years that average land size of household farms does not reach its pre-reform level. Even for cropping farms in Northern China which experienced much quicker land consolidation than other places in recent years, majority grain farms still hold land areas less than 3 hectares (Figure 3).

It is widely believed that small household farms could make use of labor-intensive technology to achieve a high yield (or land productivity) (Sen, 1962, 1966). But, comparing to capital-intensive technology, labor-intensive technology has disadvantage in improving labor productivity (or income per capita), and nor does it good to improve farm TFP and profit (Fuglie and Rada, 2015). In particular when labor costs rise as off-farm wage and employment increase over time, continuing to use labor-intensive technology may incur additional costs for agricultural production and thus become a bottleneck for farm productivity and profit growth[2]. As such, how to increase farm-level mechanization level and to facilitate their switching from



Notes: RIES is a nationally representative survey with an average sample of about 60,000 rural households each year. Adjusted RIES data set are estimated farm size excluding households living in rural but either fully rent out or gave up their land or lost land due to land acquisition by Huang and Ding (2016). The average farm size of nine provinces and four provinces are authors' estimates based on data from CCAP survey. The nine provinces include Heilongjiang, Jilin, Shandong, Henan, Shanxi, Zhejiang, Sichuan, Hubei and Guangdong. These four provinces include Heilongjiang, Jilin, Shandong and Henan

Figure 2.
The average farm size in China, 1984–2016



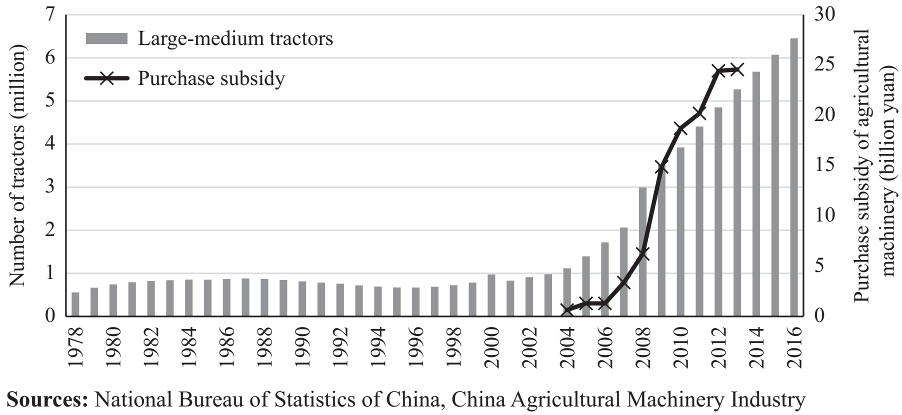
Source: Authors' estimates based on data from CCAP survey

Figure 3. The distribution of farm size in Northern China, 2003–2015

labor-intensive technology to capital-intensive technology becomes an essential question for policy makers to break through the bottleneck.

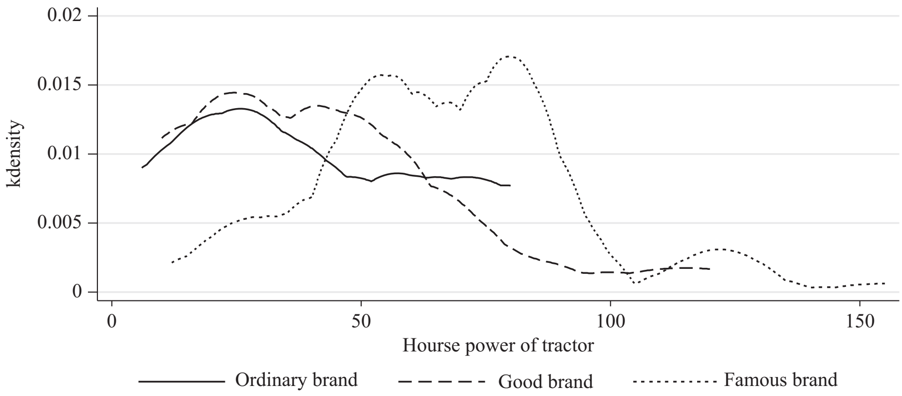
Theoretically, small-sized household farms are unlikely to make capital investment than their larger counterparts. On one hand, small household farms' willingness and ability to invest are restricted by their lesser financial capacity. On the other hand, there is a limited scope for small household farms to obtain gains from increasing returns to scale. Since making an investment in capital equipment will incur a large amount of sunk costs that small-sized household farms are unwilling and unable to afford, small-sized household farms could not maintain productivity growth through investing their own capital equipment to substitute labor as their large counterparts.

Figure 4 shows that the change of capital stock in the Chinese agricultural industry and its components over the past four decades, by using the number and total power of tractors at the industry level as indicators. Although total power of tractors has increased from 3.5 to 44.7 kilowatts between 1978 and 2016 (with an annual growth rate of 6 percent a year), the share of large- and medium-sized tractors in the total (or the structure of capital stock) does not increase relative to that of small-sized tractors until the early 2000s when land consolidation started between farms. Since large and medium size tractors are usually more



Sources: National Bureau of Statistics of China, China Agricultural Machinery Industry Yearbook (1986–2017)

Figure 4. The number of agricultural tractors and the purchase subsidy of agricultural machinery in China, 1978–2016



Source: Authors' estimation by using the CCAP farm survey data

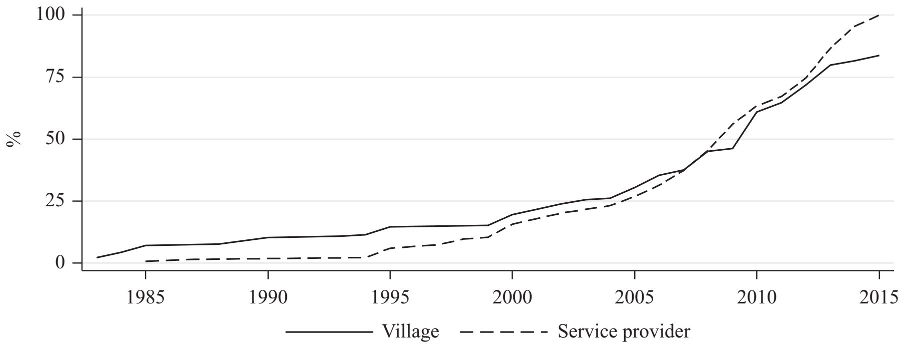
Figure 5.
The relationship between machinery power and capital service quality (brand), 2015

efficient than small-sized tractors in agricultural production (as is shown in Figure 5), such a change in the structure of capital stock over time is generally consistent with the change of average household farm size, reflecting the possible negative impact of small farm size on capital investment and technology adoption.

Although facing the farm size constraint, small household farms in Northern China have significantly improved the capital-equipment level by using mechanization services as a substitute for self-owned capital. Due to statistics from the China MARA, there are total 263.7m household farms in 2016 among which 42.3m made investment in capital machinery accounting for only 12.0 percent[3]. However, more than 72 percent of arable land is ploughed and 53 percent harvested by using capital equipment, and some of them are even very large and efficient machinery. This is mainly because that there is a rapid development of agricultural mechanization service market, providing mechanization services to household farms with relatively lower costs to meet their need for employing capital equipment in production.

Figure 6 shows an increasing of mechanization service over the past three decades. Driven by increasing demand over time, the proportion of service providers that start customer service have increased significantly, in particular after 2000.

The proportion of villages that employ mechanization services have the similar developing trend. By 2015, except for some remote mountainous areas, 91 percent of villages in China could get access to mechanization services.

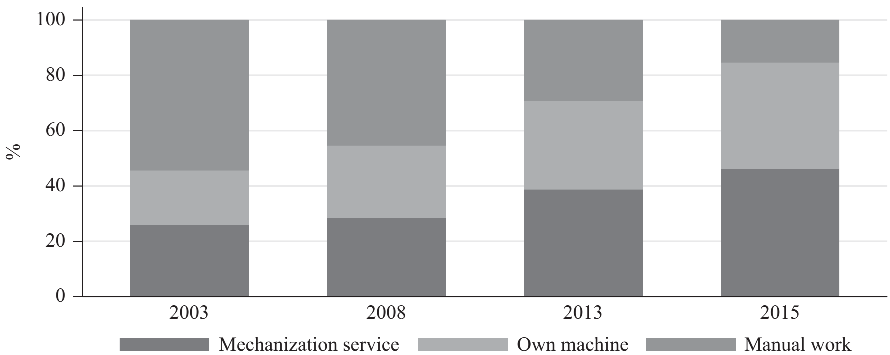


Source: Authors' estimates based on data from CCAP survey

Figure 6.
The proportion of villages start to employ mechanization services and provider start to provide service in China, 1983–2015

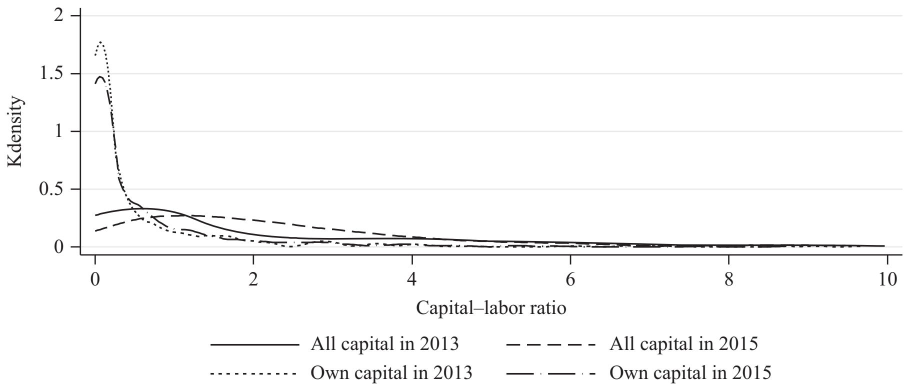
In addition to increased geographical coverage, the importance of mechanization services in farm production, in particular for grain production in Northern China, also increases over time. As is shown in Figure 7, the mechanization level for major crop production (including maize, wheat and rice) in Northeast and North China increased from 40 percent in 2003 to more than 80 percent in 2015, among which custom services accounted for more than half of this growth.

Figure 8 further compares the distribution of capital–labor ratios for household farms focusing on stable crop production in Northern China with and without considering mechanization services between 2013 and 2015. When we only consider farm self-owned capital equipment, the kernel density of estimated capital–labor ratio between farms does not change much. However, when we include capital services that farmers obtained from hiring mechanization services, the kernel density of estimated capital–labor ratio between farms shift to the right significantly. A Kolmogorov–Smirnov test (Hazewinkel, 2001) of equality of the two distributions between 2013 and 2015 is conducted. The test values for the case without considering custom services and the case with considering custom services are 728 and 656, respectively, which fail to reject at 10 percent level and reject at 1 percent level. This suggests that mechanization services nowadays have become one of the most important ways that household farms use to increase their capital-equipment levels.



Source: Authors' estimates based on data from CCAP survey

Figure 7. The mechanization level of major crops in Northern China, 2003–2015



Source: Authors' estimates based on data from CCAP survey

Figure 8. Changes in the distribution of capital–labor ratios for staple crop production in Northern China, 2013 and 2015

4. Model specification and data collection

Although mechanization services helped to improve the capital–labor ratio of household farms in China, little is known about whether they have positively contributed to farm productivity and profit performance. To answer this question, we propose a simple empirical model specification to examine the linkage between capital equipment, mechanization service and farm productivity/profit.

Specifically, we assume that farm productivity performance is a linear (log-linear) function of its capital–labor ratio and source of capital service in use such that:

$$y_{ijt} = \alpha_0 + \alpha_1 KL_{ijt} + \alpha_2 CSRto_{ijt} + \alpha_3 Dummy\_CS_{ijt} + \delta X_{ijt} + u_j + T_t + \varepsilon_{ijt}, \quad (1)$$

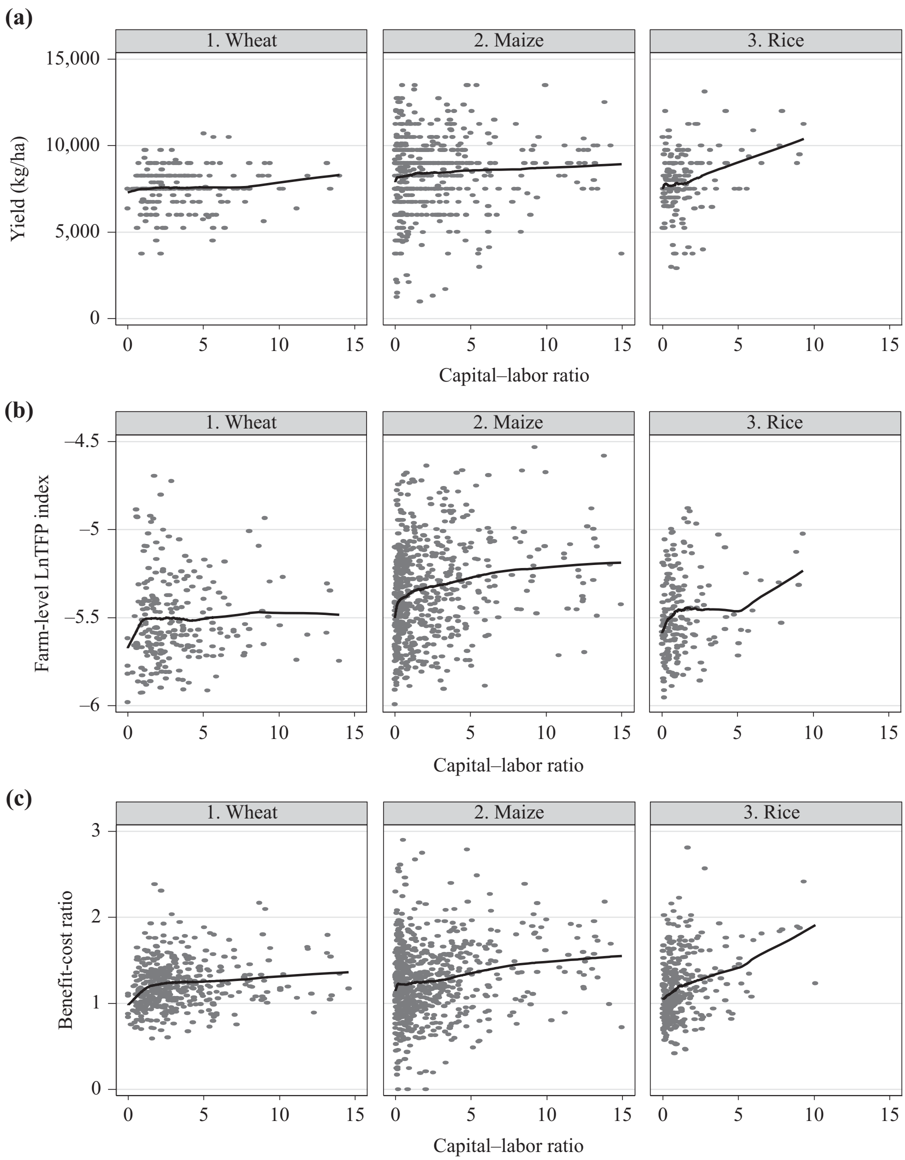
where y_{ijt} denotes household farms' productivity measure which include crop yield, LnTFP index and benefit-cost ratio; KL_{ijt} refers to capital–labor ratio at the farm level; $CSRto_{ijt}$ refers to the ratio of custom services over self-owned machinery; $Dummy\_CS_{ijt}$ denotes the dummy for those farms only using custom services. X_{ijt} is a vector which includes all other controlled variables such as logarithm of total intermediate inputs per hectare, soil quality (percentage of high-quality land), percentage of land irrigated, percentage of plots adjoining, farmers' average age and education, percentage of nonfarm employment, family's wealth. In addition, we also include dummy variables to control the village fixed effects (u_j) and time-specific effects (T_t).

Based on Equation (1), three hypotheses tests are established. First, a positive (negative) coefficient in front of KL_{ijt} suggests that increasing capital investment to substitute labor tends to improve (decrease) household farms' productivity performance. Second, a positive (negative) coefficient in front of $CSRto_{ijt}$ suggests that custom services are more superior (inferior) than self-owned capital equipment in providing capital services, when the capital–labor ratio is well controlled. Third, a positive (negative) coefficient in front of $Dummy\_CS_{ijt}$ suggests that using custom services will increase (decrease) the productivity performance of farms owning no capital equipment.

We can estimate Equation (1) by using the general least square (GLS) method with the control of the village fixed effects to all samples, as well as the sub-samples regrouped by three different commodities, namely rice, wheat and maize. For each exercise, we choose different productivity performance indicators as dependent variables for the regression so that we can distinguish between different effects of custom services on different productivity indicators. The estimation results obtained from different scenarios will provide robustness check for each other. Finally, we also account for the county-level cluster effects in all regressions to reduce the heterochasticity between household farms clustered in the same county.

Figure 9 provides the apparent relationship between capital–labor ratio and three farm productivity performance indicators, measured respectively by using yield, TFP and cost-benefit ratio.

Overall, grain farms' productivity in Northern China is generally increasing with capital–labor ratio. This result is stable even when we split our sample by enterprises, by data sets for different regions and by time or using different productivity performance indicators (i.e. crop yield, the LnTFP index and benefit-cost ratio), which indicates that switching from labor-intensive technology to capital-intensive technology will help to improve household farms' productivity. Moreover, since custom services are important sources for household farms to get access to capital services, it is in no doubt that there is a positive relationship between custom services and household farms' productivity performance. Although the scattered relationship is informative, we still need to use more thorough regression analysis to examine the relationship between custom services and household farms' productivity performance.



Notes: (a) Crop yield vs capital–labor ratio; (b) the LnTFP index vs capital–labor ratio; (c) benefit-cost ratio vs capital–labor ratio

Figure 9. The relationship between yield and capital–labor ratio in Northeast and North China: 2013, 2015

5. Empirical results: impact of custom services on household farms productivity

Using the farm-level panel data for North and Northest China in 2013 and 2015, we examine the relationship between three farm productivity performance indicators (including crop yield, the LnTFP index and benefit-cost ratio) and mechanization services, with the control of intermediate inputs, other farm characteristics and farming practice. The estimation results obtained from using the aggregate dataset and the data sets by commodities are presented in Tables II and III.

5.1 Household farms' productivity, capital–labor ratio and custom services

Table II provides the estimated relationship between farms productivity performance indicators (including crop yield, the LnTFP index and benefit-cost ratio) and their capital–labor ratio, the mechanization service to self-owned capital ratio and the dummy for farms only using mechanization services.

With the control of intermediate inputs, farm characteristics and other farming practices (as well as the village fixed effects and the time-specific effect), we show that the estimated coefficients in front of capital–labor ratio in the regressions of crop yield, farm LnTFP index and the benefit-cost ratio are all positive and significant for the farm TFP and the benefit-cost ratio regressions at the 10 and 1 percent levels, respectively. This implies that using more capital equipment to substitute labor tends to increase household farm productivity and profitability, although this may not significantly increase crop yield. A possible explanation on the insignificant relationship between crop yield and capital–labor ratio is that labor-intensive technology has the same efficiency as capital-intensive technology for household farms to improve crop yield, but capital-intensive technology could save more other inputs and thus improve farm TFP performance and profitability in total.

Moreover, for those household farms that use both self-owned capital equipment and mechanization services, farm TFP and profit performance are independent of the choice between these two ways to improve their capital–labor ratio. As is shown in Table II, the estimated coefficients in front of mechanization services to self-owned capital ratio, $CSRto_{ijt}$, are insignificant at 10 percent level throughout all three regressions when we control farm capital–labor ratio. This implies that: there is no difference in productivity performance for household farms to choose between making investment in self-own capital equipment and using the mechanization services hired from the market, when they have the same level of capital-equipment per capita. In other words, mechanization services are prefect substitutes for self-own capital equipment and provide no additional benefits to household farms than

	Crop yield	LnTFP index	Benefit-cost ratio
Capital–labor ratio	0.002 (0.002)	0.004* (0.002)	0.007*** (0.003)
CSRto	0.002 (0.003)	−0.004 (0.003)	−0.001 (0.005)
Dummy_CS	−0.036 (0.024)	−0.059*** (0.019)	−0.072** (0.036)
Intermediate input	−0.041* (0.024)	−0.268*** (0.032)	−0.494*** (0.047)
The share of high-quality land	0.0004** (0.0002)	0.0001 (0.0002)	0.0004 (0.0002)
The share of land irrigated	0.002** (0.001)	−0.0002 (0.001)	0.001 (0.0001)
The share of land adjoining	0.00003 (0.0002)	0.001** (0.0002)	0.0001 (0.0003)
The mean age of farming labor	0.001 (0.001)	−0.001 (0.001)	0.001 (0.001)
Farmers' education	0.002 (0.003)	0.003 (0.003)	0.008* (0.005)
The share of nonfarm labor	0.0003 (0.0003)	0.0002 (0.0003)	0.001 (0.001)
Family wealth	0.004 (0.008)	0.009 (0.009)	0.001 (0.011)
Dummy for year 2015	0.107*** (0.027)	0.087*** (0.031)	0.028 (0.035)
Dummy for wheat	−0.037 (0.030)	−0.118*** (0.017)	0.080 (0.031)
Dummy for rice	−0.203** (0.078)	−0.109 (0.084)	0.066 (0.087)
Dummy for village	Yes	Yes	Yes
Cluster for village	Yes	Yes	Yes
Constant	0.002 (0.002)	0.004* (0.002)	0.005*** (0.002)
Number of observations	1,369	1,369	1,369

Notes: Standard errors in parentheses. *,**,***Indicate statistically significant at the 10, 5, and 1 percent levels, respectively

Table II.
Estimated relationship between capital–labor ratio, custom service and farm-level productivity

Table III. Estimated relationship between capital–labor ratio, custom service, intermediate input and LnTFP index

	LnTFP index			Benefit-cost ratio		
	Wheat	Maize	Rice	Wheat	Maize	Rice
Capital–labor ratio	0.009*** (0.003)	0.003 (0.000)	0.013 (0.011)	0.015*** (0.002)	0.005 (0.005)	0.035*** (0.013)
CSRto	−0.004 (0.005)	0.001 (0.003)	−0.000 (0.008)	0.00002 (0.006)	−0.002 (0.008)	−0.009 (0.014)
Dummy_CS	−0.059 (0.036)	−0.038 (0.027)	−0.111*** (0.020)	−0.041 (0.054)	−0.080* (0.050)	−0.104* (0.052)
Intermediate input	−0.177*** (0.045)	−0.240*** (0.042)	−0.307*** (0.048)	−0.351*** (0.062)	−0.545*** (0.058)	−0.500*** (0.106)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Dummy for village	Yes	Yes	Yes	Yes	Yes	Yes
Cluster for village	Yes	Yes	Yes	Yes	Yes	Yes
Dummy for year 2015	0.009*** (0.003)	0.003 (0.003)	0.013 (0.011)	0.181*** (0.046)	−0.123*** (0.057)	0.152*** (0.066)
Constant	−4.414*** (0.252)	−3.941*** (0.223)	−2.617*** (0.300)	2.865*** (0.308)	4.273*** (0.344)	5.082*** (0.476)
Number of observations	405	667	300	405	667	300

Notes: Standard errors in parentheses. "NE&NC" means use the data surveyed in NE&NC, "Wheat" means only use the data about wheat, "Maize" means only use the data about maize, "Rice" means only use the data about rice. *,**,***Indicate statistically significant at the 10, 5, and 1 percent levels, respectively increasing their capital–labor ratio. Such a finding is interesting as it is quite different from what we have observed in OECD countries, where mechanization services are more superior to self-owned machinery in quality, and thus generate additional productivity gains for farms using mechanization services by promoting their adoption of the embodied technology. It suggests that household farms gain little benefits from the channel of technological progress and technology diffusion by using mechanization services in China.

Finally, for majority of household farms that have no self-owned capital equipment, using mechanization services tends to result in a weakly worse productivity performance. As mentioned before, the positive and significant coefficient in front of capital–labor ratio suggests that the household farms that using mechanization services as the only source of capital equipment will improve their productivity and profitability through increasing capital–labor ratio. However, when combining the estimated coefficients in front of the dummy for farms using only mechanization services as the supply of capital equipment, $Dummy\_CS_{ijt}$, and the estimated coefficients in front of $CSRto_{ijt}$, we show that the synthetic coefficients are negative and significant at 1 percent level (Table II). This implies: when compared to those also using self-owned capital equipment, household farms only using mechanization services could have a relatively lower productivity and profit performance. In other words, there is something wrong in practice with the mechanization service market that prevents household farms from directly using mechisation services to improve capital–labor ratio.

The above regression results are generally consistent with the finding for rice and maize farms when we split the sample by commodities (Table III)[4].

5.2 Household farms choices between self-own machinery and mechanization services

Section 4.1 specifies an important channel through which mechanization services may affect household farm productivity and profitability in Northern China: employing mechanization services enable household farms to increase their capital–labor ratio for capital-intensive technology. This makes perfect sense: When labor costs increase, household farms used to adopt labor-intensive technology are forced to adopt capital-intensive technology for efficiency and profit improvement. As mechanization services substitute for self-owned machinery, household farms can hire capital equipment to increase the capital–labor ratio when making investment in self-owned capital is not feasible. Moreover, since mechanization services could become a vehicle for embodied technology and save sunk costs for small household farms to adopt capital-intensive technology (from a theoretical perspective), we are expecting to see that they will grow more quickly than investment in self-own machinery to meet the increasing demand of household farms for capital services.

However, such a prediction is not consistent with the practice. In our sample of grain household farms in Northern China, both mechanization services and investment in self-owned capital have been increasing at the similar speed over time as farms switching from labor-intensive technology to capital-intensive technology (Table IV). In particular, when land consolation and machinery subsidy policies increase household farms' affordability to make their own capital investment, more investment in self-owned capital is used to substitute mechanization services. Such a phenomenon could be linked to our finding of the additional negative impact of using mechanization services by household farms owning no capital equipment on their productivity and profitability performance. This is a worrying issue as majority of household farms in China will rely on using mechanization services to meet their capital demand. In 2016, the total number of household farms in China was 263.4m, among which there are around 87.7 percent having no self-owned capital equipment (Table IV).

To further investigate the underlying driver of negative impact of mechanization services on farm productivity, we distinguish between two types of mechanization service

	Rural household (million)	Total number (million)	Professional (%)	The original 200,000–500,000 (%)	The original value over 500,000 (%)
1999	239.7	–	–	–	–
2000	237.7	–	–	–	–
2001	247.4	28.5	11.2	–	–
2002	254.2	29.4	11.2	–	–
2003	247.9	30.5	11.8	–	–
2004	248.4	32.0	11.3	–	–
2005	248.4	33.6	11.4	–	–
2006	252.5	34.7	11.1	–	–
2007	253.5	36.3	11.0	–	–
2008	253.9	38.3	11.0	0.9	0.09
2009	254.0	39.4	11.3	0.9	0.09
2010	254.2	40.6	11.9	1.0	0.1
2011	260.4	41.1	12.4	1.0	0.1
2012	259.8	41.9	12.4	1.0	0.1
2013	261.9	42.4	12.4	1.1	0.1
2014	262.2	42.9	12.2	1.17	0.2
2015	263.7	43.4	12.1	1.22	0.2
2016	263.7	42.3	12.0	1.25	0.2

Sources: National Statistical Bureau, China Agricultural Machinery Industry Yearbook (2002–2017); National Statistical Bureau, China Yearbook (2000–2017)

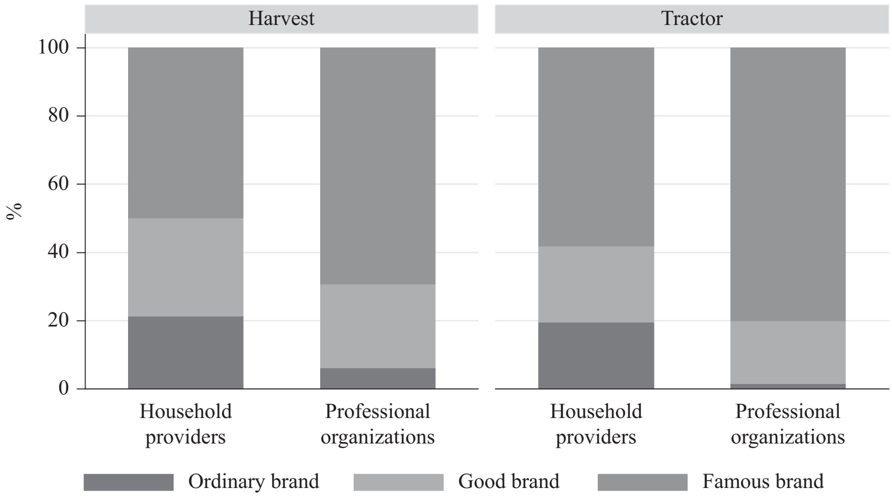
Table IV. The number of rural household with self-owned machinery in China, 2001-2015

providers (namely, service organizations and household providers) in different production stages between 2013 and 2015. Table V shows that: for the two most important production stages: ploughing and harvesting, household providers dominate professional organizations in providing mechanization services. In 2015, household providers provided mechanization services to serve 54.9 percent of total ploughing areas and 42.3 percent of total harvesting area throughout the country, which were around five and four times of those provided by professional organizations. Since household providers usually do not provide professional services (as they only own one or two pieces of machinery), it is not surprising that household farms with no self-own machinery may benefit less from hiring such custom services, which are with relatively low quality (Figure 10 and Table VI).

	Number of provider (million)	Average service area(ha)		Estimated total service area (million ha)		The percentage of estimated service area to sowing area (%)	
		Plough	Harvest	Plough	Harvest	Plough	Harvest
Household providers							
2013	5.26	18.59	14.7	97.7	77.4	59.4	47.0
2014	5.24	16.45	11.8	86.1	61.6	52.0	37.2
2015	5.25	17.42	13.4	91.4	70.4	54.9	42.3
Professional organizations							
2013	0.17	93.95	114.7	15.8	19.3	9.6	11.7
2014	0.18	91.23	103.5	16.0	18.1	9.7	11.0
2015	0.18	104.05	118.0	19.0	21.5	11.4	12.9

Sources: Authors' estimates based on data from CCAP survey and National Statistical Bureau, China Yearbook (2000–2017)

Table V. The number of service providers and service area in China, 2013–2015



Sources: Authors' estimates based on data from CCAP

Figure 10. Comparing quality of machinery owned by household providers and professional organizations, 2015

Table VI. The average number of machines of different service providers, 2013–2015

	Household providers			Professional organizations		
	2013	2014	2015	2013	2014	2015
Tractor	1.2	1.3	1.3	5.1	7.5	8.1
Rotary cultivator	0.8	1.1	1.3	3.3	3.8	4.4
Combine	0.8	0.8	0.9	1.6	2	2.5
Ridger	0.1	0.1	0.1	0.7	1.1	1.3
Subsoiler	0.04	0.04	0.03	0.2	0.2	0.3
No-tillage planter	0	0	0.02	0.4	0.5	0.8
Rice transplanter	0.3	0.3	0.3	1.8	2	2.2
Straw returning machine	0.3	0.3	0.3	0.7	0.9	1
Irrigation and drainage machine	0.02	0.02	0.1	0.2	0.2	0.2
Thresher	0.1	0.1	0.1	0.2	0.2	0.3
Dryer	0.02	0.02	0.02	0.1	0.2	0.4
Planter and sower	0.2	0.2	0.2	0.7	0.8	1.1
Spraying machine	0.1	0.1	0.2	0.5	0.8	1.1
Straw baling machine	0	0	0	0.1	0.1	0.2
Stubble cleaner	0.1	0.1	0.1	0.4	0.8	0.9
Agricultural vehicle	0.8	0.7	0.8	1.6	1.6	1.7
Other machines	0.1	0.2	0.2	0.4	0.5	0.8

Sources: Authors' estimates based on data from CCAP

6. Concluding remarks

It is widely believed that mechanization services can help to improve small household farms' productivity and profitability, through facilitating technology adoption and saving sunk costs for capital investment. For decades, mechanization services have been widely adopted by small household farms in China, as a substitute for capital investment in self-owned equipment, for improving agricultural mechanization level. However, it is not known whether and how mechanization services affect household farm productivity and profitability in China.

This paper uses a two-wave farm survey data in 2013 and 2015 to examine the impact of mechanization services on farm productivity and profitability for grain production in Northern China. We show that mechanization services improve farm productivity and profitability mainly through increasing their capacity to use capital to substitute labor but may not necessarily improve crop yield.

Moreover, we show that household farms that use mechanization services as the only source of capital equipment may benefit less compared to those own their own machinery. This provides useful policy insights calling for additional institutional arrangements to promote the future development of custom service market to address bottlenecks.

Notes

1. A detailed definition of those variables are available in Appendix 1.
2. In addition, household farms could not get access to advanced technology embodied in and associated with the use of plant and machinery, when they are not being properly equipped.
3. Among those household farms who own capital machinery, there are only 0.61 and 0.08m household farms owning capital machinery with the original investment value (at the current price) more than 200 thousand and 500 thousand respectively, which account for 1.3 and 0.2 percent of total number of farms.
4. We also conduct a robustness check by using dummy variables to examine the relative difference in productivity between farms only using self-owned capital equipment, using both self-owned capital and hired machinery and using only mechanization services. The results are shown in Appendix 2, which show the similar results.

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Appendix 1. Definition of control variables

Variable	Describe
Yield	Total output (quantity) of major grain crops (i.e. maize, wheat and rice) divided by the sowing area of the same grain crop each year (kg/ha)
Benefit-cost ratio	Total value of the main grain crops (estimated by multiplying total output by its farm-gate price) divided by the total production cost which include land rent, labor costs, capital service costs (including both self-owned and custom services) and intermediate inputs such as fertilizers and chemicals
The LnTFP index	Use the regression method based on the assumption of household farms using a Cobb–Douglas production technology, and get the logarithm value of residual that gross output minus the contributions of each input
Capital–labor ratio (KL)	Real total costs related to use capital equipment (including the opportunity costs of using self-owned machinery and the costs of using custom services) divided by the total number of hours worked
The ratio of custom service over self-owned capital (CSRto)	Land cropping area used by custom services dividing by that used by self-owned machinery
Dummy for only using custom service (Dummy_CS)	Dummy variable is used to identify household farms which do not own capital equipment but use custom services as inputs (0 = No; 1 = YES)
Intermediate input	Intermediate input such as fertilizers and chemicals (yuan)
The share of high-quality land	The share of high-quality land (%)
The share of land irrigated	The share of land irrigated (%)
The share of land adjoining	The share of linkaged plots (%)
The mean age of farming labor	The share of who aged over 65 (%)
Farmers' education	The maximum of education year of the farming labor (num. per family)
The share of nonfarm labor	The share of nonfarm labor (%)
The share of male farming labor	Share of male farming labor (%)
Family wealth	The total present value of housing, electrical appliances and machinery of family (1,000 yuan)
Time	Dummy for year 2015 (0 = No; 1 = Yes)
Maize	Dummy for maize (0 = No; 1 = Yes)
Rice	Dummy for rice (0 = No; 1 = Yes)

Table AI. Variable name and description

Appendix 2. Retained sample and deleted sample

	Sample retained			Sample deleted			Difference	
	Obs	Mean	SD	Obs	Mean	SD	*t*-value	Probability
Yield of rice (t/ha)	1,384	7.8	1.8	110	8.6	3.1	0.05	0.9
The growth rate of farm-level LnTFP	1,384	−5.5	0.3	110	−5.3	0.4	−2.0	0.04
Benefit-cost ratio	1,384	0.6	0.2	110	0.8	0.3	−6.4	0.0
Capital–labor ratio	1,384	2.7	3.6	110	10.1	17.7	−11.4	0.0
The ratio of custom service over self-owned capital	1,384	1.7	2.9	110	1.9	3.7	−0.2	0.9
Intermediate input (yuan/ha)	1,384	292.1	90.5	110	266.5	113.1	2.6	0.0

Note: *t*-test made by choosing "sample deleted" as the reference

Table AII. Comparison of retained sample and deleted sample

Total sample	1,494
Incomplete data	35
Abnormal value of variable	40
Abnormal value of multivariate cross analysis	35
Retained sample	1,384

Table AIII. Sample deleted method

Appendix 3. Robust estimation with dummies for farmers' categories

Table AIV.
Estimation results for robustness check

	Yield	LnTFP index	Benefit-cost ratio
Capital–labor ratio	0.002 (0.002)	0.004* (0.002)	0.005*** (0.002)
Dummy for only have own machine	0.046 (0.081)	0.099* (0.055)	0.099** (0.042)
Dummy for only use custom service	−0.011 (0.071)	0.027 (0.063)	0.028 (0.042)
Dummy for have own machine and custom service	0.030 (0.074)	0.066 (0.061)	0.055 (0.041)
Intermediate input	−0.042* (0.024)	−0.268*** (0.032)	−0.216*** (0.019)
The share of high-quality land	0.001** (0.0002)	0.0002 (0.0002)	0.0002 (0.0001)
The share of land irrigated	0.002** (0.0009)	−0.0001 (0.001)	0.001* (0.0004)
The share of land adjoining	5.49E-05 (0.0003)	0.001** (0.0002)	0.0001 (0.0001)
The mean age of farming labor	0.001 (0.001)	−0.002* (0.001)	0.0004 (0.001)
Farmers' education	0.002 (0.003)	0.003 (0.003)	0.004* (0.002)
The share of nonfarm labor	0.0002 (0.0002)	0.0001 (0.0003)	0.0002 (0.0002)
Family wealth	0.004 (0.007)	0.008 (0.009)	−0.001 (0.004)
Dummy for year 2015	0.109*** (0.027)	0.088*** (0.031)	0.022 (0.017)
Dummy for wheat	−0.034 (0.030)	−0.120*** (0.017)	0.028* (0.016)
Dummy for rice	−0.209*** (0.077)	−0.122 (0.083)	0.012 (0.042)
Dummy for village	Yes	Yes	Yes
Cluster for village	Yes	Yes	Yes
Constant	9.110*** (0.162)	−3.746*** (0.211)	1.787*** (0.116)
Observation	1,384	1,384	1,384

Notes: Standard errors in parentheses. *,**,***Indicate statistically significant at the 10, 5, and 1 percent levels, respectively

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