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Farm size and production efficiency in Chinese agriculture: output and profit

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Abstract

Purpose – The purpose of this paper is to analyze the relationship between farm size and agricultural production efficiency from the aspects of output and profit in order to find an optimal farm size that achieves both output and profit efficiency in agricultural production in China.

Design/methodology/approach – This study uses the 2012 China Family Panel Studies survey data and employs the stochastic frontier analysis (SFA) models to investigate empirically the relationship between farm size and agricultural production efficiency.

Findings – The study finds that there is an inverted-U curve relationship between farm size and output efficiency and a U-shaped curve relationship between farm size and profit efficiency in agricultural production in China. Based on the empirical results, the study estimates that the appropriate farm size is around 10–40 mu and the optimal farm size is around 20–40 mu both in terms of output efficiency and profit efficiency in Chinese agricultural production under the current agricultural technology and land management system.

Practical implications – The findings of this study suggest that appropriate land consolidation will bring more benefits to farmer households and agricultural production efficiency. There are some policy implications. First, governments should give long term and more stable land using rights to farmers through extending the period of land contract and verifying land using rights. Second, governments should encourage transfers of land using rights and promote land consolidation. But the implementation of this policy should consider regional differences and not be used for blindly pursuing increasing land size. Third, land consolidation should be accompanied with the development of specialized agricultural services.

Originality/value – The paper makes two major contributions to the literature. First, the authors use the SFA model to investigate the relationship between land size and agricultural production efficiency. Second, the authors establish two SFA models – the stochastic frontier output analysis model and the stochastic frontier profit analysis model – to estimate the optimal land size to achieve both output and profit efficiency of agricultural production in China.

Keywords China, Farm size, Agricultural production efficiency, Stochastic frontier analysis model

Paper type Research paper

1. Introduction

The relationship between farm size and agricultural productivity[1] is a long-debated issue. In China, the limited availability of land has become one of the main factors restricting the growth of agricultural output. Therefore, optimizing farm size becomes an important factor for the improvement of agricultural productivity. With the implementation of the family-based agricultural production contract responsibility system in early 1980s, land was contracted to farmer households based on the number of family members. As a result, not only is the management scale of land small but also land is segmented in several pieces

JEL Classification — C13, Q12, D24, Q15, Q18, R14

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across the village for each farmer household. This has led to diseconomies of scale in agricultural production and also hampered agricultural productivity. To solve this problem, since the 1990s and especially after 2000, the Chinese Government has encouraged the establishment of family farms with a moderate management scale of land in order to achieve economies of scale in agricultural production and to increase agricultural productivity. However, what would be the effect of the expansion of the farm size on agricultural productivity and what would be the optimal management scale of land to reach both output efficiency and profit efficiency in agricultural production? These are the main questions to be investigated and answered in this paper.

In this study, we use the stochastic frontier analysis (SFA) model to investigate the relationship between land size and agricultural production efficiency. There are three advantages of using the SFA method in this study. First, SFA is a method to measure efficiency, which can better identify the relationship between land size and agricultural production efficiency. Second, since production factors are not directly put in and family characteristics and land characteristics are controlled for in the second step to identify the relationship between land size and agricultural production efficiency, it can reduce the recognition interference caused by these three groups of factors (production factors, family characteristics and land characteristics). Third, in order to identify the relationship between land size and agricultural production efficiency and find out an optimal land size that generates the highest agricultural production efficiency, this study establishes two SFA models: the stochastic frontier output analysis model and the stochastic frontier profit analysis model.

The study has two main findings. First, the study finds that while there is an inverted-U curve relationship between land size and output efficiency of agricultural production, there is also a U-shaped curve relationship between land size and profit efficiency of agricultural production. Second, the study estimates that, for both the purposes of reaching output efficiency and achieving profit efficiency, the appropriate farm land size should be at the range of 10–40 mu and the optimal farm land size should be at the range of 20–40 mu under the current agricultural technology and land management system in China.

The rest of the paper is organized as follows. The next section reviews the literature. Section 3 presents the statistical analysis of the sample data. Section 4 discusses the theoretical framework of analysis. Section 5 introduces the SFA model and presents the empirical models. Section 6 conducts the empirical analysis and discusses the estimation results. Finally, Section 7 presents the conclusion and provides some policy implications.

2. Literature review

Empirical studies on the relationship between farm size and agricultural productivity have produced mixed results. In general, they can be organized into two main groups.

The first group finds a negative relationship between farm size and agricultural productivity. For example, in earlier studies, Bardhan (1973) analyzed 1,000 Indian households and found that the incomplete land and labor markets led to a negative correlation between land size and agricultural productivity. Ghose (1979) drew a similar conclusion by analyzing Indian agricultural productivity. Recently, Ali and Deininger (2015) found that labor market imperfection seems to be a key reason for the negative relationship between farm size and crop productivity using survey data from 2010 to 2011 of 3,600 rural households in 300 randomly selected villages of Rwanda. Henderson (2015) also found that labor market imperfection is the key reason for the negative relationship between farm size and agricultural productivity by using nationally representative panel data from Nicaragua. However, Barrett (1996) found that incomplete markets only partially explain the negative relationship between land size and agricultural productivity, and that the more important reason is the uncertainty of agricultural product prices. Moreover, focusing on soil quality, Carter (1984) found that, instead of incomplete markets, soil quality difference is the main factor that causes the negative correlation between land size and agricultural productivity. This conclusion was also confirmed later in Benjamin's (1995) study. However, Bhalla and Roy (1988) subdivided the samples according to geographical regions and found that differences in soil quality could explain very little of the negative correlation between land size and agricultural productivity. Barrett *et al.* (2010) even found that differences in soil quality cannot explain the negative relationship between land size and agricultural productivity. In addition, Chen *et al.* (2011), using the instrumental variable method, found that the negative correlation between land size and agricultural productivity could largely be explained by measurement errors. Carletto *et al.* (2013) confirmed this view. However, Choi *et al.* (2016), using a unique survey data set that was collected from 176 vineyards in the 14 northern US states in 2012, found a negative relationship between farm size and productivity when the farm size is instrumented by the additional farm size expansion indicator. However, improving management can make the negative relationship weaker.

The second group finds that there is a positive relationship between farm size and agricultural productivity. For example, Kevane's (1996) study found that, due to the increased use of fertilizers and agricultural machinery, the land size was positively correlated with agricultural productivity in Sudan. Heltberg (1998), taking Pakistan as an example, found that as the increase in pesticide and fertilizer use made up for the deficiency of the land, the use of modern machinery made up for labor shortage, the negative correlation between land size and agricultural productivity gradually disappeared and even showed a tendency toward positive correlation between the two. Zaibet and Dunn (1998), using data from Tunisia, Kawasaki (2010), using data from Japan and Foster and Rosenzweig (2011), using data from India, studied the relationship between farm size and agricultural productivity and reached the same conclusion. More recently, Sheng *et al.* (2015), using farm level data from 2011 to 2012 for the Australian broadacre industry, found that there is a positive relationship between farm size and farm productivity. Specifically, large farms achieved higher productivity through the use of newer production technology than small farms. Singh *et al.* (2018), using sample panel data from 160 households in Bihar, India, provided evidence for a positive relationship between farm size and productivity in small land holders, and that a strong positive relationship between farm size and productivity is a result of higher use of fertilizer, modern seeds and irrigation sources in large land holders.

Apart from the above two main groups, a small number of studies found that farm size and agricultural productivity are irrelevant. For example, Feder (1985) argued that there is no direct relationship between the planting area and agricultural productivity in the case where the credit market is imperfect. He further argued that there is moral hazard in the market. The ownership of land influences labor productivity. Usually, the labor productivity of land owners is higher than that of hired laborers.

China feeds 22 percent of the world's population with 7 percent of the world's farm land. Therefore, investigating the relationship between land size and agricultural productivity in order to find out the most appropriate land management scale to increase agricultural production efficiency has great significance to China's food security and the designing of agricultural policies. There have been an increasing number of empirical studies on the relationship between farm size and agricultural productivity in China. For example, Song *et al.* (2007), using 2006 household survey data in Jiangsu province, found a positive correlation between land size and land productivity. Li *et al.* (2010) drew the same conclusion by using 1999 to 2003 household survey data in Hubei province. Similarly, Wang *et al.* (2015), using the sample of two-period data of rice farmers in three counties of Shangrao city, Jiangxi province, found a significant positive correlation between land size and agricultural productivity. Ju *et al.* (2016), using 2009 China agricultural census data, found that fertilizer use on a per-area basis was decreased sharply with an increase in farm size and that crop productivity is higher in large-scale farms than in smallholder farms in China. Thus, increasing farm size could prevent fertilizer overuse and improve crop productivity. However, Chen and Su (2016), using the fixed point rural survey data from 2010, found that there is an inverted-U shaped curve relationship for wheat and negative relationship for rice between land size and agricultural productivity. There are also a few studies focusing on the relationship between land size and profit margins in China. For example, Li *et al.* (2010), using 1999–2003 household survey data in Hubei province, found that land size has a positive effect on profit margins. However, Shao (2004), using 1986–2001 household survey data in Shandong province, found that there is an inverted-U curve relationship between land size and profit margins. Increasing land size can improve profit margins if the land size is not too large.

The empirical studies mentioned above have made contributions to reveal the relationship between farm size and agricultural productivity. The different conclusions reached by previous studies are mainly attributed to three reasons: incomplete factor markets, soil quality differences and land size measurement errors. They argued that overcoming these three problems is the key to correctly identify the relationship between farm size and agricultural productivity. However, most previous empirical studies have focused on investigating the relationship between land size and agricultural productivity by using land yield or labor productivity as dependent variables and land size as the core explanatory variable with controlling for a series of factors to analyze the correlation between land size and agricultural productivity through regression analysis. However, we argue that this traditional regression method may not be accurate enough to identify the factors that affect agricultural production efficiency. A higher level of land productivity may not be the more efficient agricultural production. Therefore, in this study, we use the SFA model to investigate the relationship between land size and agricultural production efficiency. The SFA takes two steps to estimate. The first step uses the agricultural production factor input and output to calculate the inefficient part of the technology. The second step uses the technical inefficiency as the dependent variable to identify the correlation between land size and agricultural production efficiency. Based on the SFA estimation results, we can explore the optimal land size that generates the highest agricultural production efficiency.

3. Data sources, descriptive statistics and sample analysis

In this study, we use the data set of the 2012 China Family Panel Studies (CFPS)[2] conducted by the Center for Social Science Research at Peking University. CFPS aims to reflect the changes of society, economy and population through tracking the selected samples from three levels: individuals, families and communities. The CFPS conducts four different types of questionnaires: family, adults, children and community questionnaires. Among them, the family questionnaire includes household agricultural management, social capital and information such as population characteristics. The adult questionnaire contains information of the head of household. The community questionnaire contains information of village and province. These three questionnaires cover all the data needed for this study. In this study, we are concerned only with agriculture production, and therefore only households that are engaged in crop farming are considered[3], and samples that missed key variables needed for our study are removed. After these adjustments, this study contains a valid sample of 6,477 households (see Table I).

In order to better observe the effect of different land size on agricultural production, we divide farmer households based on their land size into six groups: 0–10, 10–20, 20–40, 40–80, 80–120 and 120–200 mu. Table II reports the proportion of farmer households by different land size in national average and in three regions (east region, central region and west region). As Table II shows, around half of farmer households operate land on the scale of

Variables	Variable specification	Observed value	Average value	SD	Minimum value	Maximum value
Output value per mu	Unit: yuan/mu	6,447	663	1,494	0.01	50,000
Cost per mu	Unit: yuan/mu	6,447	252	518	0	12,333
Profit per mu	Unit: yuan/mu	6,447	410	1,162	−5,961	47,500
Land area under cultivation	Unit: mu	6,447	19	35	0.1	1,266
Cultivated land area grouping	Unit: mu	6,447	27	22	10	200
Productive factor input						
Household labor	Total labor input per mu in all production links (unit: work day/mu)	6,447	5	20	0	940
Cost of seed, fertilizer and pesticide	Unit: yuan/mu	6,447	184	364	0	10,000
Hired labor	Unit: yuan/mu	6,447	32	161	0	5,000
Cost of mechanical irrigation services	Unit: yuan/mu	6,447	23	95	0	5,172
Cost of transportation fuels	Unit: yuan/mu	6,447	12	76	0	3,636
Labor cost	yuan/hour	6,081	12	2	5	25
Price of chemical fertilizer	yuan/kg	5,802	6	3	1	27
Family characteristics						
Family size	Number of family farmers (person)	6,447	5	2	1	15
Child ratio	Proportion of children in the family (%)	6,447	1	5	0	50
Elderly ratio	Proportion of the elderly in the family (%)	6,447	45	28	0	100
Female youth workforce ratio	Proportion of women in the farming population (%)	6,447	26	17	0	100
Average age of the family workforce	Average age of farming population (unit: year)	5,866	39	8	17	59
Average education level of family workforce	Average education years of farming population (unit: year)	5,866	6	3	0	17
Dummy variable of agricultural machinery	Agricultural machinery ownership (yes = 1, no = 0)	6,241	0.4	0.5	0	1
Land characteristics						
Land rental rate of cultivated land	Proportion of rental land to total cultivated land (%)	6,447	4	11	0	97

Notes: The family labor input factor is not included in the calculation of profit per mu. Cultivated land area includes self-owned land and rented land minus land leased (Bhalla and Roy, 1988; Carletto *et al.*, 2013). Due to data limitation, multiple cropping is not considered in calculating the cultivated land area
Source: Calculated from the 2012 China Family Panel Studies (CFPS)

Table I.
Descriptive statistics of sample variables

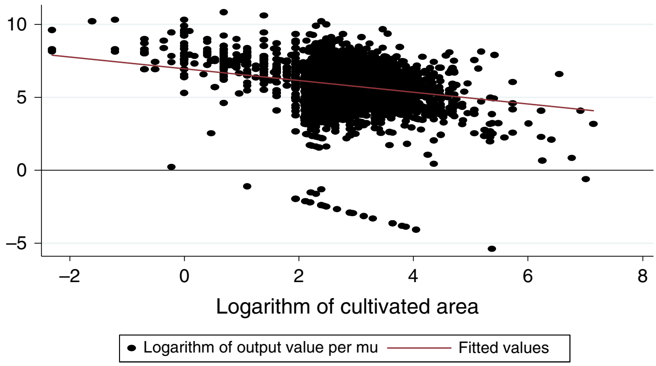
10–20 mu and around 25 percent of farmer households operate land between 20 and 40 mu. The proportion of farmer households operating land under 10 mu accounted for around 20 percent of the total sample. Farmer households operating land more than 40 mu accounted for much less, and in particular, farmer households operating land more than 80 mu accounted for less than 1 percent of the total sample. Comparing the three regions, the distribution of the proportion of farmer households by different land size is basically the same across the three regions[4].

We use the samples to conduct a simple correlation analysis between land size and unit output and unit profit by scatter diagrams (see Figures 1–2)[5]. We can see from the figures that land size is negatively correlated with unit output; however, there is no obvious correlation between land size and unit profit.

Land size grouping	0–10 mu	10–20 mu	20–40 mu	40–80 mu	80–120 mu	120–200 mu
National average						
Number of farmer households	1,257	3,315	1,493	283	55	44
Proportion (%)	19.40	51.20	23.10	4.40	0.85	0.68
East region						
Number of farmer households	350	681	258	32	5	3
Proportion (%)	26.32	51.20	19.40	2.40	0.38	0.23
Central region						
Number of farmer households	396	1,257	521	119	17	7
Proportion (%)	17.00	54.06	22.41	5.12	0.73	0.30
West region						
Number of farmer households	366	1,195	646	122	31	28
Proportion (%)	15.20	49.67	26.85	5.07	1.30	1.16

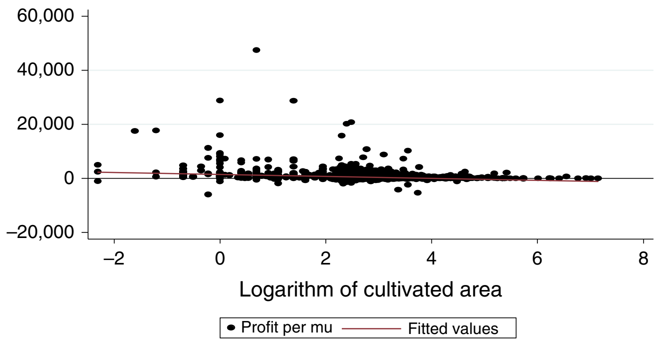
Source: Calculated from the 2012 China Family Panel Studies (CFPS)

Table II. The proportion of farmer households by different land size



Source: Calculated from the 2012 China Family Panel Studies (CFPS)

Figure 1. Scatter diagram of the relationship between land size and land unit output



Source: Calculated from the 2012 China Family Panel Studies (CFPS)

Figure 2. Scatter diagram of the relationship between land size and land unit profit

We further use the samples to conduct a simple comparison of farmers' production under different land size (see Table III). From the aspect of maximizing the yield per mu, the optimal choice of land size is 0–10 mu, followed by 10–20 and 40–80 mu, while the smallest yield per mu of land size is 120–200 mu. From the perspective of profit maximization per mu, 0–10 mu is the optimal land size, followed by 10–20 and 40–80 mu, and the smallest profit per mu of land size is 120–200 mu. The analysis shows that under different production targets, the optimal land size is the same.

However, the correlations presented in Figures 1 and 2 and Table III may not reflect the true relationship between land size and unit output and unit profit. It may be that we fail to control for some factors that may have common influence on each of the two variables, so that the true relationship between the two variables may be covered up. Also, by simply comparing the land size with output and profit per mu, we cannot accurately find out the optimal land size. In order to solve these problems and correctly identify the relationship between each of the two variables and find out the optimal land size for different production targets, in this study we will control for the characteristics of farmer households, land, village variables and other factors, and use econometric models to analyze the impact of land size on unit output and unit profit, and investigate the optimal land size under different production targets through econometric analysis.

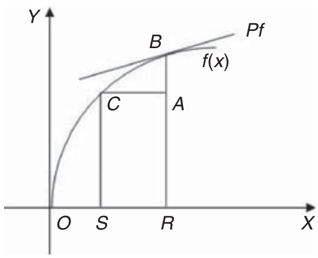
4. Theoretical framework of analyzing agricultural production efficiency

Agricultural production is a process of transforming input into output. In this process, labor, capital and other means of production are transformed into agricultural products. The production function, known as a "black box," reflects the relationship between input and output. When technical efficiency is not achieved completely, we expect the production function to choose the optimal path to express the transformation process from input to output. Our goal is to achieve maximum output at a certain level of input, or to maximize the profit at a given level of output. As shown in Figure 3, x represents factor input, y represents

Table III. Farmer production under different land sizes

Land size grouping	Average yield per mu of the farmers in the group (yuan/mu)	Average profit per mu of the farmers in the group (yuan/mu)
0–10 mu	1,013	647
10–20 mu	698	437
20–40 mu	570	352
40–80 mu	610	382
80–120 mu	603	369
120–200 mu	478	277

Source: Calculated from the 2012 China Family Panel Studies (CFPS)



Source: Authors' illustration

Figure 3. The maximum production frontier function of input and output

output and $f(x)$ represents the production function. We assume that $f(x)$ is the maximum production possible boundary under full technical effectiveness, point A represents the actual output and point B is the output of the maximum production boundary for the same input factor.

From the angle of output, for the same input OR, the maximum output should be at point B, so AB represents the distance between actual output and the maximum possible output, and BA/BR represents the technical inefficiency and should be between 0 and 1. Since AR is the actual output value, if we use the distance function to represent AR, then our target function is:

$$D_I(y, x) = \max\left\{\lambda \middle| \left(\frac{x}{\lambda}\right) \geqslant y\right\}, 0 < D(.) < 1. \tag{1}$$

The constraint conditions are: $0 < x \leqslant \text{OR}$.

From the input point of view, if the output is the same, namely AR, then the input factor on the maximum production boundary is only OS (OS < OR), OS/OR indicates the inefficiency of factor input. At this time, our goal is to minimize OR, and the distance function is expressed as:

$$D_o(y, x) = \min\left\{\theta \middle| \left(\frac{y}{\theta}\right) \leqslant f(x)\right\}, 0 < D(.) < 1. \tag{2}$$

The constraint conditions are: $\text{AR} \leqslant y < \text{BR}$.

Equation (1) represents the maximum output with given inputs. Equation (2) represents the minimization of the input with a given output, and the minimization of input is the cost minimization. The purpose of the cost minimization is profit maximization, which is the tangent p_f at point B. In this study, we will measure the efficiency of the technology by two measures: output productivity and profit margin.

According to the law of diminishing returns, if a farmer household follows the hypothesis of "rational individual," then theoretically the optimal scale of agricultural production exists. Optimal scale of agricultural production refers to the optimal combination and effective operation of agricultural production factors at a certain level of technology, when the efficiency of agricultural inputs (labor, capital, etc.) reaches the maximum or the output is maximized. Since land is an irreplaceable factor of agricultural production, the optimal scale of agriculture production largely refers to the optimal management scale of land (Wan and Cheng, 1996). In the real production process, farmer households will not blindly pursue cost reduction or simply increase production as they expand production scale. They want more net income. Therefore, we need to examine two separate relationships: the relationship between land size and production efficiency and the relationship between land size and profit efficiency, in order to reveal the optimal management scale of land.

5. Empirical analysis models

The SFA uses econometric models to estimate the optimal boundaries of output and profit, which are related to efficiency. The stochastic frontier production model estimates the possible maximum output in the absence of efficiency losses according to given factor inputs. The maximum output is compared with the actual output as the production boundary, and the difference between the maximum possible output and the actual output, which is a result of the technical inefficiency, is calculated. The stochastic frontier profit model first estimates the possible maximum production profit boundary under a certain exogenous price of production and fixed input, and then calculates inefficiency of the technology, which is the difference between the biggest possible profit and the actual profit.

The advantage of the SFA model is that at least in theory it recognizes that the actual value is not necessarily equal to the boundary value due to the inefficiency of the technology.

5.1 Stochastic frontier function models

5.1.1 Stochastic frontier output function model. According to the literature (Aigner *et al.*, 1977; Meeusen and van Den Broeck, 1977), we define the stochastic frontier output function model as:

$$Y_i = f(X_i, \beta)\exp\left(\upsilon_i - \mu_i\right). \tag{3}$$

In the model, Y_i indicates the output, X_i represents the input of agricultural production factors, i represents the sample i, $i = 1, \ldots, N$. β is the model parameter, $f(\cdot)$ is the agricultural production function. In this model, the random perturbation term ε_i is divided into two parts. One part represents the statistical error, namely the random error term, represented by υ_i. The other part represents the inefficiency of the technology and is called the non-negative error term, represented by μ_i. Thus, the technical efficiency of SFA is defined as:

$$\mathrm{TE}_i = \exp\left(-\mu_i\right) = \frac{Y_i}{f(x_i, \beta)\exp(\upsilon_i)}. \tag{4}$$

Given the known μ_i distribution, the mean of technical efficiency can be calculated by Equation (4), but the technical efficiency of a single sample cannot be calculated. The reason may be that the estimate of the parameters in the model can be calculated based on the observed values of the sample points, and the residual value ε_i is calculated according to these estimates, but the estimated values of individual υ_i and μ_i cannot be further obtained. In order to get the technical efficiency of each sample value, Jondrow *et al.* (1982) defined technical efficiency as: $\mathrm{TE}_i = \exp(E(\mu_i/\varepsilon_i))$, referred to as "JLMS" technique, and they derive the expression of $E(\mu_i/\varepsilon_i)$ using the semi-normal distribution, thus the technical efficiency can be obtained. Therefore, this study assumes that υ_i obeys the normal distribution $N(0, \sigma_v^2)$, μ_i is independent from υ_i and is subject to the semi-normal distribution $N^+(m_i, \sigma_\mu^2)$, thus the technical efficiency can be expressed by $\exp(E(-\mu_i))$[6].

When setting specific production function models, there are usually two choices, the Cobb–Douglas production function (C–D function) and the Transcendental Logarithm Function (Translog function). When only capital (K) and labor (L) are considered, the natural logarithm of the C–D function can be expressed as the following linear form:

$$\ln Y = \beta_0 + \beta_1 \ln K + \beta_2 \ln L. \tag{5}$$

In the function, β_0, β_1 and β_2 are estimated parameters.

The Translog function is essentially the approximate second-order Taylor expansion of the production function $f(\ln K, \ln L)$ at (0, 0). The specific form is as follows:

$$\ln Y = \beta_0 + \beta_1 \ln K + \beta_2 \ln L + \beta_3(\ln K)^2 + \beta_4(\ln L)^2 + \beta_5 \ln K \times \ln L. \tag{6}$$

The advantages of the C–D function lie in the direct economic meaning of its parameters (represents the output elasticity of input factors), while the Translog function considers the influence of interaction between input factors to the output, it overcomes the defect of the C–D function that elasticity of substitution is fixed to 1. But what kind of production function should be chosen needs to be judged according to the objective statistical test results.

This study selects the Translog function to do the likelihood ratio test. The null hypothesis is whether $\beta_3 = \beta_4 = \beta_5$ equals 0. The results show that the null hypothesis is rejected at the 1 percent significance level. That means this study should choose the Translog function model as the production function estimation model[7]. The specific form of the Translog function is as follows:

$$\ln Y_i = \beta_0 + \beta_1 \ln L_i + \sum_j^n \beta_j \ln k_{j,i} + \sum_j^n \beta_{jj} \left(\ln k_{j,i}\right)^2 + \beta_2 (\ln L_i)^2 + \sum_j^n \sum_k^n \beta_{jk} \ln k_{j,i} \times \ln L_i + \upsilon_i + \mu_i. \quad (7)$$

In Equation (7), Y_i represents the agricultural output of farmer i, L_i represents the total labor force in each production link; $k_{j,i}$ represents the jth agricultural capital investment of farmer i, including seed, fertilizer, mechanical irrigation, transportation fuel and other inputs as specified in Table I. $(\ln k_{j,i})^2$ and $(\ln L_i)^2$ are the square terms of the jth agricultural capital input and labor input. $\ln k_{j,i} \times \ln L_i$ is the interaction term of the jth agricultural capital input and the labor input.

5.1.2 Stochastic frontier profit function model. Equation (8) is the maximum profit boundary function at stochastic frontier – the maximum profit at a certain factor price w, output price p and fixed input q:

$$\pi(w, p, q) = \pi(w, q, pe^{-\mu}). \quad (8)$$

There is:

$$\ln \pi^\alpha = \ln \pi(w, p, q) + \ln h(w, p, q, \mu). \quad (9)$$

In Equation (9), $\ln \pi^\alpha$ is the semi-natural logarithm of actual profit, $\ln \pi(w, p, q)$ is the semi-natural logarithm of the maximum profit at stochastic frontier and $\ln h(w, p, q, \mu)$ represents the natural logarithm of profit loss due to the inefficiency of technology. Thus, the Translog function of the stochastic frontier profit function is:

$$\ln \pi^\alpha = \beta_0 + \beta_h \ln w_{h,i} + \beta_l \ln land_i + \frac{1}{2\beta_{hh}\left(\ln w_{h,i}\right)^2} + \frac{1}{2\beta_{ll}(\ln land)^2} + \beta_{hl} \ln w_{h,i} \times \ln land_i + \mu_i + \upsilon_i. \quad (10)$$

In Equation (10), $\ln \pi^\alpha$ is the semi-natural logarithm of actual profit, $w_{h,i}$ is hired labor cost of farmer i, $land_i$ is the cultivated land area of farmer i. In this paper, land is regarded as a fixed cost that does not change with agricultural production scale, μ_i indicates the profit/loss caused by the inefficiency of the technology, υ_i is the random disturbance term.

5.2 Technical efficiency model

The following equation is the technical efficiency model:

$$\mu_i = \pi_0 + \pi_1 \ln land_i + \pi_2 (\ln land_i)^2 + \sum_{n=1}^{6} \eta_n scalabledummy_{in} + \sum \gamma_k C_{ik} + \sum_{m=1}^{5} \varepsilon_m regionaldummy_{im} + \epsilon_i. \quad (11)$$

In Equation (11), μ_i represents the inefficient term of agricultural production of farmer *i*. $land_i$ represents the cultivated land area of farmer *i*. $(\ln land_i)^2$ represents the logarithmic square of land area, reflecting the nonlinear relationship between land area and technical inefficiency. $scalabledummy_{in}$ represents a set of variables of land size, reflecting the influence of different land size on technical inefficiency. The land size is divided into six groups: 0–10, 10–20, 20–40, 40–80, 80–120 and 80–200 mu. The 0–10 mu is the control group which is given a value of "0" to indicate the land size group that farmers belong to and the rest of the land size groups are given a value of "1" (Li *et al.*, 2015). C_{ik} represents the variables of family characteristics and land characteristics. Family characteristics include the following variables: family population size is defined as family members registered as permanent residents that lived at home at least six months; children are defined as under 16 years old; elderly are defined as over or equal to 60 years old; female workforce is defined as women between the ages of 16 and 60 who have not lost working ability; and other variables of household characteristics include the average age of the family, the degree of education, and whether there is farm machinery in the household. Regarding land characteristics, due to sample limitation, we only select the variable of the proportion of rented land in total cultivated land area. $regionaldummy_{im}$ represents the variables of geographic characteristics of the farmers' village, aiming to control for the influence of different landscapes on the inefficiency of agricultural technology. The villages are divided into six types: hills, mountains, plateaus, plains, grasslands and fishing villages. The "hills" is the control group and is given a value of "0" and the other groups are given a value of "1."

6. Estimation results and analysis

There are two methods to estimate efficiency: "One-step" method and "Two-step" method. The "Two-step" method is preferred by earlier researchers. In this method, the influence factors of technical efficiency are not considered first, the distance function of the frontier function is estimated, then the technical inefficiency (relative to the technical efficiency) is calculated, and the influence factors of the dependent variable on its own are returned. However, Wang and Schmidt (2002) pointed out that a disadvantage of this approach is that there is a difference between the two phases of the function distribution of the technical inefficiency, which results in biased and inconsistent results. Coelli and Battese (1996) improved the technical efficiency estimation method and proposed the "One-step" method, namely, the simultaneous implementation of the above-mentioned two steps. Considering that the "One-step" method can more accurately estimate the inefficiency of technology, this study adopts the "One-step" method to estimate the stochastic frontier function model and the technical efficiency model.

6.1 Estimation of stochastic frontier output function

6.1.1 Estimation of stochastic frontier output model. Table IV shows the estimated results of the stochastic frontier output model (Equation (7)) and the technical output efficiency model (Equation (11)). In Table IV, Model 1 does not include the variables of family characteristics and land characteristics. Model 2 controls for only the variables of family characteristics. Model 3 jointly controls for the variables of family characteristics and land characteristics. The first half

Variables	Model 1	Model 2	Model 3
Stochastic frontier output function model			
Explained variable: output value per mu (log) (unit: yuan/mu)			
Agricultural input factor variables (log)			
Household labor	0.068** (0.032)	0.068* (0.035)	0.067* (0.035)
Costs of seed, fertilizer and pesticide	0.127*** (0.035)	0.121*** (0.044)	0.218** (0.107)
Hired labor	0.063** (0.025)	0.053** (0.027)	0.119*** (0.044)
Costs of mechanical irrigation services	0.082*** (0.028)	0.078** (0.030)	0.055** (0.027)
Costs of transportation fuels	0.063* (0.033)	0.057* (0.034)	0.077** (0.030)
Square of household labor	0.017*** (0.006)	0.017*** (0.006)	0.017*** (0.006)
Square of the costs of seed, fertilizer and pesticide	0.066*** (0.004)	0.065*** (0.005)	0.065*** (0.005)
Square of hired labor	0.044*** (0.005)	0.045*** (0.005)	0.044*** (0.005)
Square of the costs of mechanical irrigation services	0.023*** (0.005)	0.022*** (0.005)	0.022*** (0.005)
Square of the costs of transportation fuels	0.030*** (0.005)	0.030*** (0.005)	0.030*** (0.005)
Interaction of household labor and the costs of seed, fertilizer and pesticide	−0.021*** (0.007)	−0.022*** (0.008)	−0.022*** (0.008)
Interaction of household labor and hired labor	0.006* (0.004)	0.006 (0.004)	0.006 (0.004)
Interaction of household labor and the costs of mechanical irrigation services	0.000 (0.004)	0.002 (0.004)	0.002 (0.004)
Interaction of household labor and the costs of transportation fuels	0.003 (0.005)	0.004 (0.005)	0.004 (0.005)
Interaction of the costs of seed, fertilizer and hired labor	−0.046*** (0.006)	−0.045*** (0.006)	−0.045*** (0.006)
Interaction of the costs of seed, fertilizer and mechanical irrigation services	−0.033*** (0.006)	−0.032*** (0.006)	−0.032*** (0.006)
Interaction of the costs of seed, fertilizer and transportation fuels	−0.032*** (0.007)	−0.032*** (0.008)	−0.032*** (0.008)
Interaction of the costs of hired labor and mechanic irrigation services	0.005* (0.003)	0.007*** (0.003)	0.007** (0.003)
Interaction of the costs of hired labor and transportation fuels	0.002 (0.003)	0.003 (0.003)	0.003 (0.003)
Interaction of the costs of mechanic irrigation services and transportation fuels	0.004 (0.003)	0.004 (0.003)	0.003 (0.003)
Constant term	4.507*** (0.083)	4.567*** (0.098)	4.576*** (0.099)
Significance of inefficiency test			
t-value	25.91	24.44	24.43
p-value	0.000	0.000	0.000
Technical efficiency impact factors model			
Explained variable: technical inefficiency term			
Key explanatory variables			
Actual cultivated area (log)	−0.067 (0.105)	−0.199* (0.117)	−0.198* (0.117)
Square of actual cultivated area	0.034 (0.026)	0.065** (0.029)	0.065** (0.029)
Actual cultivated land 10–20 mu	−0.483*** (0.073)	−0.404*** (0.081)	−0.404*** (0.081)
Actual cultivated land 20–40 mu	−0.650*** (0.125)	−0.569*** (0.136)	−0.534*** (0.137)
Actual cultivated land 40–80 mu	−0.188 (0.208)	−0.183 (0.225)	−0.084 (0.232)
Actual cultivated land 80–120 mu	−0.547 (0.349)	−0.517 (0.381)	−0.370 (0.390)
Actual cultivated land 120–200 mu	0.676 (0.516)	0.406 (0.552)	0.449 (0.553)
Family characteristics variables			
Family size		0.036** (0.016)	0.033** (0.016)
Child ratio		0.046 (0.509)	0.081 (0.510)
Elderly ratio		−0.599*** (0.145)	−0.596*** (0.145)

(*continued*)

Table IV. Estimation results of stochastic frontier output function model and technical output efficiency model

Variables	Model 1	Model 2	Model 3
Female youth workforce ratio		−1.497*** (0.201)	−1.500*** (0.201)
Average age of the family workforce		−0.003 (0.003)	−0.003 (0.003)
Average education level of family workforce		−0.014* (0.008)	−0.014* (0.008)
Dummy variable of agricultural machinery		−0.330*** (0.050)	−0.329*** (0.050)
Land characteristics			
Land rental share of cultivated land			−0.467* (0.258)
Constant term	0.534*** (0.147)	1.252*** (0.265)	1.267*** (0.265)
Dummy variables of village landscape	Yes	Yes	Yes
Log likelihood	−6,808.332	−5,889.2381	−5,887.625
Observed value	6,070	5,305	5,305

Notes: Robust standard errors are in parentheses. *,**,***Significant at the 10, 5 and 1 percent levels, respectively
Source: Authors' estimation

Table IV.

of Table IV shows the estimated results of the stochastic frontier output model. The estimation results show that, first, it makes little difference for the production function estimation whether the variables of family characteristics and land characteristics are controlled for or not. The reason is that output mainly changes with the change of input factors, while the factors such as farmers' family characteristics and land characteristics may have more influence on technical efficiency of agricultural production. Second, capital inputs have a larger impact than labor inputs on agricultural output. This may be related to the larger capital inputs such as fertilizers and pesticides in agricultural production in China. Third, input factors are positively correlated with output, but the interaction terms of seed and fertilizer with other input factors are negatively correlated with output, which indicate that with higher input of other production factors, further increasing input of seed and fertilizer may hinder agricultural production output.

6.1.2 Estimation of technical output efficiency model. The estimation results of the technical output efficiency model are reported in the second half of Table IV. Since Model 3 controls for both the variables of family characteristics and land characteristics, we interpret the estimation results based on Model 3. The estimation results show that, first, the variable of cultivated land area is negative and statistically significant at the 10 percent level, while the variable of the square of cultivated land area is positive and statistically significant at the 5 percent level. This reveals that there is a U-shaped curve relationship between cultivated land area and output technical inefficiency. In other words, there is an inverted-U curve relationship between cultivated land area and output technical efficiency. This implies that with the increase of farm size, output technical efficiency increases and when farm size increases to a certain level (turning point), output technical efficiency reaches its highest level. However, with further increase in farm size, output efficiency will begin to decline. Second, in terms of different groups of farm size, farmer households with land size of 10–20, 20–40, 40–80 and 80–120 mu have higher output efficiency than those with land size of 0–10 mu. The output efficiency of farmer households with land size of 10–20 and 20–40 mu is 150 and 171 percent higher, respectively, than that of those with land size of 0–10 mu at the 1 percent significance level. Although output efficiency of farmer households with land size of 40–80 and 80–120 mu is higher than that of those with land size of 0–10 mu, the effect is not significant. However, output efficiency is 45 percent lower for farmer households operating land size of 120–200 mu than that of those operating land size of 0–10 mu. Therefore, the estimation results may suggest that the appropriate farm land size should be at the range of 10–40 mu and the optimal farm land size should be at the range of 20–40 mu for farmer households when the optimization of output efficiency of agricultural production is the target.

Third, in terms of family characteristics, family size and child ratio have negative effects on output efficiency. The reasons may be that the larger the family size is, the more the elders and children need to be looked after, thus leading to a lack of labor and a negative impact on output efficiency. The average age and average education level of family laborers represent the work experience of farm households. As a result, they have a positive effect on output efficiency. Similarly, the elders have a positive effect on output efficiency because they can pass their experiences to their family members. The female labor force plays a positive and important role in increasing output efficiency. In addition, owning agricultural machinery has a significantly positive effect on increasing output efficiency. Finally, the share of rented land has a positive and significant effect on increasing output efficiency. This implies that appropriate land consolidation and transformation may increase the output efficiency of agricultural production.

6.2 Estimation of stochastic frontier profit function

6.2.1 Estimation of stochastic frontier profit model. Table V shows the estimated results of the stochastic frontier profit model (Equation (10)) and the technical profit efficiency model (Equation (11)). Same as in Table IV, in Table V, Model 1 does not include the variables of family characteristics and land characteristics. Model 2 controls for only the variables of family characteristics. Model 3 jointly controls for the variables of family characteristics and land characteristics. The first half of Table V shows the estimated results of stochastic frontier profit model. The estimation results reveal two interesting findings. First, hired labor has a positive and significant impact on profit while the square term of hired labor is insignificant. The explanation is that farmers tend to hire more productive labor which will increase profit. However, with the increase in hired labor, the law of diminishing return will set in and the contribution of hired labor to profit will decrease and even becomes 0 or negative. Second, the variable of cultivated area is negative and the variable of square term of cultivated area is positive and both are statistically significant. This reveals that there is a U-shaped curve relationship between cultivated area and profit. With the increase of cultivated area, initially profit will decline. However, after the cultivated area reaches a certain level (turning point), profit will start to increase. This implies that appropriate land consolidation will tend to increase profit of agricultural production.

6.2.2 Estimation of technical profit efficiency model. The estimation results of the technical profit efficiency model are reported in the second half of Table V. The estimation results show that, first, the variable of cultivated area is positive and statistically significant at the 1 percent level, while the variable of the square term of cultivated area is negative and statistically significant at the 10 percent level in Model 1 (but insignificant in Models 2 and 3). This reveals that there may be a weak inverted-U curve relationship between cultivated area and profit inefficiency. In other words, there may be a U-shaped curve relationship between cultivated area and profit efficiency. This implies that with the increase of farm size, profit efficiency decreases and when farm size increases to a certain level (turning point), profit efficiency reaches its lowest level. However, with further increase in farm size, profit efficiency will begin to increase. Referring to the finding of the impact of land size on agricultural production profit in the first half of Table V, this finding implies that appropriate land consolidation will also tend to increase profit efficiency of agricultural production. Second, in terms of different groups of farm size, farmer households with land size above 10 mu have higher profit efficiency than those with land size of 0–10 mu. The profit efficiency of farmer households with land size of 10–20 and 20–40 mu is 259 and 285 percent higher, respectively, than that of those with land size of 0–10 mu at the 1 percent significance level. Although farmer households with

Table V. Estimation results of stochastic frontier profit model and technical profit efficiency model

Variables	Model 1	Model 2	Model 3
Stochastic frontier profit function model			
Explained variable: profit value per mu (log) (unit: yuan/mu)			
Agricultural input factor variables (log)			
Hired labor (log)	0.795*** (0.124)	0.808*** (0.126)	0.822*** (0.124)
Square of the logarithm of hired labor (log)	−0.021 (0.094)	0.028 (0.094)	0.011 (0.094)
Actual cultivated area (log)	−0.794*** (0.109)	−0.809*** (0.121)	−0.648*** (0.107)
Square of the logarithm of actual cultivated area (log)	0.259*** (0.048)	0.267*** (0.052)	0.175*** (0.050)
Logarithmic interaction term of hired labor and actual cultivated area	0.048** (0.022)	0.031 (0.022)	0.032 (0.023)
Constant term	4.902*** (0.192)	4.870*** (0.200)	4.780*** (0.184)
Significance of inefficiency test			
t-value	13.85	13.25	13.62
p-value	0.000	0.000	0.000
Technical efficiency impact factors model			
Explained variable: technical inefficiency term			
Key explanatory variables			
Actual cultivated area (log)	1.332*** (0.396)	1.539*** (0.472)	1.567*** (0.448)
Square of actual cultivated area	−0.093* (0.054)	−0.094 (0.061)	−0.097 (0.059)
Actual cultivated land 10–20 mu	−0.981*** (0.159)	−0.906*** (0.187)	−0.951*** (0.184)
Actual cultivated land 20–40 mu	−1.012*** (0.227)	−0.984*** (0.268)	−1.049*** (0.263)
Actual cultivated land 40–80 mu	−0.690** (0.319)	−0.610* (0.370)	−0.665* (0.375)
Actual cultivated land 80–120 mu	−0.624 (0.469)	−0.716 (0.537)	−0.834 (0.541)
Actual cultivated land 120–200 mu	0.128 (0.696)	−0.052 (0.755)	−0.491 (0.802)
Family size		−0.005 (0.026)	−0.004 (0.026)
Child ratio		−0.168 (0.916)	−0.187 (0.943)
Elderly ratio		0.039 (0.238)	0.009 (0.242)
Female youth workforce ratio		−1.000*** (0.343)	−1.013*** (0.346)
Average age of the family workforce		0.002 (0.006)	0.003 (0.006)
Average education level of family workforce		−0.020 (0.013)	−0.021 (0.013)
Dummy variable of agricultural machinery		−0.768*** (0.094)	−0.770*** (0.093)
Land characteristics			
Land rental rate in cultivated land			−1.933*** (0.561)
Constant term	−1.798*** (0.692)	−2.008** (0.877)	−1.973** (0.841)
Dummy variables of village landscape	Yes	Yes	Yes
Log likelihood	−7,217.384	−6,138.268	−6,122.303
Observed value	4,892	4,255	4,255

Notes: Robust standard errors are in parentheses. *,**,***Significant at the 10, 5 and 1 percent levels, respectively
Source: Authors' estimation

land size of 40–80, 80–120 and 120–200 mu also have higher profit efficiency, the estimation results are either marginally significant at the 10 percent level (for the group of 40–80 mu) or insignificant (for the groups of 80–120 and 120–200 mu). Therefore, from both the perspectives of profit maximization and profit efficiency, the appropriate farm land size should be at the range of 10–40 mu and the optimal farm land size should be at the range of 20–40 mu. In addition, the female labor force plays an important role in increasing profit efficiency. Finally, agricultural machinery has a significant effect on increasing profit efficiency of agricultural production.

7. Conclusion and policy implications

The main aim of this paper is to investigate agricultural production efficiency from the aspects of output and profit. By using the 2012 CFPS data and employing the SFA models, this paper explored in depth the relationship between land size and agricultural production efficiency and estimated the optimal management scale of land in terms of achieving both output and profit efficiency of agricultural production. The study has two main findings. First, the study finds that while there is an inverted-U curve relationship between land size and output efficiency of agricultural production, there is also a U-shaped curve relationship between land size and profit efficiency of agricultural production. This implies that with the increase in land size, initially output efficiency will increase but profit efficiency will decline and when land size increases to a certain level (the turning points), output efficiency will reach the highest level while profit efficiency will reach the lowest level. After the turning points, with further increase in land size, output efficiency will start to decrease while profit efficiency will begin to increase. Second, the study estimates that, for both the purposes of reaching output efficiency and achieving profit efficiency, the appropriate farm land size should be at the range of 10–40 mu and the optimal farm land size should be at the range of 20–40 mu under the current agricultural technology and land management system in China. Based on these results, around 20 percent of farmer households can improve agricultural production efficiency by increasing farm land size to the appropriate scale of 10–40 mu and more than two thirds of farmer households can improve agricultural production efficiency by increasing farm land size to the optimal scale of 20–40 mu.

The findings of this study suggest that appropriate land consolidation will bring more benefits to farmer households and agricultural production efficiency. Therefore, the Chinese Government should design and implement policies to encourage appropriate land consolidation. First, governments should give long term and more stable land using rights to farmers through extending the period of land contract and verifying land using rights. Second, governments should encourage transfers of land using rights and promote land consolidation. Subsidizing framers who operate large land size has certain positive effect on promoting land consolidation. However, the implementation of this policy should consider regional differences and not be used for blindly pursuing increasing land size. The purpose is to achieve an optimal scale of land management in order to achieve both output and profit efficiency of agricultural production. Third, land consolidation should be accompanied with the development of specialized agricultural services, including research and development (R&D), technical extension and agricultural machinery. Therefore, governments not only should increase investments in agricultural R&D, technical extension and agricultural machinery, but also should provide technical trainings to improve farmers' ability to use modern agricultural technology and agricultural machinery in order to increase agricultural production efficiency.

Notes

1. The measurement methods of agricultural productivity are divided into two categories: single factor productivity (SFP) and total factor productivity (TFP). Among them, SFP includes land productivity, labor productivity and capital productivity. TFP is a comprehensive indicator that includes technological progress, efficiency improvement, economies of scale, institutional innovation, specialization, division of labor, etc., which represent factors other than input factors. This study uses land productivity to measure agricultural productivity.

2. CFPS was launched in 2010 and has conducted four surveys in 2010, 2012, 2014 and 2016, respectively. However, only the 2012 data set can provide all the variables that are needed for this study. For example, in 2010 data set, we cannot get the specific cost items that households invested in agricultural production, such as seed cost, fertilizer cost, mechanical cost, labor cost and so on. In 2014 and 2016 data sets, we cannot get the land size and the income from the crop production of households. Therefore, in this study, we can only use the 2012 data set. In addition, according to a

series of indicators such as weather and rainfall, 2012 is a normal year which can represent the general situation of agricultural production in China.

3. Because the input and output of production in crop farming is different from forestry, fishery and animal husbandry, in this study, we only take crop farming as the research object.
4. We further divided the farmer households by land size into 12 groups in three regions and conducted a number of *t*-test to see whether there is significant difference between the two regions in the three regional pairs: east region and central region, east region and west region, and central region and west region. The *t*-test *p*-values are 0.9973 between east region and central region, 0.9928 between east region and west region and 0.9957 between central region and west region, respectively. Therefore, the *t*-test results reveal that there is no significant difference among regions in terms of the proportion of farmer households by different land size.
5. Before taking logarithm for land area and unit output, 0.001 are added to their original values in order to avoid a sample observation value of 0 (MaCurdy and Pencavel, 1986). Unit profit has a negative value, so semi logarithm is used for unit profit.
6. In this study, the stochastic frontier profit model makes the same function distribution setting for μ_i and υ_i.
7. We made a similar likelihood ratio test in making choices on the stochastic frontier profit function. The results reject the null hypothesis at the 1 percent significance level, which means that the Translog function form should be chosen as the stochastic frontier model.

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