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Abstract

Purpose – Whether there exists an inverse relationship (IR) between farm size and its efficiency remains a hotly debated question among agricultural economists. In most studies to date, farm efficiency is measured by land productivity. Thus, the IR actually measures the relationship between farm size and land productivity. The purpose of this paper is to examine and understand the IR from a novel angle by using multiple definitions of farm efficiency indicators like labor productivity, profit ratio, total factor productivity (TFP) and technical efficiency (TE).

Design/methodology/approach – By using the farm-level panel data from Hubei province in China from 1999 to 2003, this paper employs the two-way fixed effect model of panel data and the stochastic frontier analysis of Battese and Coelli model to investigate the relationship between farm size and its production efficiency derived from the multiple definitions of production efficiency indicators including land productivity, labor productivity, profit ratio, TFP and TE.

Findings – The study confirmed the IR between land productivity and farm size, as in many formal studies. However, the relationship between farm size and other agricultural efficiency indicators may be positive, negative or uncorrelated at, depending on how the farm efficiency is defined. Therefore, the paper concluded that the relationship between farm size and its production efficiency is mixed. This paper provides economic explanations for the IR through the comprehensive study using the expansion of agricultural efficiency indicators.

Practical implications – Because different agricultural efficiency indicators have different policy implications for China's future agricultural and land policy, the findings have tremendous policy implications, particularly in terms of the current debate on large or small farm development strategy, the also so-called "go big or small" agricultural strategy. In this sense, the Chinese household responsibility system has played a critical role in its agriculture and will continue to play a critical role in terms of social security and social equality. Any reform to this system should proceed with caution.

Originality/value – While most existing studies only try to explain the IR from the perspective of land productivity, this paper attempts to propose a novel angle to examine the IR by using multiple definitions of agricultural efficiency and hopes to find some new conclusions.

Keywords China, Agricultural policy, Food policy

Paper type Research paper

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1. Introduction

Sen (1962, 1966) found an inverse relationship (IR) in Indian agriculture between the farm size and its land productivity. Since Sen's pioneer work, many researchers (Berry and Cline, 1979; Binswanger *et al.*, 1993; Assuncao and Maitreesh, 2003; Bizimana *et al.*, 2004) further investigated whether and why such IR exists. Because most of these studies conducted under smallholder agriculture in developing countries, the IR between the farm size and its land productivity is often regarded as the typical feature of the smallholder agriculture in developing countries. However, the existence of such IR remains a hotly debated question among agricultural economists. Some researchers doubted the existence of an IR between the farm size and its land productivity. For instance, Nehring *et al.* (1989), Bravo-Ureta and Rieger (1990) and Kumbhakar (1993) demonstrated that the relationship between the two is positive. Carter and Wiebe (1990), Benjamin (1995) and Lamb (2003), on the other hand, held that the relationship between the two is probably non-linear. Bagi (1982), Bagi and Huang (1983), Bravo-Ureta (1986) and Moussa and Jones (1991) all showed that no statistically significant relationship between the farm size and the land productivity could be established.

The existing literatures mainly have provided such economic explanations about the IR as follows:

- the input factor market is not perfect and efficient, which includes the differences of land, labor force and credit market between the large-scale farmers and small-scale farmers, especially the role of labor market (Sen, 1966; Carter, 1984; Reardon *et al.*, 1996; Newell *et al.*, 1997);
- the differences in the land quality and utilization degree (Byiringiro and Reardon, 1996; Lamb, 2003);
- farms' heterogeneity, e.g. Assuncao and Maitreesh (2003) pays attention to some inconspicuous heterogeneities such as farmers' farming skills and occupational choice;
- Chayanov's peasant self-exploitation theory; and
- the farms are in face of the differences in the transaction costs, supervision costs and principal-agent problems in the farm's inner organization and management, like Eswaran and Kotwal (1985).

There have been a few empirical studies particularly for Chinese agriculture. Benjamin and Brandt (2002) attributed the IR in China's agriculture to the local administrative (instead of market) allocation of land and the extent of unevenly developed non-agricultural opportunities. Wu *et al.* (2005) observed a strong IR between grain's productivity and farm size by using the cross-sectional data from 227 Chinese farm households. Using a sample of 548 households in 48 Chinese villages, Gao and Zhang (2006) showed the IR using IV estimation and fixed effect models. Different from Wu *et al.* (2005) and Gao and Zhang (2006) did control the selection bias and heterogeneity of land quality. However, Chen *et al.* (2010) still insisted that the IR may be explained by the unobserved land quality rather than inherent to China's agriculture. Hence, the issue of the IR between farm size and efficiency or productivity remains largely an empirical question in Chinese agriculture.

However, in the above existing "IR" literatures, we found that the agricultural production efficiency of a farm is often measured by "production per unit area" or "value per unit area", namely by the land productivity. In many developing countries food security is the priority and therefore achieving high land productivity is the most important goal for these countries. Evidently, production per unit area is an indicator of single factor productivity (SFP), and thus cannot reflect the whole agricultural production process comprehensively. Agricultural production efficiency is a multi-dimensional concept in the production process, at least including land productivity, labor productivity, profit ratio, total factor productivity (TFP) and technical efficiency (TE) which reflects the utilization of related technologies. Thus, the obvious question becomes "Does the inverse relationship still hold with a broader definition of agricultural efficiency?"

China is the largest developing country with a vast population, limited farmland, and rich rural laborers. Essentially, the household responsibility system (HRS), implemented after the collapse of the collectivization system in the late 1970s, is an agricultural strategy for small farms based on land-sharing. Lin (1992) has demonstrated that the contributions made by the HRS accounted for 46.89 percent of the agricultural growth during the reform period of 1978-1984. After the one-time burst of growth due to the institutional innovation of HRS, the debated policy has inspired many (sometimes dramatic) land reforms after the introduction of HRS. The relationship of farm size and agricultural efficiency is a key actor in designing the rural development strategy, further land reform, and rural equity. Is such a small farm based on HRS production efficient? Could HRS still fit the challenge of the new millennium with rapid urbanization and great improvement of agricultural technology? On the other hand, since the reform, the cultivated land per farm has been declining as the total cultivated land area declined but the population kept growing. Nevertheless, the total agricultural output per farm has been increasing. Is this an indication that smaller is better?

Although China's economy has experienced more than 30 years of rapid growth and urbanization, small-scale household-based agriculture remains and will continue to be a prominent feature of China's future agriculture in a fairly long period of time. China's agriculture nowadays is also facing the historic opportunity with the three major challenges: the rapidly growing non-agricultural employment, the slower population growth and the adjustment of agricultural production structure. In some more developed (e.g. coastal) provinces, there are louder and louder calls for policy changes to allow land transfer and to promote large-scale agricultural production. The controversy over the farm size and its production efficiency, adds more uncertainty to the policy making. If small-scale rural farm does enjoy comparative advantages in agricultural efficiency, it has significant policy implications for China's future agricultural and land policy. So understanding such IR is still a hot issue in terms of both theoretical research and practical policy-making now, especially in China.

This paper sets to investigate the relationship between the agricultural efficiency and farm size in a comprehensive way. It attempts to make its own contributions to the existing literatures in the following aspects:

- to enrich the related empirical literatures on the farm's IR with a China case study;
- while most formal studies explained the IR with the perspective of land productivity, our paper attempts to expand in the framework of agricultural efficiency indicators to include labor productivity, profit ratio, TFP and TE besides land productivity; and
- to provide economic explanations for the IR through our comprehensive study using the expansion of agricultural efficiency indicators.

While most existing studies only try to explain the IR from the perspective of land productivity, this paper attempts to propose a novel angle to examine the IR by using multiple definitions of agricultural efficiency and hopes to find some new conclusions. However, the paper indeed does not try to examine the existing economic explanations about the IR between farm size and land productivity, but pays special attention to the relationship between land productivity, other related agricultural efficiency indicators and farm size.

The rest of the paper is organized as follows. The next section described our analytic model. Section 3 briefly introduced the datasets we used and the variables in our econometrical analysis. Section 4 was about the empirical results and discussions. We finally concluded with a summary and some policy implications.

2. Conceptual framework and empirical model

Most formal studies to the following classical equation (1) employed ordinary least squares (OLS) estimation:

$$Efficiency_i = C + \beta \ln OP_i + \varepsilon_i \tag{1}$$

where $Efficiency_i$ is the land productivity of the corresponding farm i, OP_i is the actual farmland area, ε_i is classical random noise term. If $\beta < 0$ and statistically significant, then it can determine that the IR exists, such as in Carter (1984) and Heltberg (1998).

However, equation (1) is often criticized for ignoring the other factors affecting the land productivity of farm, such as land quality differences (Lamb, 2003), farm heterogeneity (Assuncao and Maitreesh, 2003), land fragmentation (Wu *et al.*, 2005) and many other factors. We improved equation (1) by introducing a set of exogenous variables to control the effect of the above-listed factors on the production efficiency of a farm. These characteristic variables can also be defined as farm's endowments, which could be expressed in the human capital and social capital of a farm such as education, technically training, personal experience, social network and resource availability. Specifically, this paper would first estimate the following equation:

$$Efficiency_i^f = C + \beta \ln OP_i + \sum_j \delta_j X_{ij} + \varepsilon_i \tag{2}$$

where X_{ij} is the control variables introduced to account for the influence of farm's endowment. Other variables remain the same as defined in equation (1). Besides the land productivity, the agricultural efficiency indicators based on equation (2) could also include the labor productivity and profit ratio of corresponding farm.

Second, we expand the agricultural efficiency indicator to include TFP which can comprehensively reflect the efficiency of the whole agricultural production process. We use the production function of the Cobb-Douglas form to calculate TFP. Following Fan (1991) and Zhang and Colin (1997), we use the following functional form:

$$Y_i = A_0 e^{\eta t} K_i^{\alpha_K} L_i^{\alpha_L} M_i^{\alpha_M} \exp(\varepsilon_i) \tag{3}$$

where Y_i is the output level of farm i, K_i, L_i and M_i represent the physical capital, labor and land inputs of farm i, respectively. α_K, α_L and α_M are their respective output elasticities, t is the time trend term, and η is often called the technological progress rate. When estimating the equation (3), its natural logarithm is often estimated:

$$\ln Y_i = \ln A_0 + \eta t + \alpha_K \ln K_i + \alpha_L \ln L_i + \alpha_M \ln M_i + \varepsilon_i \quad (4)$$

The sum of factor output elasticities is often defined as the coefficient of returns to scale (RTS). Let us define $RTS = \alpha_K + \alpha_L + \alpha_M$, and normalize each factor's output elasticity, we obtain: $\alpha_K^* = \alpha_K/RTS$, $\alpha_L^* = \alpha_L/RTS$, $\alpha_M^* = \alpha_M/RTS$.

Then, the TFP indicator can be defined as:

$$TFP_i = Y_i / \left(K_i^{\alpha_K^*} L_i^{\alpha_L^*} M_i^{\alpha_M^*} \right) \quad (5)$$

After we calculated TFP from equation (5), we could estimate the relationship between farm's scale, farm endowment and TFP as follows:

$$TFP_i = C + \beta \ln OP_i + \sum_j \delta_j X_{ij} + \varepsilon_i \quad (6)$$

The TE is one of the most commonly used efficiency indicators to measure the efficient state of production units. Based on equation (3), random disturbance term ε_i is expressed as a compound disturbance term $\varepsilon_i = (v_i - u_i)$, and then the production function can be converted into stochastic frontier production function:

$$Y_i = A_0 e^{\eta t} K_i^{\alpha_K} L_i^{\alpha_L} M_i^{\alpha_M} \ \exp(v_i - u_i) \quad (7)$$

The error term $\varepsilon_i = (v_i - u_i)$ in the equation (7) is a compounded error term, consisting of two separate components: v_i is the classical white noise term, $v_i \sim iidN(0, \sigma_v^2)$ mainly includes measurement error and uncontrollable random factors, such as climate and luck; u_i is the non-negative, representing production technical inefficiency of farm i, which is independent of white noise v_i. In the one-step approach (Battese and Coelli, 1995), u_i is set as an independent and identically distributed non-negative truncated normal distribution with a mean m_i and a variance σ_u^2:

$$u_i \sim iidN^+(m, \sigma_u^2) \quad (8)$$

$$m_i = C + \sum_j \delta_j X_{ij} + w_i \quad (9)$$

where m_i corresponds to technical inefficiency function, and e^{-m_i} reflects the TE level of farm i. The larger the m_i, the higher the technical inefficiency. X_{ij} represent the exogenous variables, and δ_j are the parameters to be estimated. w_i is a random error term, subjecting to distribute the non-negative truncated normal distribution with mean 0 and variance σ_w^2. For instance, $w_i \geq -(C + \delta_j X_j)$, which can ensure the non-negative nature of u_i.

So we can calculate the level of TE as:

$$TE_i = E(Y_i | u_i, Z_{ij}) / E(Y_i | u_i = 0, Z_{ij}) = \exp(-u_i) \quad (10)$$

where Z_{ij} represent the factor input vector, if $u_i = 0$, then $TE_i = 1$, meaning this farm is in the state of total TE, and its production point is on the production frontier; if $u_i > 0$, then $0 < TE_i < 1$, and this state is called technical inefficiency state, and its production point is below the production frontier. Thus, the average TE is calculated as:

$$TE = \frac{1}{n}\sum_{i=1}^{n} TE_i \tag{11}$$

where n is the number of farms. The stochastic frontier production function in the equations (7)-(9) are jointly estimated using maximum likelihood (ML) method. Variance parameters are used in the likelihood function (Battese and Corra, 1977; Coelli, 1995):

$$\gamma = \sigma_u^2/\sigma_s^2, \quad \sigma_s^2 = \sigma_v^2 + \sigma_u^2, \quad (0 \leq \gamma \leq 1) \tag{12}$$

where γ reflects the proportion of technical inefficiency in all compound variances of the whole compound disturbance term.

3. Data and variable definition

The data in the paper are the household/farm datasets from the 15 fixed observation villages (managed by Ministry of Agriculture of China) in Hubei province during the years of 1999-2003. After removing missing data, abnormal values and discontinuous observation, the remaining dataset consists of 2,155 observations for 431 households/farms over five years. Located in central China, Hubei is on the middle reaches of the Yangtze river. It is one of main grain production provinces in China. Beyond grain, cotton, oil crops and live pigs are also important agricultural products. The region is mostly subtropical. The 15 observation villages all belong to agricultural villages, which means that their livelihood depends mainly on agricultural production. Among the 15 villages, two are located in the suburb, four in fertile plain, seven hilly and four mountainous. As it comes to the economic development level, three villages are above average, ten are on the average, two are below average at the counties where the villages are located. Therefore, from both geographical location and economic levels, the samples selected in the paper are typical in China.

Two sets of variables are used in the Section 2's model: one is the main input-output variables and the other is farm endowment variables. Output Y is the total income (in RMB) from farming during a year, including from both main grain crops and other cash crops. Input K is the quantity of material costs which mainly includes costs of machinery/animal operations, seed, chemical fertilizer, manure, agricultural plastic film, farm chemicals, irrigation, fuels and energy, cost of small farm tools and total depreciation on the fixed asset. Input variable L is the total work days that the rural farm put into the crop farming during a year. Input M is the total sown areas that farmers have planted, considering the factor of multiple cropping or replanting in a year. Compared to the variable of farmland areas, the total sown areas the farmers have planted can reflect human efficiency in the utilization degree of farmland resources. OP is the cultivated areas of a farm which is the actual land areas the farmer has put into use (or has contracted) during a year. Because of the factors of multiple cropping, the OP (actual farmland area) and M (land input) are different. In most times, the M is bigger than OP. The farm endowment variables include education, land fragmentation (average land area per plot), non-agricultural employment variable (share of farm's non-agricultural income within its total income), market participation (share of total amount of sale within total output), and three dummy variables to include informal education or training, family background (1 = one of the farm members is a local cadre, 0 = none), credit availability (1 = the farm ever obtained the loan in that year, 0 = none). Education is calculated as the average year of education by each farm labor as follows:

$$Education = \sum(0 \times H_0 + 6 \times H_1 + 9 \times H_2 + 12 \times H_3)/Farmlabor \qquad (13)$$

H_j represents the number of labors at different educational levels in each farm. j = 0, 1, 2, 3 denotes illiterate and semiliterate, primary school, junior school, senior high school and higher education levels, respectively. The *Farmlabor* represents the number of farm's labor force who engaged in agricultural activities. The Table I below provides summary statistics for all variables used in the econometric analysis.

4. Empirical results and discussions

We used OLS with two-way fixed effect model (TWFE) of panel data (OLS-FE) for the estimation of farm's production efficiency, farm size and each farm endowment variables. One-step method of stochastic frontier approach (SFA, Battese and Coelli, 1995) was used to estimate farm TE. While there are many models to estimate the TE and its determinants, such as two-stage data envelopment analysis (DEA-Tobit analysis) and other SFA two-stage approaches[1], the model developed by Battese and Coelli (1995) is a classical model, which can resolve "bias" due to the omission of relevant variables in the first stage of frontier estimation during the two-stage procedure. Furthermore, the Battese and Coelli (1995) model can be simultaneously estimated by the method of ML, which has desirable large-sample (or asymptotic) properties. First, the method of ML is preferred because other estimates such as OLS cannot be used to compute a farm's TE. The estimated "intercept" coefficient obtained from the OLS is "biased downwards", even though the estimated "slope" coefficients are consistent. Second, the ML estimator is asymptotically more efficient than the OLS estimator (Coelli *et al.*, 2005). In the end, the ML estimator is consistent and asymptotically efficient (Coelli *et al.*, 2005;

Variable	Max.	Min.	Mean	Var.	SD
Y (yuan, in RMB)	15,295.4382	55.0000	2,733.5394	4,599,728.4451	2,144.6978
K (yuan, in RMB)	3,575.5891	20.0000	700.5102	330,272.9313	574.6938
L (days)	1,149.0000	10.0000	210.4323	15,911.2134	126.1397
M (μ)	29.0000	0.2000	6.8872	21.6969	4.6580
OP (μ)	100.0000	0.3000	5.6441	59.6957	7.7263
Education (years per farm-labor)	12.0000	0.0000	6.6783	5.9016	2.4293
Land fragmentation (μ per plot)	25.0000	0.1333	1.2329	3.6062	1.8990
Non-agricultural employment (non-agricultural income/total income)	0.9752	0.0000	0.4088	0.0792	0.2813
Market-participation (amount of selling output/total output)	16.9365	0.0000	0.4595	0.3562	0.5968
Technical training (dummy variable)	1.0000	0.0000	0.0970	0.0876	0.2960
Family background (dummy variable)	1.0000	0.0000	0.1118	0.0994	0.3152
Credit availability (dummy variable)	1.0000	0.0000	0.0292	0.0284	0.1685
Farm-labor (persons)	6.0000	0.0000	2.6900	1.1434	1.0693

Note: n = 2,155
Source: The 15 fixed observation villages (managed by Ministry of Agriculture of China) in Hubei province during the years of 1999-2003; A μ is one 15th of a hectare

Table I.
Summary statistics of the sample households

Wooldridge, 2006). So the three-step ML method (Quasi-Newton methods) in the only software package of Frontier 4.1 (Coelli, 1996) was used to estimate equations (7)-(9).

At the same time, geographic dummy variable D at village level is also introduced to control the impacts of factors that cannot be measured and reflected explicitly in different locations (at village level). In addition, rural consumer price index (CPI) and agricultural means of production price index (PPI) in Hubei province were applied to convert variables Y and K into the constant values at the baseline year of 1999. Table II is the estimation results of equation (2), using various agricultural efficiency definitions.

4.1 Farm size and land productivity

The land productivity ($Efficiency^1$) is measured in value per unit area, namely $Efficiency^1 = Y/OP$. The estimation results are shown in the second column of Table II. The coefficient (−235.46) is negative and statistically significant. Indeed, there exists an IR between farm size and its production efficiency measured in the land productivity. The land productivity of value per unit area, for small farm is much higher than that of bigger farm. Chinese agriculture, which is dominated by smallholders, fits into traditional agriculture described by Sen (1966).

From the perspective of land productivity efficiency, our results show that farms with smaller land holdings do enjoy an efficiency comparative advantage. After the HRS, the farm size becomes smaller and so enjoys an advantage in efficiency in land productivity, comparing to the period before HRS. Even under the current HRS, the small farm seems more efficient in land productivity. If the policy goal is to ensure land

Table II. The estimations of farm size, efficiency and farm endowments

	$Efficiency^1$	$Efficiency^2$	$Efficiency^3$	$Efficiency^4$	$Efficiency^5$
C	985.478***	16.164***	698.044***	−0.104	3.499***
	(46.147)	(1.406)	(84.166)	(0.065)	(0.518)
ln (OP)	−235.463***	2.251***	483.128***	0.136***	0.117
	(24.812)	(0.756)	(45.232)	(0.035)	(0.279)
Education	6.391	−0.440***	14.837*	0.001	0.071
	(4.807)	(0.147)	(8.769)	(0.007)	(0.054)
Technical training	105.195***	2.457**	102.065*	0.235***	2.228***
	(34.822)	(1.061)	(63.477)	(0.049)	(0.391)
Family background	−32.874	−0.266	−87.031	−0.0002	0.246
	(41.524)	(1.266)	(75.695)	(0.059)	(0.466)
Land fragmentation	−12.061**	−0.631***	−137.392***	−0.042***	−0.124*
	(6.082)	(0.185)	(11.088)	(0.009)	(0.068)
Non-agricultural employment	−203.272***	−2.198*	−425.594***	−0.163***	−0.892**
	(37.680)	(1.148)	(68.696)	(0.053)	(0.423)
Market-participation	−51.480***	−0.782*	−80.694***	−0.063***	−0.586***
	(13.296)	(0.405)	(24.238)	(0.019)	(0.149)
Credit availability	−44.794	0.481	27.897	−0.011	0.720
	(47.941)	(1.461)	(87.393)	(0.068)	(0.538)
Log-likelihood	−15,097.80	−7,575.20	−16,384.01	−957.95	−5,422.61
Adjusted-R^2	0.437	0.401	0.656	0.465	0.267
F-statistic	4.778***	4.259***	10.279***	5.227***	2.779***

Notes: Coefficients are statistically significant at: *10, **5 and ***1 percent levels; the numbers within the parentheses are standard errors productivity and food security, the small land size under HRS is both efficient and rationale, and we do not need to promote land transfer to create large-scale farming.

4.2 Farm size and labor productivity

Ensuring the food security by raising land productivity is always the first priority of Chinese agricultural policy. However, with rapid urbanization and rising labor costs, agricultural labor productivity becomes more and more important in China. We construct two labor productivity indicators. One is the labor productivity based on the farm's actual working days of the labor input which is defined as $Efficiency^2 = Y/L$. The other is the labor productivity based on the number of farm's labor force who engaged in agricultural activities ($Efficiency^3$), which is defined as $Efficiency^3 = Y/Farmlabor$. Columns 3 and 4 in Table II show the estimated results of equation (2). As we can see, there exist a statistically significant positive relationship (PR) between the farm's efficiency measured by the labor productivity and its land size, no mater which labor productivity indicators are used. The coefficient for $Efficiency^3$ (based on labor days, 483.13) is much higher than that of $Efficiency^2$ (based on farm labor, 2.25).

The big farm has the advantage of per capita output due to its higher labor productivity and even larger land per capita. If our policy were to improve farmers' income and to reduce surplus rural labor, a case could be made to create larger farms by promoting land transfer and voluntary subcontracting. In fact, the PR between farm's labor productivity and land size provides empirical evidence for the explanation of IR between the land productivity and land size. The small farm put more laborers in per unit land, so it is more labor intensive. In the absence of non-agricultural employment opportunities and their lower opportunity cost of labor, small farms tend to use more family labor to compensate their lack of capital and land. Therefore, intensive cultivation (so higher land use intensity) but lower labor productivity is common for smaller farms. In contrast, bigger farms tend to use more capital such as agricultural machinery and land to compensate the high monitoring and information cost of labor. Therefore, their land productivity is lower than those of smaller farms, but the labor productivity is higher.

4.3 Farm size and profit ratio

Schultz (1964) showed that farmers, like other economic entities with their own objective function and specific constraints, have achieved the most efficient resource allocation under their own constraints. This is the assumption of "poor but efficient". This assumption adds profit maximization behavior to farmers who would respond to changes in market prices. This section examines whether the small farms and big farms are different in profit maximization. Due to the co-existence of IR (farm size and land productivity) and PR (farm size and labor productivity), we constructed two indicators of profit ratio. One indicator is the profit rate including farm's labor input cost, which is defined as:

$$Efficiency^4 = (Y - K - L \times P_L)/(K + L \times P_L) \tag{14}$$

where P_L is the price of labor (average labor cost per day in rural areas of Hubei province). The other is the profit rate without including labor cost which is defined as:

$$Efficiency^5 = (Y - K)/K \tag{15}$$

If labor cost is included in profit ratio (*Efficiency* ^{4}), the great majority of farms have negative profit rate. That is to say, from the perspective of complete cost accounting, most farms are profitless in crop production or even struggle on the brink of bankruptcy. By contrast, farm's profit rate is basically positive if labor cost is not included (*Efficiency* ^{5}). This means that farmers are profitable when they take no account of labor cost. Columns 5 and 6 in Table II show the results. The results are very different between *Efficiency* ^{4} and *Efficiency* ^{5}. The β coefficient between farm size and *Efficiency* ^{4} is small (0.136) but statistically significant. This indicates that the larger farm may enjoy a higher profit. However, the β coefficient for *Efficiency* ^{5} is not statistically significant. This shows that farm size does not matter if the profit ratio does not include the labor cost. The different conclusion on the relationship between farm size and profit ratio, with or without labor cost, is very interesting. According the definition of the price of labor (P_L) in the paper, both small and big farms face the same labor price but bigger farms have significantly higher profit ratios. By excluding the labor cost, there is no difference in cost-benefit efficiency between big and small farms. However, if the labor cost is fully accounted for, smaller farms' profit ratio is much lower, and even negative. This means that small farms are "self-exploiting", ignoring their own labor cost in agricultural production. They overuse their own labor to compensate for the lack of such inputs as capital and land, forming the so-called "Involution" of labor (Huang, 1990).

4.4 Farm size and TFP

SFP indicators as defined in the above can only reflect the effect of a single factor on output. Because multiple input factors are needed in agriculture production, the factors may substitute each other due to their different scarcity levels. In particular, the farms usually respond to price changes in the factor market. That the smaller farms overuse their own labor to compensate their lack of capital and land is just one example. The TFP indicator can fully reflect the comprehensive use of different inputs during the process of production. TFP is defined as the ratio of total output to total input. As described in Section 2, we first estimated the output elasticity of each factor in farm's production function (equation (3) or (4)), and then calculated the TFP from equation (5). Finally, equation (6) is estimated to examine the relationship between farm size and the TFP. Results are shown in Table III.

As shown in Column 2 in Table III, the output elasticity of the land is the largest (0.552), followed by the output elasticity of capital (0.299). The smallest one is the output elasticity of labor (0.106). The statistically significant η value (0.024) indicates the technological progress over time in Hubei agriculture. The results are consistent with the general characteristics of Chinese agriculture: land is the scarcest factor, and capital plays an important role (Wu *et al.*, 2005), but labor is the most abundant factor and its output elasticity is the smallest. From the coefficient of RTS, Wald test shows that the hypothesis $RTS = 1$ cannot be rejected. This indicates agriculture in China to be constant RTS as demonstrated in the previous literature, such as Lin (1992). Column 4 of Table III shows the estimation results of the relationship between the farm's TFP and land size, controlled by farm endowments. Although there may be IR between farm's TFP and land size as indicated by negative value of β (-1.776), the value is not statistically significant. So we conclude the farm's TFP is basically uncorrelated with land size. That is, there is no

Production function estimation	Estimated results	TFP explanatory variables	Estimated results
$\ln A_0$	4.173***	C	72.903***
	(0.157)		(3.812)
α_K	0.299***	ln (OP)	−1.776
	(0.021)		(2.049)
α_L	0.106***	Education	0.614
	(0.024)		(0.397)
α_M	0.552***	Technical training	18.504***
	(0.032)		(2.876)
η	0.024***	Family background	−1.073
	(0.006)		(3.430)
$RTS = \alpha_K + \alpha_L + \alpha_M$	0.957	Land fragmentation	−0.953*
			(0.502)
Wald test	2.004	Non-agricultural employment	−12.444***
(H_0: $RTS = 1$)	Cannot reject		(3.112)
α_K^*	0.312	Market-participation	−7.664***
			(1.098)
α_L^*	0.111	Credit availability	−4.921
			(3.960)
α_M^*	0.576		
Log-likelihood	−830.486	Log-likelihood	−9,723.653
Adjusted-R^2	0.826	Adjusted-R^2	0.256
F-statistic	24.513***	F-statistic	2.679***

Notes: Coefficients are statistically significant at: *10, **5 and ***1 percent levels; the numbers within the parentheses are standard errors

Table III. The estimation of TFP, farm size and farm endowments

significant production efficiency difference in comprehensively use of land, labor and capital resources between small and big farms from the angle of TFP.

4.5 Farm size and TE

The TE indicator reflects the extent of the agricultural technology application and diffusion, and is one of the most commonly used indicators to measure agricultural efficiency. As shown in Section 2, one-step method and equations (7)-(9) are used to estimate the relationship between farm's TE and land size. Table IV shows the estimation results.

Even though we used a different method (SFA) to estimate the production function here, the estimated coefficients are very close to those in Table III. This is clearly shown in Column 2 of both Tables III and IV. In both tables, the land elasticity (0.634) is the largest and labor elasticity the smallest. The RTS, which is the sum of these three elasticities, is close to 1 (1.004 to be exact), shows constant RTS. Such similarity also shows that our production function estimation is robust. However, the high weight of technical inefficiency γ ($\gamma = 0.966$) shows a relative large contribution from technical inefficiency to the overall variance. In this sense, SFA model is better than the average production function estimation.

The β coefficient in Table IV is 0.018 and not statistically significant. This indicates that the farm's TE is basically uncorrelated with the land size. In another word, there is no significant difference in the use of agricultural technology and the achievement of

Table IV. Stochastic frontier production function estimation and results of TE, farm size and farm endowments

Frontier production function	Coefficient of estimation	*t*-test value	Technical inefficiency function	Coefficient of estimation	*t*-test value
$\ln A_0$	3.995*** (0.141)	28.264	*C*	− 7.227*** (0.892)	− 8.102
α_K	0.263*** (0.015)	17.132	ln (*OP*)	0.018 (0.133)	0.138
α_L	0.107*** (0.018)	6.032	Education	− 0.345*** (0.034)	− 10.068
α_M	0.634*** (0.022)	29.151	Technical training	− 2.437*** (0.515)	− 4.735
η	0.037*** (0.005)	7.636	Family background	0.772*** (0.139)	5.559
σ^2	2.769*** (0.345)	8.026	Land fragmentation	0.034* (0.023)	1.493
γ	0.966*** (0.005)	188.906	Non-agricultural employment	0.169 (0.204)	0.828
TE	0.786		Market-participation	0.662*** (0.087)	7.583
Log-likelihood	− 1,109.321				
LR test	354.540		Credit availability	− 0.539* (0.416)	− 1.295

Notes: Coefficients are statistically significant at: *10, **5 and ***1 percent levels; the numbers within the parentheses are standard errors; LR test assumes an asymptotical χ^2 or mixed χ^2 distribution; as we estimated a technical inefficiency function, the negative sign of a coefficient in the above table means positive effect of that variable on TE, and positive sign means negative effect

the maximum potential output capacity between the big and small farms. Similar conclusions appeared in the previous literature, such as Khanana (2001). In general, agricultural machinery technology tends to substitute labor and favors larger farms. But just as Ellis (1993) pointed out, the net welfare effect of such technology is more of factor substitution effect rather than productivity growth effect. On the other hand, agricultural biological technology such as breeding is input-intensive and scale-neutral. Its net welfare effect is more of productivity growth effect rather than factor substitution effect. Agro-chemical technological progress such as the use of chemical fertilizer tends to improve land productivity, without specific requirements on the land size, and so it is also scale-neutral. Taking it as a whole, Hayami and Ruttan (1985) showed that the modern agricultural technology mostly tends to scale-neutral, and the scale variable is not an efficient variable in the decision making of farmers. The empirical evidences by Khanana (2001) also demonstrated there is no significant relationship between agricultural technical diffusion and land size, but the adoption and diffusion of the complex agricultural technology (such as agricultural machinery) have significant positive correlation with farm's land size.

5. Discussion and conclusions

Using the farm-level panel data from Hubei province in 1999-2003, the paper investigated the relationship between farm's agricultural production efficiency and its land size. Considering that previous studies used land productivity as the only agricultural production efficiency indicator, the current paper is more comprehensive in expanding production efficiency indicators to land productivity, labor productivity, profit ratio, TFP and TE. Our study confirmed the IR between land productivity and farm size as in many formal studies. However, the relationship between farm size and agricultural efficiency may be positive, negative or uncorrelated at all, depending on how we defined the farm efficiency. Also, different agricultural efficiency indicator has different policy implications for China's future agricultural and land policy. However, the farm-level panel data used in our paper is just from one province in China. Agricultural technology, climate, and sometimes even institutions could vary drastically from one province to another in China. So any extension in policy implications to other regions, especially the eastern coastal regions in China should be with caution.

Our basic conclusions can be summarized as follows. Farm size and agricultural efficiency defined in land productivity has a strong IR. On the contrary, farm size and agricultural efficiency defined in labor productivity has significant PR. Similarly, profit ratio with labor cost shows significant PR with farm size. But the profit ratio without labor cost, as family labor is usually not counted in the agricultural production, shows no significant relationship with farm size. Furthermore, if we define farm efficiency using more comprehensive TFP or the TE, farm size and agricultural efficiency demonstrate no significant relationship. Due to the scare non-agricultural employment opportunity and dual segmented factor market in China, smallholder farmers has "self-exploitation" tendency to use more labor per acre by ignoring their own labor cost. Smallholders use their own low labor cost to compensate their lack of land or capital and generate higher yields. This is the reason behind the co-existence of an IR between farm size and land productivity and a PR between farm size and labor productivity. It is one of the characteristics of labor intensive, smallholder agriculture in China. Furthermore, there is no significant efficiency difference in comprehensive use of land, labor and capital resources (TFP) between small and big farms. This is consistent with the Chayanov's "self-exploitation" hypothesis. The different conclusion on the relationship between farm size and profit ratio, with or without labor cost confirms the above hypothesis.

Our findings have tremendous policy implications, in particular in terms of the current debate on large or small farm development strategy, the so-called "go big or small" agricultural strategy. Indeed, small farms are more efficient than their larger counterparts, and enjoy comparative advantages in land productivity. Because of the China's agricultural resource endowment of vast farm labors and less farmland presently, the small farm size favors the goal of food security in terms of producing more. In this sense, the household contract responsibility system (HRS), which produced the smallholder farming in China, is efficient and remains an effective institutional arrangement. So the land redistribution to break up large farms may be proposed, or the effort to promote consolidation should not be pursued at present. On one hand, agricultural land is increasingly under the pressure from rapid urbanization recently. On the other hand, agriculture is tasked to provide enough and more diverse food for an increasing population. So further stabilizing and improving HRS, in particular safeguarding farmers' rights of land contract should become a policy objective, especially for the rural area where non-farm economic opportunities are still rare.

However, larger farms have higher labor productivity and higher profit ratio (including labor cost). In terms of increasing farmers' income, and the rising wages recently, there is an argument to be made to increase the farm size by encouraging voluntary land transfer/exchange through land rental markets. A rapidly growing

Chinese non-farm economy has attracted large numbers of rural labor into the major cities. This has indeed provided opportunities for land consolidation and for reducing land fragmentation, especially in Chinese southeastern coastal regions. It is possible for some farmers in these areas to take in more land which can exploit the scale economies of modern agricultural technologies. So some forms of land reform like land consolidation or redistribution to form large farms could first be experimented in Chinese coastal regions where agriculture is less and less attractive because of the abundant opportunities from non-agricultural employment. The current study showed that improving farm's production efficiency should not a reason for the "go big or small" strategy. Farm efficiency and farm size has either positive, negative, or even neutral correlations, depending on the definition of farm efficiency. The more comprehensive farm efficiency, using TFP or TE, is uncorrelated with farm size. In other words, both small and large farms could be efficient in comprehensive use of land, labor and capital resources and make good use of the new farming technologies. Land tenure is a complex issue and farm efficiency is just one of the many factors we need to consider in further reform of the Chinese HRS. The HRS played a critical role in Chinese agricultural reform and continues to play a critical role in terms of social security and social equality. Any reform to this system should proceed with caution.

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Note

1. The stochastic production function frontier and the inefficiency-effects model are estimated in two steps separately.

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