Technical Efficiency of Chinese Grain Production:

A Stochastic Production Frontier Approach

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Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 27-30, 2003

TECHNICAL EFFICIENCY OF CHINESE GRAIN PRODUCTION: A STOCHASTIC PRODUCTION FRONTIER APPROACH

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Abstract: This article examines technical efficiency of the Chinese grain sector using the framework of stochastic production frontier. The results reveal that: the marginal products of labor and fertilizer are much smaller than that of land; human capital and farm-level specialization have positive effect on efficiency, land fragmentation is detrimental to efficiency, and elder farmers are as efficient as younger farmers. We also examine the effects of size, mechanization and geographic location. Simulation results show that significant output gains can be obtained by eliminating land fragmentation, improving rural education and promoting specialization and mechanization.

***Key words*:** Technical Efficiency, Chinese Grain Production, Stochastic Production Frontier, Land Fragmentation

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The paper was benefited by comments of Dr. Quinn Weinger, Dr. Kenneth Koehler and participants at Labor and Human Resource Workshop of Department of Economics, Iowa State University. The usual disclaimer applies.

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Introduction

As the world's largest food supplier and consumer, China's Agriculture sector always draws extensive attention. Brown (1995) argued that China has exploited obvious resources of added agriculture production. However, some researchers have been more optimistic e.g. Lin (1995) and Huang, Rozelle, and Rosegrant (1995). Wan and Cheng (2001) found that simply by eliminating land fragmentation the grain production of China would rise by 71.4 million metric tons, which is no less than 3.9 percent of current output for the crops considered in their paper. Abdulai and Huffman (2000) summarized results of several agricultural efficiency studies. Wang, Wailes, and Cramer (1995) showed that much higher average profit inefficiency exists for Chinese Agriculture than those for other countries. Mao and Koo (1997) decomposed the production inefficiency of Chinese Agriculture over 1984-1996 and concluded that the deterioration in technical efficiency in many provinces indicates China has the potential to increase productivity through improving technical efficiency. Evenson and Gollin (2002) show that considerable yield potential resides in Green Revolution crop varieties and elite lines.

This article estimates a stochastic production frontier based on a rural household level panel dataset and tries to identify the sources of inefficiency in Chinese grain production. To our knowledge, no other study exists that applies stochastic production frontier model to household-level data for Chinese grain sector[1]. The paper is organized as following: section 2 reviews studies on Chinese agriculture with a focus on the grain production; section 3 goes over literature on technical efficiency and establishes the stochastic production frontier model; section 4 describes the data set and section 5 presents the results. Section 6 summarizes the conclusions.

[1] Tian and Wan (2000) applied similar model but based their analysis on the national and provincial averages.

Literature Review on Chinese Agriculture

Development of Chinese Agriculture Production

The productivity of Chinese agriculture was improved significant in early 1950s. Studies by Chinn (1977; 1980) credited it to collectivization for having eliminated the land fragmentation and thus the scale diseconomies.

However, Chinese grain production had endured two decades of stagnation after 1958. Lin (1990) argued that the plunge of agricultural output was mostly due to the policy enforcing participation in the commune system.

After the political change in the late 1970s, the household-based farming system, under which households acquire the right to use the farmland and in return contribute a part of their output (a quota) to the state authorities, was permitted or even promoted. Lin (1987) attributed 20 percent of the productivity growth to the institutional change result in/from eliminating "shirking" behavior in the collective farming. De Brauw, Huang, and Rozelle (2001) found that incentive reforms generated large increases in output and productivity. They stressed that the gains from market liberalization occurred after incentive reform had already occurred.

We end this section with a quote of Lin (1988): "In short, the shift of institutions in Chinese agriculture was not carried out by any individual's willingness but evolved spontaneously in response to underlying economic forces."

Production Function Studies

Marginal Effects

For Chinese agriculture, land is scarce while labor is more abundant. Intuitively, it suggests that the marginal product of land is high while that of labor is low according to Sen (1960). He claimed that in developing countries the marginal product of labor use is likely to be very low—near zero. Wan and Cheng (2001) obtained negative labor elasticities and land elasticity close to unity.

Xu (1999) suggested that the role of industrial inputs in Chinese agricultural production may have been underestimated and most of the gain in total factor productivity is attributable to the evolving mix of agricultural inputs but the contribution of institutional change may have been overestimated.

Widawsky et al. (1998) found that under intensive rice production systems in eastern China, pesticide productivity is low compared to the productivity of host-plant resistance. Their regression results showed that the marginal product of pesticide use was negative. Hence they concluded that pesticides might be overused in eastern China and suggested host-plant resistance as an effective substitute.

Scale Economies

Chinn (1977) found prewar Chinese Agriculture could explore scale economy. After reforms, as a footnote by Lin (1988), China needed to take advantage of scale economies. However, they were overlooked because re-collectivization was deemed to be the sole means of exploiting scale economies. Lin (1988) expressed his concern that the gain from scale economies might be outweighed by additional monitoring cost.

Although 1950s Chinese Agriculture technology and mechanism were not suitable for large-scale production, the small land plots nowadays may be a constraint to apply modern agricultural technologies. Applying a shadow-price profit frontier model, Wang, Cramer, and Wailes (1996) obtained a positive and significant coefficient for the dummy of large farms in the profit efficiency estimation. Yang (1996) found the average plot size has a significant positive effect on productivity.

Wan and Cheng (2001) concluded that no significant scale economies existed, which may be subject to doubt. Argument for eliminating land fragmentation such as saving the land lost in forming plot boundaries and access routes, reduce the waste of input, can also be applied on the enlargement of farm size. The real land elasticities may be higher than their estimates due to the heterogeneity of land.

Huffman and Evenson (2001) have more on the defining and effect of farm size. They use output as the measure of size and concluded that a larger farm size increases crop sub-sector specialization; farm size and specialization have significant effects on farmers' off-farm work participation rate.

Regional Disparities

Yang (1996) found that for respective crops, the level of factor productivities is generally higher in the major producing areas than that in the fringe areas due partly to more suitable natural conditions and more specialized skills.

Research and public investment

Findlay (1997) suggests that the following changes are important for Chinese grain production: the extent of public investment in infrastructure and R&D, the design of the extension system and the long run development of farmer education policy.

Fan (2000) included in his model a stock-of-knowledge variable constructed from the past research investment. His results show that the rate of return to research investment are high and increasing over time, ranging from 36% to 90% in 1997.

Determinants of Efficiency

Many factors can potentially affect efficiency in agriculture. An individual's education affects his/her ability to allocate inputs efficiently. Whether households can respond to the market efficiently depends on how information systems work. Abdulai and Huffman (2000) considered non-farm employment, education, credit availability, age of household head, rice share of total area, distance to market, and regional dummies as explanatory variables for profit inefficiencies.

The potential explanatory variables for Chinese agricultural production inefficiencies are discussed in the followings.

Human Capital: Education

Wang, Cramer, and Wailes (1996) suggested that Chinese farmers who have higher education are more efficient than those with lower education, which can be explained by the allocative efficiency in Huffman (1977). Yang (1997b) found that the highest education level among household members gave better fit than the household head's education or household members' average education. Yang (1997a) also concluded that schooling does not enhance labor productivity when carrying out routine farm tasks. Cheng (1998) found that the effect of household head's education on grain output is significant positive.

Village office position

Cheng (1998) incorporated a "village official position" indicator into the production function for grain output and found the effects are significant positive. He argued that it is more likely to be caused by the collective ownership of some large farm equipment and privileged access to state subsidized farm inputs.

Input and Output Market

The education level of rural labor force might be correlated with the extent of openness of agricultural product market. While the Chinese government imperatively lowered the prices of major agricultural products to guarantee the development of heavy industry in 1950s, they created a large distortion in the farming sector. The lower price caused large out-migration from farming. Most of the better-educated rural population managed to leave the farms, either taking a job in urban areas or an off-farm job in their home area. A free market of agricultural products may provide farmers higher output prices and thus higher profit. A consequence of the high reward to farming would be some educated labor moving back into agriculture. Although Chinese agricultural product markets are close to free market after the reforms, the extent has been fluctuating. The Chinese rural labor market, however, remains distorted. Wang and Zhou (2001) and Tian and Wan (2000) noted that the rural labor force remains largely undereducated. China's access to WTO will likely free the agricultural market in a more profound way. Although a loss of welfare in the short-run seems unavoidable for Chinese Agriculture, the improvement in the labor force and better access to technology and credit markets will definitely bring Chinese Agriculture long-run benefits.

Tenure System

Mao and Koo (1997) suggested that the agricultural growth in China might have depleted the potential contributions of institutional innovations in 1979-1984. A new land tenure institution innovation will be beneficial to Chinese Agriculture. Many researchers argued that the privatization would provide farmers stronger incentives to make long run investments in land. Li, Rozelle, and Brandt (1998), however, pointed out that land privatization for China at this time may have a high cost to society, given there is no institutions such as land courts, land registration system, or credit markets.

Lohmar, Zhang, and Somwaru (2002) found that the land rental activity intensity differs according the region though it is wide spread in China and concluded that land rental activity increases aggregate agricultural production by transferring land from low intensity farm households to those willing to farm the land more intensively.

Model Specification

Conceptual Previews

Technical Efficiency

Technical efficiency is defined as the ability to minimize input use while maintaining a given output level, or the ability to maximize output production while fixing the amount of input use. Koopmans (1951) provided a formal definition.

Definition 3.1: An output-input vector $(y,x) \in \{(y,x): x \text{ can produce } y\}$ is technically efficient if, and only if, $(y',x') \notin \{(y,x): x \text{ can produce } y\}$ for $(y',-x')$ $\geq (y,-x)$.

We have two different ways to measure technical efficiency, output-oriented and input-oriented, which are given below.

Definition 3.2: An output-oriented measure of technical efficiency is a function $TE_o(y,x) = [\max\{\phi : \phi y \in \{y : x \text{ can produce } y\}\}]^{-1}$

Definition 3.3: An input-oriented measure of technical efficiency is a function $TE_I(y,x) = \min\{\theta : \theta x \in \{x : x \text{ can produce } y\}\}$

The two measures agree if and only if the technology is constant return to scale. This article uses the output-oriented measure due to its popularity in empirical works.

The existence of technical inefficiency has been subjected to heated debate. While Koopmans (1951) clarified the concept and Farrell (1957) provided empirical application, Stigler (1976) and Muller (1974) observed that measured technical inefficiency might be the result of model misspecification.

Although obtaining an exact model of technical efficiency for empirical work is nearly impossible, we cannot incorporate all information into a model with reasonable complexity. However, a technical efficiency index can be constructed, and it can be explained by a set of explanatory variables, either by a two-stage procedure or integrated one-step estimation.

Stochastic Frontier Production Function

Two approaches, parametric and non-parametric, exist for estimating a model of technical efficiency. The non-parametric approach applies the method of linear programming, i.e., DEA method. A parametric approach involves estimation of a frontier model, which is referred to as stochastic production frontier (SPF) model. The major difference of SPF model and DEA method is the way they treat the random disturbance. SPF incorporated the random noise. Therefore it is more robust to measurement error and other disturbances. However, it is less robust to model misspecification and endogeneity.

In this article, we pursue the parametric approach. Grain production is subject to weather disturbances and land quality composition, which may affect efficiency. Our data set is recorded by different local accountants thus it is subject to serious measurement error problem.

The origin of stochastic frontier production function dates back to Meeusen and van den Broeck (1977), Aigner, Lovell, and Schmidt (1977), and Battese and Corra (1977). Their model can be summarized as: $y = f(x;\beta)\cdot\exp\{v-u\}$ where y is scalar output, x is a vector of inputs and β is a vector of technology parameters. Jondow et al. (1982) extended this model and obtained producer-specific estimates of efficiency. Greene (1980a; 1980b), Stevenson (1980), and Lee (1983) proposed various distributions for the error term while the normal-half normal distribution specification gradually gained popularity in the empirical works.

Cross section and panel data have been used in fitting stochastic frontier production functions, e.g., see Hoch (1962) and Mundlak (1961). While most early attempts assumed time invariant technical efficiency, Cornwell, Schmidt, and Sickles (1990), Kumbhakar (1990), and Battese and Coelli (1992) relaxed this assumption. Battese and Coelli (1992) estimated the production frontier while assuming the firm effects follow an exponential function in time. This article adopts the model of Battese and Coelli (1995) since our data set has a relatively short time span. We explore the model in detail in the following sections.

Explaining Technical Efficiency

Kumbhakar and Lovell (2000 p263) summarized three approaches for incorporating exogenous influences on inefficiency. The first approach is to incorporate the exogenous variables into the production frontier directly, which can be written as: $\ln y_i = \ln f(x_i, z_i; \beta) + v_i - u_i, \quad i = 1, \cdots, I,$ where i indexes producers; x_is are the input usage and z_is are the exogenous variables to explain the inefficiency indexes. v_is are random variables and are assumed to be *iid* $N(0,\sigma_v^2)$. They capture the effect of random noise on the production process; u_i is assumed to be greater than zero to capture the effect of technical inefficiency. This approach cannot distinguish the influence of exogenous variables on the production frontier from the influence of those variables on technical inefficiency.

The second approach is to regress the technical efficiency indexes on firm-specific explanatory variables after the estimation of the production frontier. This approach is usually referred to as two-stage approach, and it has been considered to be a useful exercise. However, as Kumbhakar and Lovell (2000) and Coelli (1996) pointed out, the two-stage estimation procedure has been recognized as inconsistent in its assumptions regarding the independence of the inefficiency effects in the two estimation stages. It requires that the variables used to explain inefficiency must be uncorrelated with the exogenous variables in production frontier functions, which seems unlikely in most cases. Coelli (1996) claimed that two-stage estimation is less efficient than single-stage estimation procedure.

The third is developed by Desprins and Simar (1989). It can be expressed as: $\ln y_i = \ln f(x_i; \beta) - u_i,\ E(u_i \mid z_i) = \exp\{\gamma' z_i\}$ where β and γ are technology and environment parameter vectors to be estimated, u_i is the technical efficiency, and x_i and z_i are as defined before. This approach fixes the problem in the first approach and the two-stage procedure, respectively, while failed to incorporate the random disturbance.

Battese and Coelli (1995) may be viewed as presenting a fourth approach. They propose a model that is equivalent to the Kumbhakar, Ghosh, and Mcguckin (1991) specification. We follow their model in our study.

Empirical Model:

Battese and Coelli (1992) applied a stochastic frontier model to an unbalanced panel data set. The model assumes firm effects to be distributed as truncated normal random variables, which are also permitted to vary systematically with time. Battese and Coelli (1995) extended the model by incorporating exogenous variable to explain the inefficiency. Their model may be expressed as: $Y_{it} = x_{it}\beta + (V_{it} - U_{it})$, i=1,...,N, t=1,...,T, where: Y_{it} is the natural logarithm of the output of the i-th farm in the t-th time period;

x_{it} is a k×1 vector of the natural logarithm of the input quantities of i-th firm in t-th time period;

β is the coefficient vector of the regressors;

V_{it} are random variables which are assumed to be *iid* $N(0,\sigma_v^2)$. They are incorporated to reflect the random disturbances that are independent of the U_{it}.

U_{it} are non-negative random variables assumed to account for technical inefficiency in production. They are assumed to be independently distributed as truncations at zero of the $N(m_{it},\sigma_u^2)$ distribution or more widely used notation of $N^+(m_{it},\sigma_u^2)$, where: $m_{it} = z_{it}\,\delta$. We have the relationship of U_{it} and the output-oriented technical efficiency TE_o as $TE^{it}{}_o = \exp(-U_{it})$.

z_{it} is a p×1 vector of variables which may influence farm-level efficiency; and δ is an 1×p parameter vector to be estimated.

By the virtue of maximum likelihood estimation, we can use the re-parameterization of Battese and Corra (1977), replacing σ_v^2 and σ_u^2 with $\sigma^2=\sigma_v^2+\sigma_u^2$ and $\gamma=\sigma_u^2/(\sigma_v^2+\sigma_u^2)$. Battese and Coelli (1993) presented the log-likelihood function of this model as:

$$L^*(\beta,\delta,\sigma_V^2,\sigma_U^2;y) = -\tfrac{1}{2}\Big(\sum_{i=1}^{N} T_i\Big)\ln(2\pi\sigma^2) - \tfrac{1}{2}\sum_{i=1}^{N}\sum_{t=1}^{T_i}\frac{(y_{it}-x_{it}\beta+z_{it}\delta)^2}{\sigma^2} - \sum_{i=1}^{N}\sum_{t=1}^{T_i}\ln\frac{\Phi(d_{it})}{\Phi(d_{it}^*)},$$

where, $d_{it} = z_{it}\delta/(\gamma\sigma^2)^{1/2}$, $d_{it}^* = \mu_{it}^*/(\gamma(1-\gamma)\sigma^2)^{1/2}$, $\mu_{it}^* = (1-\gamma)z_{it}\delta - \gamma(y_{it} - x_{it}\beta)$

Guilkey, Lovell, and Sickles (1983) compared the three functional forms for the production frontier: the translog, the generalized Leontief, and the generalized Cobb-Douglas. They found that the translog form provides a dependable approximation to reality provided that reality is not too complex. The translog form is also more flexible in incorporating substitution effects among inputs. Thus, we use the translog specification in this study.

Model 1: $$\ln(Y_{it}) = \beta_0 + \sum_{l=1}^{4} d_{(year)l} + \sum_{j=1}^{4} \beta_j \ln(x_{ijt}) + \sum_{j \le k}^{4} \sum_{k=1}^{4} \beta_{jk} \ln(x_{ijt}) \ln(x_{ikt}) + V_{it} - U_{it},$$

where the subscript i indicates the household; t for the time, and j, k is the index for input use. Here we use four inputs for Chinese agriculture production. For i household at time t, x_{i1t} is land cultivated under grain; x_{i2t} is the labor employed in grain production; x_{i3t} is chemical fertilizer use and x_{i4t} is the capital depreciated during grain production. Their units are Mu[2], man-day, kilogram, and RMB Yuan[3] respectively. The d_{year} s are the year dummies for 1996-1999 while year 1995 is set as the baseline. β_j, β_{jk}, V_{it} and U_{it} are defined as before[4]. In our study, due to the restriction of data availability, we consider the effect of household education level, village officer position, specialization and land fragmentation.

Estimation may be biased with unobserved panel heterogeneity. A fixed effect model can be used to correct this as Wooldridge (2001) described. Greene (2002) discussed the estimation of fixed effects in stochastic frontier models. In our setting, two candidate models are the ones with village effects or household effects. The model with village effects is:

Model 2:

$$\ln(Y_{it}) = \beta_0 + \sum_{l=1}^{4} d_{(year)l} + \sum_{v=1}^{28} d_{village} + \sum_{j=1}^{4} \beta_j \ln(x_{ijt}) + \sum_{j \le k}^{4} \sum_{k=1}^{4} \beta_{jk} \ln(x_{ijt}) \ln(x_{ikt}) + V_{it} - U_{it},$$

and the model with household effects is:

Model 3:

$$\ln(Y_{it}) = \beta_0 + \sum_{l=1}^{4} d_{(year)l} + \sum_{i=1}^{591} d_{household} + \sum_{j=1}^{4} \beta_j \ln(x_{ijt}) + \sum_{j \le k}^{4} \sum_{k=1}^{4} \beta_{jk} \ln(x_{ijt}) \ln(x_{ikt}) + V_{it} - U_{it}.$$

An interpretation of Model 2 and 3 is that we are shifting the production frontier for villages or individual households to account for unobserved heterogeneities.

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2) 1 Mu=1/15 Hectare

3) 1 RMB Yuan=$0.12 approximately

4) Note that the x vector in the likelihood function is all the explanatory variables in the translog functional form, including the cross-production term and the dummy variables.

To explain the inefficiency U_{it}, we define that: $m_{it} = \delta_0 + \sum_{k=1}^{17} \delta_k z_k$, where z_1-z_3 is the highest education level attained in the household: z_1 is one if the level of education of the most educated household member is greater than 5 years but less or equal to 8 years; z_2 is one if it is greater than 9 years but less or equal to 11 years; z_3 is one if it is greater or equal to 12 years. z_4 is the village officer dummy variable which takes a value of one whenever a household member holds an official position in a village. z_5 is the number of the plots under grain production, which is used to represent the land fragmentation. However, previous studies (e.g. Wan and Cheng 2001; Fleisher and Liu 1992) incorporated it in the frontier function, which may introduce serious collinearity problem. Here we circumvented this trap by putting it in the inefficiency term. As Coelli (1996) claimed, explanatory variables could appear in both the production function and the inefficiency explanatory term. z_6 is the ratio of land under grain production relative to all land. It is a proxy for households' specialization in grain production.

z_7- z_{10} are dummies describing the age of the household head: z_7 is one when the head's age falls above 31 year and below 40 year. z_8 is one when the head's age is greater than 40 years but less than 50 years. z_9 is one when the head age is between 51 and 60, and z_{10} is one when the head is older than 61 years. The reference age group occurs when the head is less than 30 years old. z_{11}-z_{14} are time dummy variables. Time in the frontier function reflects the trend of technology change while time as an explanatory variable for technical inefficiency captures time-varying efficiency. z_{15} is one if the household owned or partially owned any kind of machinery for grain production. z_{16} is one if the grain output of the household is large than 3000 kg. z_{17} is the one if the household are located in southern provinces.

The particular frontier software used is FRONTIER 4.1 developed by Tim Coelli[5]. He used a three-step estimation method in obtaining his final maximum likelihood estimates. First, Unbiased estimates of the β parameters are obtained via OLS. A two-phase grid search of γ is conducted in the second step with β set to the OLS estimates and other parameters (μ, η or δ's) set to zero. The third step involves an

5) Please refer Coelli (1996) for detailed documentation of this software.

iterative procedure (using the Davidson-Fletcher-Powell Quasi-Newton method) to obtain the final maximum likelihood estimates with the values selected in the grid search used as starting values. The panel data set needs not to be balanced.

The Data

Dataset Description

The data for our study is a part of a large comprehensive survey conducted by Research Center for Rural Economy (RCRE) since 1986 in 29 provinces in China covering over 20,000 households. The number of surveyed households wanes slightly over time due to sample attrition. The survey was discontinued in 1992 and 1994 for financial reasons. The data set for our study contains 591 farm households living in 29 villages from 9 provinces in China from 1995 to 1999. It is randomly selected from the larger sample.

As accounted by Benjamin, Brandt, and Giles (2001), sampling for this data set was conducted by provincial offices under the Ministry of Agriculture. Each provincial research office first selected equal numbers of three types of counties: upper, middle and lower income; then they chose a representative village in each county. Forty to 120 households were randomly surveyed within each village. Village officers and accountants filled out a survey form on general village characteristics every year.

RCRE claimed that 80 percent of the households remained in the survey for the period of 1986-1997. Chen (2001) found that there are cases where some new households are using the id of old households. He compared the characteristics of those households and corrected them.

Descriptive Statistics

Table 1 presents socio-demographic characteristics of the RCRE households. The data set is unbalanced since some households did not engage in grain production for a few years, or we had to discard a few observations because of mistakes in data recording. This should not be troubling since they are a trivial fraction of the whole data set. Using general retail price index, Chen (2001) converted all monetary variables such as prices, income, or expenditures into real term with 1986 as the base year.

Over the five-year period (1995-1999), no clear trend exists for most of the indexes. Some indexes fluctuate, e.g., the gross income and labor force.

Household size is getting smaller, which is partially due to the achievement of family planning policy. Another possible explanation is the labor migration is occurring from rural areas to urban areas or coast areas. The household highest education is increasing over time though the trend is not significant, which is reasonable since the government has been reducing illiteracy for a long time.

There is no obvious trend for agricultural land cultivated under grain. However, the number of plots is decreasing, which may reflect the effort of land consolidation or the result of labor out-migration. Productive asset depreciation on cropping production does not appear to increase or decrease monotonously though it seems that it is lower in 1999 than in earlier years. This may due to the fact that grain price is lowered after the Asia financial crisis, and farmers shifted investments to non-grain production or off-farm activities.

Compared to Kurkalova (1999), the descriptive data shows that Chinese agriculture is more labor intensive than Ukrainian agriculture. The number of agricultural workers per hectare of agricultural land for Ukrainian is about 0.14 for the period of 1989-1992, while it ranges from 4.82 to 5.04 for RCRE data set.

Input usage and output produced for the RCRE households are summarized in Table 2. Grain output per household does not change significantly over time but the yield per hectare increased slightly. The labor usage per hectare fluctuated over the period, but the trend is negative. The reason may be that farmers are more apt to engage in off-farm activities.

Fertilizer usage is increasing over time. This reflected the trend that young farmers are more likely to use chemical fertilizer and overlooked the importance of organic manure. Huang (2001) claimed that the percentage of chemical fertilizer in Chinese agriculture increased from 40% of total fertilizer use in 1980s to above 50% in 1990s and suggested that chemical fertilizer is overused in rural China. He also noted that 60% of rural Chinese labor force is female and old people that are under-educated. This may contributed to the misusage of fertilizer.

Capital input per hectare is increasing over time, which is within our expectation since Chinese farmers is supposed to employ more capital with their incomes increase.

We examined the ratio of the land under grain production to the overall land and found that households usually use more than eighty percent of their land in grain production on average. A frequency plot of the ratio is presented in Figure 4.

Result

Production Frontier Estimates

Table 3 presents the MLE estimates of the three models. The results are strikingly similar. The marginal effects show same pattern though model 3 has a smaller number for marginal product of land, which may due to the inclusion of the fixed effects. The inefficiency coefficients have the same sign for all three models except the village officer dummy. BIC and Hann-Quinn criterion prefer model 2, which we adopt in the following. We omit the lengthy report of village dummy estimates.

Likelihood ratio test results presented in table 5 show that translog specification is preferred to Cobb-Douglas function. Inferences based on model selection criterions agree with this conclusion.

Given the estimated parameters of model 2, we evaluated the marginal effects of land, labor, fertilizer and capital for every household at the sample mean of the inputs as 0.679, 0.035, 0.056 and 0.125. We also evaluated them at the sample median and obtained similar results. The estimates and the corresponding 95% confidence intervals are given in table 9. Likelihood ratio tests confirmed that land, labor, fertilizer and capital are effective inputs (see table 5).

Our estimate of land elasticity of output is comparable to Fleisher and Liu (1992) where they obtained land elasticity of 0.70. There are a number of households that have negative marginal products for labor and/or fertilizer. The indication of excessive labor agrees with Wan and Cheng (2001). Existence of negative marginal product of fertilizer is consistent with Huang (2001) and Widawsky et al. (1998). Huang (2001) found that farmers in China have been applying seemingly excessive fertilizer. He emphasized that the structure of chemical fertilizer using of Chinese agriculture is about 1:0.31:0.01 for N, P and K fertilizers, which is far more imbalanced compared to the 1:0.5:0.5 of developed countries and 1:0.45:0.36 of the world. Another trend he revealed is the increasing use of chemical fertilizer by young farmers who are less likely to use organic manure.

Lin (1989) obtained input elasticities of land 0.49, labor 0.21, fertilizer 0.15, and capital 0.06. Although differing somewhat from those in the existing literature, our estimates show the general important impact of land in Chinese agriculture.

The scale elasticity, evaluated at the sample mean of the inputs, is 0.896. The 95% confidence interval is [0.874, 0.917], which does not include unity. We cannot reject the hypothesis of decreasing return to scale.

A peculiarity of Chinese agriculture is that land is community-owned and supposed to be distributed to households “fairly”. Therefore, households with less land may be compensated by being allocated land of better quality. This will influence the marginal effects of inputs and the scale elasticities. We also note that the properties of the frontier may not necessarily agree with the average production technology since the frontier is shifted upward from the average.

Putterman and Chiacu (1994) summarized several recent studies of Chinese agriculture and presented a table of various elasticity estimates. Table 9 compares our result with theirs. A trend revealed, though not consistently by all studies, is that the share of labor and fertilizer seems to have been falling for two decades.

The estimates of σ^2 and γ are 0.178 and 0.893 respectively and the estimate of σ_v^2 is 0.019. The estimate of σ_v^2 is much less than the estimate of σ_u^2, which is 0.159. This implies that the one sided inefficiency random component dominates the measurement error and other random disturbances.

Technical Inefficiency

The result on technical efficiency is also reported in table 3-4. Technical efficiency is estimated as $\widehat{TE^{it}}_o = \exp(-\widehat{U}_{it})$. Overall mean efficiency is 0.853. The average technical efficiency is 0.844, 0.869, 0.857, 0.883, and 0.810 for 1995 to 1999 respectively. Figure 1 presents the frequency histogram of technical efficiency for individual years and overall. Based on the point estimates and their standard errors in table 8, we conclude that the sample households were most likely less efficient in 1999 than other years, but otherwise there is an increasing trend of efficiency. Figure 2 and 3 present the fraction histograms of technical efficiency respectively for the nine provinces and twenty-nine villages. Figure 2 and table 9 show that Jiangsu and Anhui have the highest mean efficiency. Figure 3 agrees with the regression result that there exists individual village effect, which is likely due to different soil and climate, different regional policy and income level.

The results show that the highest education level among household members improves technical efficiency, which agrees with Yang (1997a; 1997b) that collective decision-making may be used in Chinese agricultural production. We also estimated the model with household head's education and average household education. The likelihood dominance rule (Herriges & Kling 1996) prefers the measure of highest education. Consistent with the common belief that elementary education has higher marginal effect in developing countries, the efficiency gain from elementary education is greatest according to the estimates of model 2.

For model 2, our estimate for the coefficient of village officer dummy is positive, which means that a member of household holding a position as village officer maybe detrimental to technical efficiency, but it is not significantly different from zero. This finding is at odds with the conclusion of Cheng (1998). However, since Cheng used a data set collected in 1994-1995, this may reveal a shift over time in the role of village officer. Cheng (1998) argued that village officers have privileged access to some inputs owned by the community and quotas approved by upper level authorities. Clearly, the input markets have gained more openness since later 1990s than earlier. Therefore village officers gradually lose their privilege over those inputs and fast diminishing quotas. Cheng (1998) acknowledged that village officers are taking significant time and effort in performing their duty for disproportioned wages, which may contribute to the technical inefficiency in the result of model 2 that a member being a village officer may not bring a household any advantage. Model 3 yields different result, which indicates the position of village officer may be advantageous for a specific household.

The number of plots has a negative effect on the technical efficiency. An excessively large number of plots indicates significant land fragmentation. This result agrees with Wan and Cheng (2001), which concluded that Chinese agriculture could improve its output significantly by eliminating land fragmentation.

The ratio of land under grain production to overall land reflects the extent of specialization on grain production. The coefficient is negative and statistically significant. This is important because it suggests local authorities encourage farmers to specialize in grain production. Certainly, they may need protection against unexpected natural and market coincidence by insurance company or governmental agencies.

The dummies for the household head age show a rather complicated effect. Households with heads in their 40s are more efficient than other households except those with head more than 61 years old. This may need further exploration since a household with a head who is more than 61 years old is probably head of a large household. Nonetheless, our result show there is little evidence supporting the common view that households with elder heads are less efficient.

The dummies for large farm and mechanized farm have positive and statistically significant coefficient while the coefficient of southern farm dummy is negative. It is reasonable that large farms and mechanized farms are more efficient since they may apply better technology. Table 8 reveals that southern farms are more efficient than their counterparts, which may due to the possible collinearity problem.

Evaluating the inputs at the sample geometric mean and sample median, we simulated the output change due to eliminating the number of plots by one, increasing the percentage of household with highest education of 6 and 8 years by one percent[6], increasing land ratio by one percent and increasing the percentage of mechanized farm by one percent. The result presented in table 10 shows that significant output gains can be achieved. The difference between the two results may due to a few outliers that have access to large amount of inputs, e.g., land and capital. The median measure might be a better representative of the average Chinese farms. The output gains are more significant for the median measure.

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6) We achieve this by decreasing the percentage of household with highest education less than 6 years at the same time and holding the percentages of household with highest education greater than or equal to 9 years constant. We choose to study this group since its coefficient estimate in the inefficiency term is the greatest.

Conclusions:

In this paper, a translog frontier production function is fitted to farm-level grain production data. Our results reveal that land is the most important input in China and contributes significantly to the household production. Marginal products of fertilizer and labor are relatively small and in some cases negative, which indicates that, some of the households might employ excessive labor in grain production, and some farmers apply too much fertilizer.

Human capital is an important determinant of Chinese agricultural technical efficiency. The highest education in the household is considered to be most influential in determining technical efficiency. The marginal product of elementary education is the greatest. Eliminating land fragmentation, promoting specialization, and use of machinery will bring significant efficiency gains for grain production, which suggested land tenure system innovation to promote specialization.

Further studies are needed to investigate the effect of land quality on the estimates of marginal effect and scale elasticity. Provincial disparity is an interesting topic to explore further with approaches such as spatial economics. Profit function will enable us to study the allocative efficiency. However, we need additional information on prices to apply this approach for the RCRE data set.

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Table 1: General descriptive statistics for Chinese farm households (1995-1999)[7]

Variables	Unit	1995	1996	1997	1998	1999
Household Size	Number	4.28	4.27	4.26	4.21	4.19
		(1.34)	(1.38)	(1.36)	(1.39)	(1.36)
Land Under Grain	Hectare	0.658	0.668	0.635	0.666	0.673
		(0.585)	(0.637)	(0.591)	(0.622)	(0.599)
Land Plots	Number	6.04	6.08	5.99	5.65	5.59
		(4.58)	(4.68)	(4.80)	(4.52)	(4.62)
Labor Force	Number	2.57	2.59	2.58	2.53	2.55
		(1.08)	(1.09)	(1.07)	(1.06)	(1.03)
Highest Education	Year	7.158	7.152	7.256	7.362	7.379
		(2.417)	(2.421)	(2.346)	(2.282)	(2.231)
Fixed Productive Asset	Yuan	1223.1	1412.2	1354.0	1369.8	1231.1
Depreciation on Crop Production	(Real Term)	(1107.2)	(3668.3)	(3631.9)	(3305.6)	(2831.2)
Gross Income Per Year	Yuan	11724.7	12372.4	12754.7	12495.8	11757.6
	(Real Term)	(7617.0)	(8868.8)	(10153.9)	(8676.6)	(10332.5)
Land under Grain	Percent	0.860	0.873	0.874	0.871	0.875
/Agricultural Land		(0.103)	(0.095)	(0.098)	(0.112)	(0.113)
Agricultural labor force	People	5.955	5.985	6.33	6.06	6.03
/agricultural land	/Hectare	(5.025)	(4.680)	(6.29)	(5.16)	(4.70)
Observations	Number	572	538	539	539	520

Table 2: Input and output summary for Chinese farm households (1995-1999)

Variables	Unit	1995	1996	1997	1998	1999
Grain Output Per	Kilogram	3042.7	3116.2	3188.0	3338.0	3116.5
Household		(2430.5)	(3878.0)	(3981.1)	(4052.8)	(3583.6)
Labor input Per	Man Day	210.5	222.3	208.7	202.1	200.8
Household		(143.0)	(179.4)	(178.2)	(152.2)	(151.4)
Fertilizer Usage Per	Kilogram	476.7	522.3	488.2	534.1	498.4
Household		(454.5)	(693.5)	(547.2)	(584.1)	(473.7)
Capital Depreciation in	Yuan	1223.1	1412.2	1354.0	1369.8	1231.1
Grain Production Per Household	(Real Term)	(1107.2)	(3668.3)	(3631.9)	(3305.6)	(2831.2)
Yield output/ hectare	Kg/	4888.1	4906.3	5111.9	5219.0	4977.6
	Hectare	(1579.0)	(1545.9)	(3204.3)	(1685.7)	(1919.9)
Labor input / Hectare	Man-Day/	427.7	461.5	440.6	430.3	422.6
	Hectare	(400.2)	(465.2)	(404.8)	(366.8)	(345.5)
Fertilizer / Hectare	Kg/	887.2	903.2	952.7	1029.2	982.1
	Hectare	(663.2)	(619.8)	(770.7)	(830.7)	(682.9)
Capital Depreciation	Yuan/	1941.8	2175.1	2092.8	2199.0	1919.2
/Hectare	Hectare	(894.2)	(1313.9)	(1148.9)	(1516.7)	(1113.6)
Observations	Number	572	538	539	539	520

[7] The data set consists of 591 households, 2708 observations.

Table 3. Maximum-likelihood Estimates for Parameters of the stochastic frontier

Sample of Chinese farm households (1995-1999)

Variables	Parameter	Model 1	Model 2	Model 3
Constant	β_0	9.075***	7.064***	7.440***
Ln(land)	β_1	1.366***	0.851***	0.711***
Ln(labor)	β_2	-0.230*	-0.267***	-0.078
Ln(fertilizer)	β_3	-0.423***	0.215**	0.160**
Ln(capital)	β_4	-0.509***	-0.401***	-0.522***
$(\ln(\text{land}))^2$	β_{11}	-0.109***	-0.047***	-0.037**
$(\ln(\text{labor}))^2$	β_{22}	-0.010	0.020**	0.001
$(\ln(\text{fertilizer}))^2$	β_{33}	-0.010	-0.012	0.004
$(\ln(\text{capital}))^2$	β_{44}	0.001	0.041***	0.050***
Ln(land)*ln(labor)	β_{12}	-0.004	-0.071***	-0.009
Ln(land)*ln(fertilizer)	β_{13}	-0.187***	0.021	-0.005
Ln(land)*ln(capital)	β_{14}	0.122***	0.039*	0.029
Ln(labor)*ln(fertilizer)	β_{23}	0.076***	0.027**	0.005
Ln(labor)*ln(capital)	β_{24}	-0.018	0.012	0.009
Ln(fertilizer)*ln(capital)	β_{34}	0.082***	-0.029*	-0.025***
Year 1996 Dummy	D_{96}	-0.028	-0.022	-0.032***
Year 1997 Dummy	D_{97}	-0.006	-0.002	-0.022***
Year 1998 Dummy	D_{98}	0.018	-0.001	-0.042***
Year 1999 Dummy	D_{99}	0.046*	0.027*	0.026***
Variance Estimates				
	σ^2	0.205***	0.178***	0.450***
	Γ	0.742***	0.893***	1.000***
ln(likelihood)		-496.42	611.95	1559.29

Note: a) Model 1: Without any fixed effects; Model 2: with village fixed effects; Model 3, with household fixed effects. b) * indicates the parameter is significant at 10% significance level, ** for 5% and *** for 1%.

Table 4: Inefficiency Model coefficient estimates:

Sample of Chinese farm households (1995-1999)

Variables	Parameter	Model 1	Model 2	Model 3
Constant	δ_0	0.883***	0.938***	1.718***
Highest education (6-8 years)	δ_1	-0.487***	-0.455***	-0.729***
Highest education (9-11 years)	δ_2	-0.511***	-0.381***	-0.565***
Highest education (>12 years)	δ_3	-0.530***	-0.423***	-0.834***
Village officer Dummy	δ_4	0.024	0.008	-0.423***
Number of plot	δ_5	0.014***	0.015***	0.040***
Land Ratio	δ_6	-0.338***	-0.500***	-1.680***
Household head age (31-40 yrs old)	δ_7	0.183***	0.011	0.012
Household head age (41-50 yrs old)	δ_8	0.152**	-0.092*	-0.223***
Household head age (51-60 yrs old)	δ_9	0.300***	0.028	-0.112
Household head age (>=61 yrs old)	δ_{10}	-0.065	-0.340***	0.035
Year 96 Dummy	δ_{11}	-0.293***	-0.281***	-0.457**
Year 97 Dummy	δ_{12}	-2.577***	-1.796***	-1.455**
Year 98 Dummy	δ_{13}	-0.504***	-0.967***	-1.270***
Year 99 Dummy	δ_{14}	-0.109*	-0.213***	-0.696***
Mechanized (Dummy)	δ_{15}	-0.090	-0.172***	-0.542***
Large Farm (Output>3000kg)	δ_{16}	-0.088	-0.274***	-1.330***
Southern (Dummy)	δ_{17}	0.257***	0.311***	0.502***
Variance Estimates				
	σ^2	0.205***	0.178***	0.450***
	Γ	0.742***	0.893***	1.000***
Ln(likelihood)		-496.42	611.95	1559.29
BIC		650.55	-347.17	926.51
HQ Criterion		577.05	-473.44	-258.92

Table 5: Likelihood Ratio Test for Functional Form and Input Effect

H_0	Hypothesis	Llik	λ	D.F	Critical Value[8]	Inference
H0: $\beta_{ij}=0$	Frontier is of Cobb-Douglas Form	556.19	111.52	10	18.31	Reject
H0: $\beta_1=\beta_{1j}=0$	Var. Land does not affect production frontier	-72.39	1368.7	5	11.07	Reject
H0: $\beta_2=\beta_{2j}=0$	Var. Labor does not affect production frontier	596.69	30.52	5	11.07	Reject
H0: $\beta_3=\beta_{3j}=0$	Var. Fertilizer does not affect production frontier	581.11	61.68	5	11.07	Reject
H0: $\beta_4=\beta_{4j}=0$	Var. Capital does not affect production frontier	507.31	209.28	5	11.07	Reject
H1: Negation	Translog functional form	611.95				

Table 6: Time Trend of Technical Efficiency

Year	Mean	Std. Dev.	Observations
1995	0.844	0.006	572
1996	0.869	0.005	538
1997	0.857	0.005	539
1998	0.883	0.004	539
1999	0.810	0.008	520

Table 7: Provincial Distribution of Technical Efficiency

Province	Mean	Std. Dev.	Observations
Anhui	0.907	0.005	294
Hebei	0.779	0.007	659
Helongjiang	0.920	0.002	362
Jiangsu	0.908	0.002	292
Liaoning	0.737	0.017	110
Shandong	0.872	0.007	145
Shanxi	0.794	0.009	249
Sichuan	0.887	0.003	411
Yunnan	0.867	0.007	186

Table 8: Comparison of Technical Efficiency

	Output		Mechanization		Geography	
	Large	Small	Yes	No	North	South
Mean Efficiency (Model 2)	0.934	0.809	0.892	0.839	0.821	0.894

[8] The critical values correspond to 5 percent level of significance.

Table 9: Elasticities estimates for Chinese agricultural production function (various studies)

		Land	Labor	Fertilizer/ current inputs	Capital	Scale Elasticity	Period	Data Type
Our Study	Geometric mean	0.679 (0.648, 0.711)	0.035 (0.015, 0.056)	0.056 (0.036, 0.076)	0.125 (0.102, 0.148)	0.896 (0.874, 0.917)	1995-1999	Households
	Sample median	0.679 (0.647, 0.712)	0.035 (0.014, 0.057)	0.056 (0.036, 0.076)	0.125 (0.102, 0.148)	0.896 (0.874, 0.918)		
Wan & Cheng (2001) [9]		0.771	0.102		0.127	1	1970-85	Production Team
		0.805	-0.007		0.202	1		
		0.993	-0.211		0.296	1.08		
		0.903	-0.006		0.085	0.982		
		0.796	-0.002		0.319	1.113		
Putterman (1993)		0.66	0.06	0.06	0.02		1970-85	Production Team
Tian & Wan (1993)		0.66	0.06	0.06	0.02		1970-85	Production Team
Fleisher & Liu (1992)		0.70	0.20	0.09	0.06	1.05	1986	Households
Kim (1990)		0.52	0.09	0.05	0.08		1980-84	Production Team
Kim (1990)		0.66	0.08	-0.01	0.23		1981-87	Province
Weimer (1990)		0.54	0.20	0.11	0.09		1970-79 1983-85	Province
Lin (1992)		0.63	0.13	0.18	0.06		1970-79 1981-87	Provincel
Park (1989)		0.46	0.04	0.30	0.00		1985	Households

Table 10: Simulated output percentage change due to

+% Output	-1 # plots	+ 1% land ratio	+1% highest education	+1% Mechanization
Evaluated at Sample mean	1.6%	0.6%	0.5%	0.3%
Evaluated at Sample median	3.8%	2.3%	2.2%	1.8%

[9] For Maize, Later rice, Wheat, Early rice and Tubers respectively.

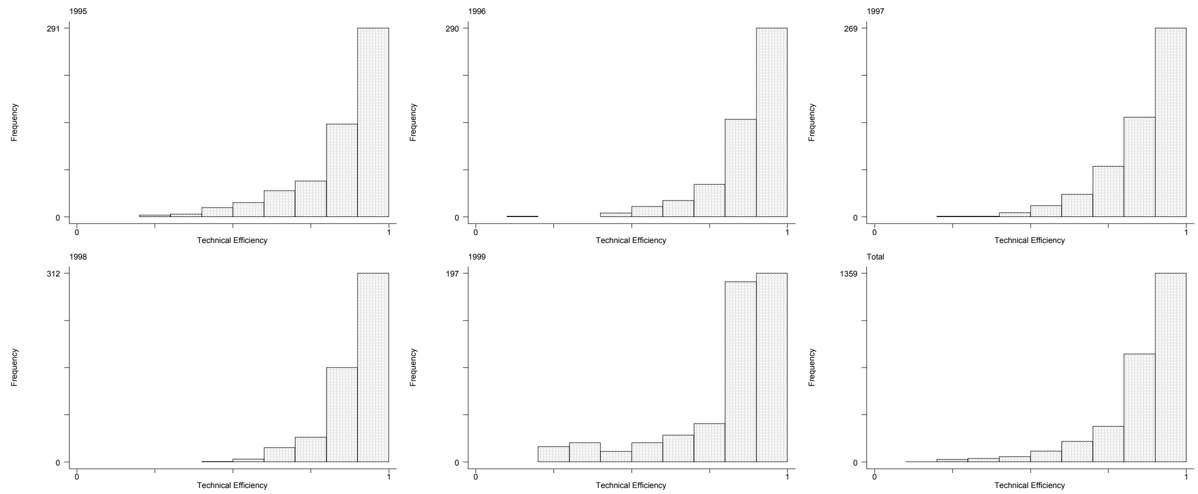

Figure 1: Technical Efficiency (1995-1999, Overall)

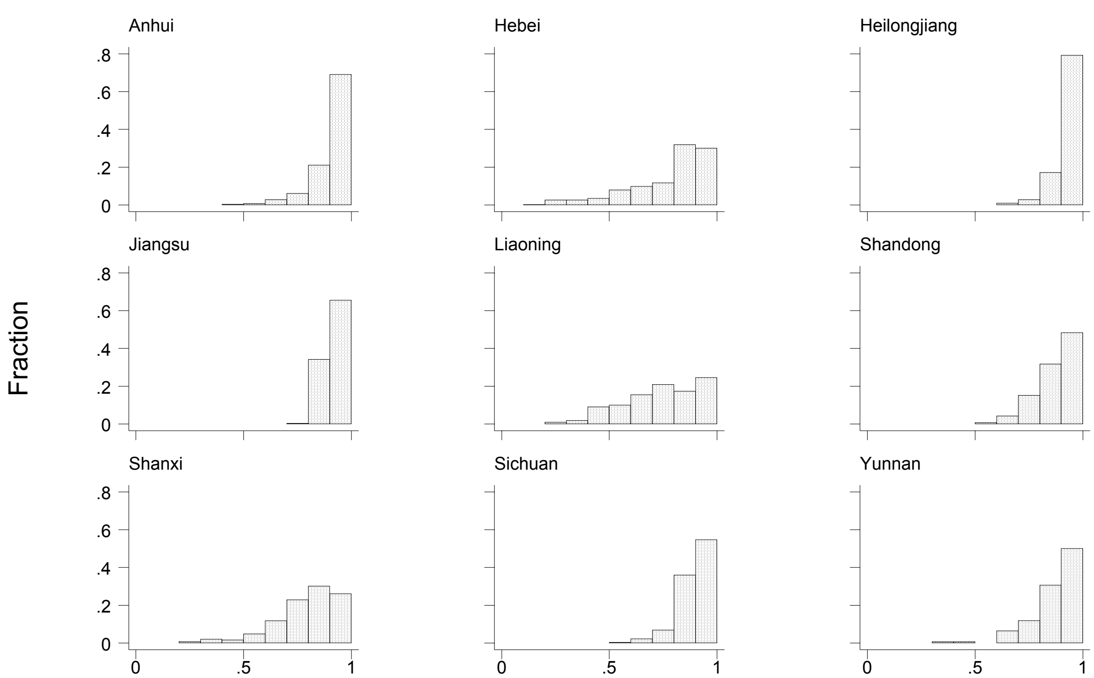

Figure 2: Technical Efficiency (Provinces)

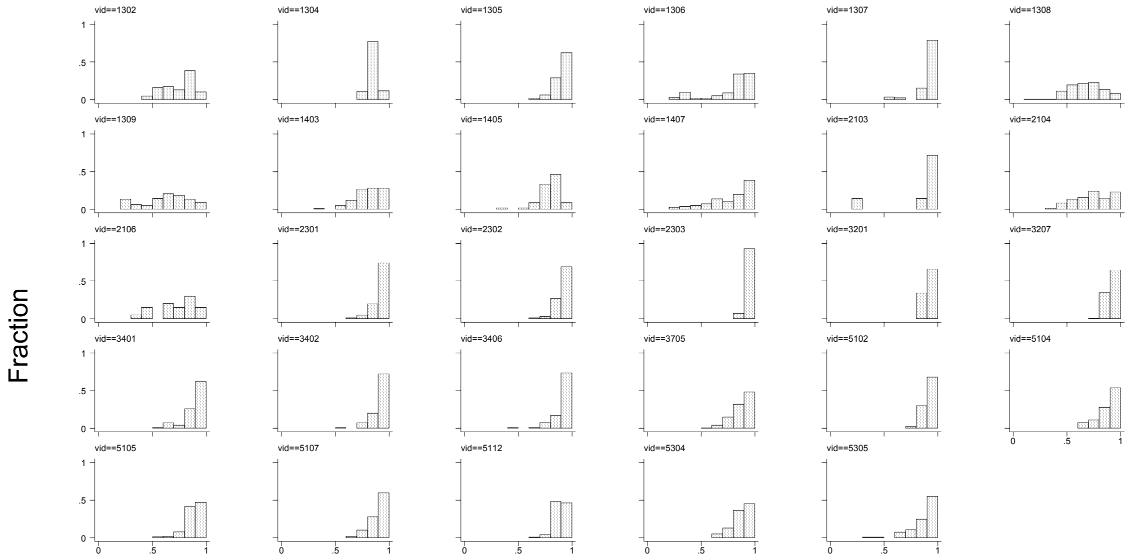

Figure 3: Technical Efficiency (Village)

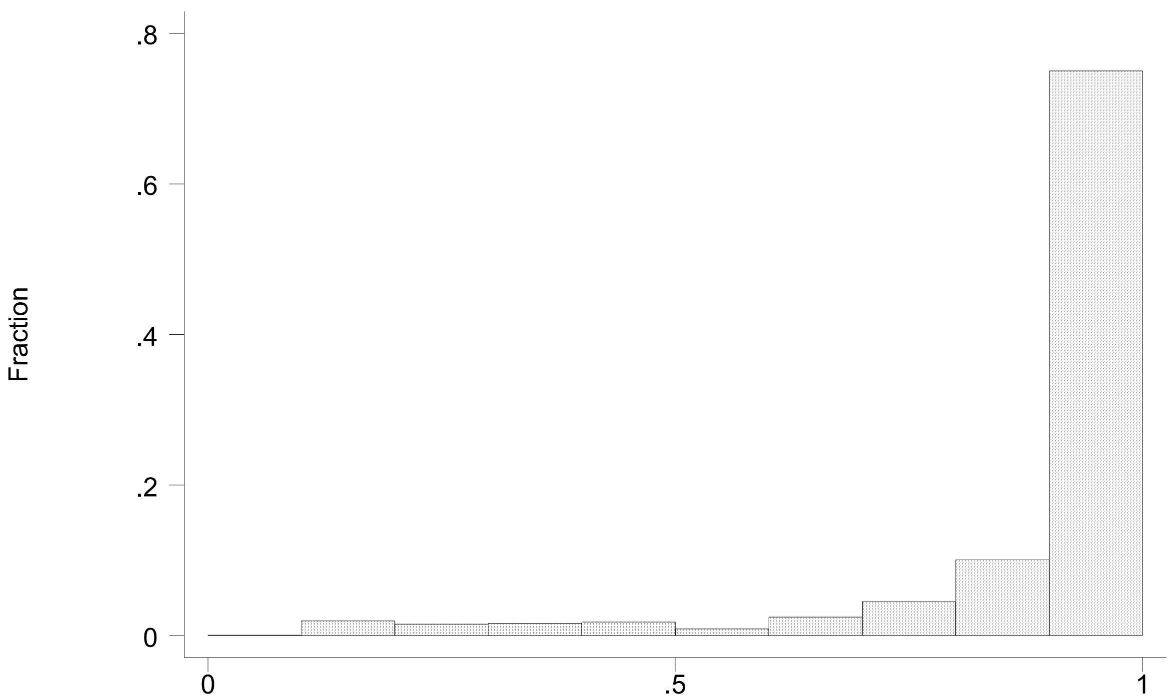

Figure 4: Histogram of Land Under Grain Production/Total Land