ELSEVIER

Agricultural Economics 17 (1997) 191–199

AGRICULTURAL ECONOMICS

Potential of China's grain production: evidence from the household data

Yiping Huang [a,b,*], K.P. Kalirajan [c]

[a] National Centre for Development Studies, Australian National University, Canberra, Australia

[b] China Center for Economic Research, Peking University, Beijing, China

[c] Department of Economics, Research School of Pacific and Asian Studies, Australian National University, Canberra, Australia

Accepted 9 June 1997

Abstract

This study investigates whether China has achieved its potential in grain production fully with the existing technology. A stochastic varying coefficients frontier approach is applied on recent household survey data of 1000 grain farmers covering the periods 1993–95. The results indicate that, on average, the actual grain outputs are about 15–35% lower than the potential output. The analysis has identified households' human capital stock, land size and market-oriented reform as important factors contributing positively to grain production efficiency. © 1997 Elsevier Science B.V.

1. Introduction

The structural change of the Chinese economy that has been brought about by economic reforms has important implications for its grain demand–supply situation. While increase in income level has led to continued growth in demand, the supply has either slackened or stagnated due to increased competition for production resources between agricultural and non-agricultural activities. Garnaut and Ma (1992) pointed out the possibility that China would have to import large amounts of grain by the end of the century. This caused some anxieties among economists and policymakers in China, as China is not yet confident about shifting its policy towards relying heavily on grain imports. The grain crisis at the end of 1993 and in 1994 raised the alarm. Grain issues became one of the policy priorities and a hot topic from the mid-1990s, resulting in a number of research studies on China's grain production. [1]

Although most Chinese economists and officials agree with the above studies concerning the predictions of future demand for grain, they disagree on their discussions of supply growth. Hu Angang of the Chinese Academy of Sciences, for example, pointed to the dramatic gains made in grain production since the birth of modern China in 1949 and argued that China had an enormous unexploited potential for expanding its food production (cited in Brown, 1995). A substantial study on China's agri-

* Corresponding author. E-mail: yiping.huang@anu.edu.au.

[1] For instances, see Brown (1995), Rosegrant et al. (1995), Huang (1995), and RIDA (1995).

PII S0169-5150(97)00025-X

cultural scientific research priority and grain yield potential led by Justin Lin of the China Center for Economic Research found that the grain yield potentials are in general two to three times the current actual yield levels (Lin, 1995). It is suggested that if the areas sown to grain remain constant, total grain output can grow faster than population by one percentage point and grain supply can meet the demand for the next 50 yrs. At the same time, Lin (1995) also stressed that realisation of this potential is dependent on a number of factors including a favourable policy environment and substantial investment. Other economists have warned about the opportunity costs of this required investment.

The key disagreement in the grain policy debate lies in China's choice between increasing imports and continued reliance on domestic production. A major issue is thus the ability and efficiency for China's grain production to keep pace with the growth of demand. While the above studies are concerned with a long-run phenomenon, this study looks at the short-term grain production potential. The hypothesis is that although the efficiency of grain production improved significantly following the implementation of the household responsibility system, most farmers are still not on their production frontiers due to various reasons. The ratio of the actual output to the potential output given by the frontier is defined as technical efficiency (Farrell, 1957). While both the actual and the potential outputs emanate from the same level of inputs, the latter is obtained by following the 'best practice' methods of the application of inputs. Therefore, a significant amount of inefficiencies can be eliminated without substantial investment, by following the 'best practice' methods. It is in this context, the objective of this study is to examine whether it is possible to increase grain output with the given technology, by effectively using the existing resources.

The paper is organised as follows. Section 2 outlines the methodology, which is applied in Section 3 using the recent farm household survey data. The farm-specific and input-specific technical efficiency measures are estimated for three major crops: rice, wheat and maize. Section 4 attempts to identify some of the key factors explaining the variation in technical efficiency among the sample grain producers. The overall conclusion is given in Section 5.

2. Technical efficiency and grain production potential: methodology

In Fig. 1, $y = f(x)$ denotes the frontier production function from which the potential output is estimated. For a given input level x, point A, which is well below the frontier, indicates the level of output y_1 obtained during the pre-reform period due to various institutional and organisational constraints. Economic reform which removed most of these constraints, improved technical efficiency and output has risen to y_2 (from point A to point B). Production at B, however, is still not on the frontier. The gap between the potential output y_3 and y_2 (or between B and C) is the current technical inefficiency and is the major concern of this paper.

For the purpose of measuring farm households' technical efficiency, the stochastic varying coefficient frontier approach is applied. [2] This method is a modification over the conventional fixed coefficient probabilistic frontier function of Timmer (1971), and the stochastic frontier function of Aigner et al. (1977) and Meeusen and van den Broeck (1977). [3] It is argued that technical efficiency stems from the 'method' of applying inputs, regardless of the levels of inputs. The alternative methods of applying various inputs will influence output differently and, thus, the production coefficients will vary from farm to farm. Therefore, the assumption of the conventional frontier production function analysis—that the slope coefficients are the same for both those who are using the 'best practice' methods and those who are not—is not consistent with the concept of technical efficiency (Kalirajan and Obwona, 1994). Logically, the slope coefficients for those who are using the 'best practice' methods should be larger than for those who are not following the 'best practice' methods. The varying coefficients modelling facilitates such an representation of a production system

[2] Other frequently applied methodologies in analyses of productivity and technical efficiency include the deterministic modelling and non-parametric method.

[3] This approach has been applied to analyses of grain production in India and China (Kalirajan and Shand, 1994; Kalirajan and Huang, 1995).

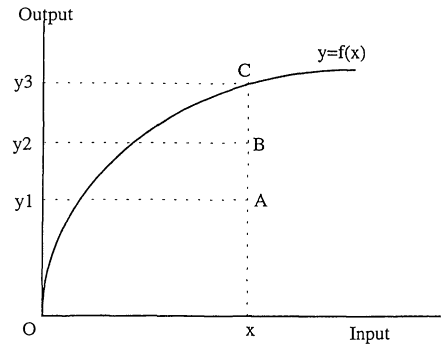

Fig. 1. Technical efficiency of grain production.

(Swamy, 1971).Assuming a Cobb–Douglas technology,

$$\ln Y_i = \alpha_{1i} + \sum_{k=2}^{K} \alpha_{ki} \ln X_{ki} \quad i = 1,\ldots,N \tag{1}$$

where Y_i is the output level of the ith farm; X_{ki} is the level of the kth input used by the ith farm; and α_{ki} is the actual response of the output to the method of application of the kth input by the ith farm. It is further assumed that the individual response coefficient of output with respect to an input fluctuates around its mean value. Let $\alpha_{ki} = \overline{\alpha}_k + u_{ki}$ for $k = 1,\ldots,K$ and $i = 1,\ldots$,N, where $E(\alpha_{ki}) = \overline{\alpha}_k$, $E(u_{ki}) = 0$ and $\mathrm{var}(u_{ki}) = \sigma_{ukk}$ for $j = k$ and 0 otherwise; $\alpha_{1i} = \overline{\alpha}_1 + u_{1i}$ which is the intercept term for the ith farm.Eq. (1) can therefore be rewritten as

$$\ln Y_i = \overline{\alpha}_1 + \Sigma \overline{\alpha}_k \ln X_{ki} + w_i \tag{2}$$

where $w_i = \Sigma_{k=2}^{K} u_{ki} \ln X_{ki} + u_{1i}$; $E(w_i) = 0$ for all i; $\mathrm{cov}(w_i, w_j) = 0$ for $i \neq j$ and $var(w_i) = \sigma_{u11} + \Sigma_{k=2}^{K} \sigma_{ukk} (\ln X_{ki})^2$

Following the estimation procedures suggested by Hildreth and Houck (1968), the mean response coefficients $\overline{\alpha}$'s and the variances σ_{ukk} can be estimated and the individual response coefficients α_{ki}'s can be obtained as described in Griffiths (1972).

Drawing on Kalirajan and Obwona (1994), the assumptions underlying Eq. (2) are as follows. First, technical efficiency is achieved by adopting the best practice techniques which involve the efficient use of inputs. Technical efficiency stems from two sources: the efficient use of each input which contributes individually to technical efficiency and can be measured by the magnitudes of the varying slope coefficients α_{ki}'s, and any other firm-specific intrinsic characteristics which are not explicitly included may produce a combined contribution over and above the individual contributions.This 'lump-sum' contribution, if any, can be measured by the varying intercept term. Second, the highest magnitude of each response coefficient and the intercept, form the production coefficients of the potential production function. Let α_k^*'s be the estimates of the coefficients of the frontier production function, that is $\alpha_k^* = \max_i \{\alpha_{ki}\}$ $k = 1,\ldots,K$ and $i = 1,\ldots,N$.

The potential frontier output for individual farmers can be calculated as

$$\ln Y_i^* = \alpha_1^* + \sum_{k=2}^{K} \alpha_k^* \ln X_{ki}, i,\ldots,N \tag{3}$$

The characteristics of the α_k^*'s ($k = 1,\ldots,K$) warrant some explanations, which bear implications for the zero covariance assumption above. Basically, there are two different arguments about α_k^*'s. First, as the 'best practice' method varies from input to input, it is reasonable to assume that not every farmer would be applying all the inputs efficiently. Consequently, the frontier coefficients α_k^*'s need not come from any single observation. For example, α_1^* may come from the 8th farmer, α_2^* may come from the 12th farmer and so on. Second, the possibility that all the α_k^*'s may be selected from a single observation cannot be completely ruled out. The human capital theory literature argues that a firm which uses some inputs efficiently may also use all inputs efficiently. In this study, the former assumption, which is more general, is made and the results support this assumption. [4]

Drawing on Farrell (1957) definition of technical efficiency, a measure of firm-specific technical efficiency (E_i) of the ith farm can now be calculated as the ratio of the actual output to the potential output.

$$E_i = \frac{Y_i}{\exp(\ln Y_i^*)} \tag{4}$$

where the numerator refers to the realised output for

[4] We are grateful to an anonymous referee for pointing out this aspect of production.

a given set of inputs and the denominator shows the estimated potential output, which is the technologically feasible maximum output for the same set of inputs under the production environment faced by farmers.[5] This measure varies between 0 and 1. In addition, the input-specific efficiency measures (IE_{ki}) of the kth input for the ith farm can also be obtained as the ratios of the actual response coefficient to the relevant frontier response coefficients that indicate the 'best practice' methods.

$$\mathrm{IE}_{ki} = \frac{\alpha_{ki}}{\alpha_k^*}, k = 1, \ldots, K \text{ and } i = 1, \ldots, N \quad (5)$$

3. Data set and empirical results

The data used in this study is from a household survey organised by the Chinese Ministry of Agriculture and the China Economy Research Unit of the University of Adelaide.[6] The survey covers about one thousand grain farm households in Guangdong, Jiangxi, Shandong, Sichuan and Jilin for three years between 1993 and 1995.[7] To determine an appropriate functional form for the production relation, two conventional functional forms are attempted, the Cobb–Douglas and the translog functions. The nested hypothesis test suggests that the Cobb–Douglas function is a preferred form for the current data set.[8]

The following Cobb–Douglas form in the above discussed stochastic varying coefficients framework is adopted for empirical work:[9]

$$\ln Y_i = C + \alpha_{Ti} \ln T_i + \alpha_{Li} + lnL_i + \alpha_{Ki} \ln K_i + \alpha_{Fi} \ln F_i + \overline{\omega}_i \quad (6)$$

where Y is households' output of a grain crop (rice, wheat or maize) (measured in kilograms), T is the land areas sown to that grain crop (measured in μ's), L is the labour day spent on production (measured in days), K refers to other costs such as rent paid to machinery and others (measured in yuans) and F is the fertiliser applied to that grain crop (measured in kilograms). All these variables are transformed into indices before estimation with the mean value of the sample being set to 100.

The model is estimated using the computer program TERAN for individual provinces and individual crops and the results are reported in Table 1, which include the mean response coefficients and the frontier coefficients.[10]

The Breusch–Pagan LM test statistics for random coefficient variation indicate that, in the present modelling, individual heteroscedasticity is rejected in favour of vector heteroscedasticity, lending support to the varying coefficient model specification (Breusch and Pagan, 1979). In addition, the actual input-specific response coefficients did vary across sample farm households, which implies that sample farmers exercised different technical practices in grain production. This further validates the importance of the varying coefficients frontier approach over the conventional constant-slope but varying intercept production frontiers in estimating technical

[5] This maximum possible output may differ from the technologically feasible maximum output that can be obtained from scientifically controlled experiments.

[6] This survey was a part of a large research project on grain in China funded by the Australian Center for International Agricultural Research.

[7] Due to data errors, analysis on rice in Guangdong and wheat in Sichuan could not be carried out.

[8] The null hypothesis is that the coefficients of the cross and squared terms in the translog function taken together are not significantly different from zero. The calculated F-statistics using 1993 data are as follows:

Output/Province	F-statistics
Maize–Jilin	$F_{(1096)} = 1.88$
Maize–Sichuan	$F_{(1057)} = 1.73$
Maize–Shandong	$F_{(10,122)} = 1.86$
Rice–Guangdong	$F_{(1061)} = 1.94$
Rice–Sichuan	$F_{(1083)} = 1.81$
Wheat–Shandong	$F_{(1099)} = 1.69$

None of the statistics were significant at the 5% level.

[9] The time and cross-sectionally varying coefficients models are the most general of the models for analysing panel data. They are also the most difficult to handle notationally, computationally and analytically. Given a panel database, the assumption that the coefficients of the explanatory variables have common means plus some components associated with cross-sectional units may be realistic only when the time frame (T) is not large (Swamy, 1971) which is the case in this study. We are thankful to the referee for this clarification.

[10] The maximum values of the actual response coefficients for each input represent the frontier coefficients.

Table 1
Stochastic varying coefficients frontier function

	Maize: Jilin			Maize: Sichuan			Maize: Shandong		
	1993	1994	1995	1993	1994	1995	1993	1994	1995
Sample	111	136	133	72	98	84	137	154	136
GLS estimation results									
C	0.02	0.03	0.03	0.04	0.07	0.06	0.01	0.11	0.01
	(2.2)	(2.1)	(3.6)	(1.6)	(3.9)	(4.3)	(0.8)	(12.8)	(1.9)
T	0.42	0.44	0.38	0.46	0.54	0.52	0.55	0.48	0.47
	(3.3)	(5.8)	(9.2)	(4.4)	(4.1)	(6.8)	(6.4)	(2.1)	(6.7)
L	0.20	0.22	0.24	0.23	0.25	0.22	0.23	0.20	0.24
	(2.0)	(3.1)	(4.3)	(1.8)	(1.7)	(2.2)	(3.4)	(5.5)	(2.9)
K	0.17	0.21	0.17	0.12	0.11	0.13	0.13	0.18	0.16
	(5.4)	(4.2)	(8.1)	(3.2)	(4.0)	(8.2)	(7.7)	(3.6)	(1.9)
F	0.19	0.14	0.17	0.16	0.12	0.11	0.11	0.12	0.14
	(3.5)	(3.6)	(5.3)	(4.1)	(1.9)	(3.3)	(6.5)	(8.1)	(4.0)
σ^2	0.09	0.15	0.07	0.22	0.17	0.08	0.10	0.12	0.03
Frontier coefficients									
C	0.06	0.11	0.09	0.12	0.10	0.15	0.08	0.18	0.07
T	0.57	0.55	0.42	0.63	0.65	0.66	0.70	0.57	0.61
L	0.24	0.25	0.25	0.24	0.27	0.24	0.25	0.23	0.26
K	0.19	0.29	0.21	0.14	0.15	0.21	0.15	0.21	0.19
F	0.22	0.19	0.21	0.19	0.17	0.19	0.15	0.16	0.19
	Rice: Guangdong			Rice: Sichuan			Wheat: Shandong		
	1993	1994	1995	1993	1994	1995	1993	1994	1995
Sample	76	141	166	98	138	151	114	99	101
GLS estimation results									
C	0.03	0.02	0.03	0.02	0.02	0.04	0.03	0.09	0.04
	(3.8)	(1.6)	(3.3)	(2.7)	(2.8)	(3.9)	(1.7)	(12.2)	(2.1)
T	0.48	0.47	0.51	0.52	0.43	0.46	0.45	0.48	0.51
	(7.1)	(4.3)	(12.1)	(15.6)	(8.7)	(4.6)	(3.3)	(5.1)	(2.9)
L	0.21	0.23	0.21	0.21	0.23	0.24	0.21	0.25	0.22
	(3.1)	(4.4)	(6.9)	(3.1)	(2.2)	(4.8)	(3.9)	(2.2)	(1.5)
K	0.16	0.16	0.12	0.12	0.11	0.13	0.11	0.13	0.13
	(12.3)	(6.5)	(4.3)	(1.8)	(2.0)	(5.4)	(3.4)	(5.5)	(3.1)
F	0.14	0.11	0.09	0.08	0.14	0.15	0.15	0.09	0.11
	(3.3)	(4.9)	(7.7)	(3.2)	(3.5)	(7.3)	(4.3)	(11.2)	(5.2)
σ^2	0.08	0.04	0.05	0.05	0.09	0.06	0.12	0.07	0.04
Frontier coefficients									
C	0.07	0.03	0.04	0.10	0.08	0.07	0.12	0.13	0.04
T	0.56	0.61	0.65	0.64	0.51	0.59	0.66	0.56	0.61
L	0.24	0.25	0.24	0.25	0.25	0.27	0.24	0.28	0.27
K	0.23	0.19	0.20	0.17	0.23	0.15	0.18	0.23	0.19
F	0.18	0.19	0.15	0.23	0.19	0.28	0.22	0.21	0.17

Source: Authors' estimation using the computer program TERAN.
Note: Figures in parentheses are *t*-ratios of estimates. Breusch–Pagan Lagrange Multiplier (LM) statistic for random coefficient variation produced the following χ^2 values with 4 *df*:(1) Maize: 1993—Jilin (9.87), Sichuan (10.06), and Shandong (11.23); 1994—Jilin (10.34), Sichuan (9.93), and Shandong (10.66); 1995—Jilin (9.84), Sichuan (12.04), and Shandong (12.33). (2) Rice: 1993—Guangdong (12.36), and Sichuan (11.86); 1994—Guangdong (13.08), and Sichuan (10.58); 1995—Guangdong (10.34), and Sichuan (12.28). (3) Wheat: 1993—Shandong (13.36); 1994—Shandong (11.85); 1995—Shandong (11.27).
The critical value of χ^2 for 4 *df* at the 5% level of significance is 9.49. Therefore, all the tests are significant indicating that the varying coefficient modelling is appropriate for the present data set with the selected variables.

Table 2
Calculated average technical efficiency (%)

Farm-specific technical efficiency	Guangdong	Sichuan	Shandong	Jilin
Maize production		0.65	0.68	0.71
Rice production	0.86	0.69		
Wheat production			0.73	

efficiency measures. On examining the average response coefficients given by the GLS estimation from Table 1, it may be noted that all the production coefficients are significant and that the sum of the coefficients of inputs showing the returns to scale vary between 0.90 and 1.05. While this paper does not directly examine why there seems to be slight indications of decreasing returns to scale in grain production, a direct examination of the determinants of technical efficiency is attempted.

Using the method outlined in Section 2, the farm-specific and input-specific technical efficiency measures were calculated. The results are summarised in Tables 2–4. [11]

In general, the average levels of technical efficiency of grain production range from 65% to 86%. In other words, given the agricultural inputs and the technology, the current grain output can be raised by 15 to 35% if the technical inefficiencies are eliminated. For individual crops, technical efficiency of maize production is more or less similar (between 65 and 71%) among the major producing provinces: Jilin, Sichuan and Shandong. The level of technical efficiency of rice production is higher in Guangdong (86%) than in Sichuan (69%). The average level of technical efficiency of wheat production in Shandong is 73%. For individual provinces, it seems that the largest potential exists in Sichuan province, while the smallest potential occurs in Guangdong province.

Tables 2–4 also indicate that, in maize production, land was used least efficiently while labour was used most efficiently. In rice production, both land and labour were used quite efficiently. And in wheat production, land and fertilisers were used relatively more efficiently, compared to the use of labour and capital. Overall, fertilisers were not used very efficiently in the production of all three major grain crops (efficiency ranging from 66 to 75%). This efficiency is likely to be related to the availability of appropriate fertilisers, the knowledge of fertilisers and the scientific methods of application. The return is still high for measures improving the effectiveness of fertiliser application.

Using the tests of significance involving sample means, the hypothesis of no difference in the average efficiency measures between the provinces with respect to concerned crops has been tested. The results which are given in Tables 2–4 indicate that (1) in the production of rice, there is a significant difference in technical efficiency between Guangdong and Sichuan, (2) in the production of maize, there is significant difference in technical efficiency between Guangdong and Jilin, and (3) in the rest of the cases there are no significant differences.

[11] It should be noted that the technical efficiency is measured by comparing the household's actual output of a particular crop with the best practice of the province in that year.

Table 3
Test results for differences of mean technical efficiency measures

Crop/provinces	*Z*-statistic
Maize:	
Sichuan vs. Shandong	−1.67
Shandong vs. Jilin	−1.54
Sichuan vs. Jilin	−2.48
Rice:	
Guangdong vs. Sichuan	3.67

The test statistic used: Z = (mean technical efficiency of province 1 − mean technical efficiency of province 2) divided by (square root of standard deviation of province 1 plus the standard deviation of province 2).
For a two-tailed test the results are significant at the 5% level, if the calculated Z values lie outside the range −1.96 to 1.96.

Table 4

Input-specific technical efficiency	Land	Labour	Capital	Fertiliser
Maize production	0.57	0.83	0.71	0.68
Rice production	0.85	0.88	0.69	0.66
Wheat production	0.76	0.66	0.53	0.75

Note: The best practice of production in the province is taken as a reference (setting to 1).
Source: From the authors' estimation results.

Overall, the findings point to an optimistic view of grain supply. Without requiring large investment and more resources, China's current grain output can be raised by a significant margin even if only part of the technical inefficiency is eliminated.

4. Determinants of technical efficiency

The next step identifies the determinants of technical efficiency, which has policy implications for the elimination of the existing technical inefficiency. The first variable considered is the household's average education level. This variable reflects the household's human capital stock and the individual worker's ability to understand and apply modern production technology. It is expected that this variable is positively correlated with the household's level of technical efficiency. The second variable is the household head's agricultural experience. The household head here is treated as the planner and decision maker of the household's agricultural production. Long agricultural experience is expected to enhance the household's technical efficiency. The third variable is the size of arable land area. It is likely that if the arable land area is large, the household is able to gain some scale economies. A positive correlation between land size and technical efficiency can also be hypothesised.

The fourth variable is the proportion of state purchased quota in the household's total grain output. The impact of this variable on technical efficiency is not that straight forward. The hypothesis is that if the household is forced to produce a certain amount of grain for delivery to the state, under administrative pressure, it may have to produce without considering too much about efficiency. A negative correlation is thus hypothesised, but this can be tested.

The fifth variable is a household's commodity rate of grain production, that is the ratio of grain for sale to total output. For similar reasons as for the state quota, if the household's purpose is to produce for its own consumption, self-sufficiency instead of efficiency may be a dominant factor in decision making. It is thus expected that the commodity rate has a positive impact on technical efficiency. The final variable considered is the proportion of labour days spent on off-farm activities. It is likely that when non-agricultural opportunities exist, the households would be more interested in using the existing labour (and other resources) more efficiently.

The following linear form is used in empirical estimation:

$$E_i = \beta_0 + \Sigma_k \beta_k X_{ki} + \rho_i \qquad (7)$$

where E is the estimated farm-specific technical efficiency and X is a set of the determinants discussed above. The estimation results are reported in Table 5. It was also attempted to use the input-specific technical efficiency as dependent variables in similar exercises. But the results are surprisingly

Table 5
Determinants of technical efficiency of the state enterprises

	Maize production	Rice production	Wheat production
Sample	1061	770	314
Household's average education level	0.0325 (3.6)	0.0132 (2.1)	0.0387 (1.7)
Household head's agricultural experience	0.0014 (11.2)	0.0075 (3.6)	0.0022 (4.9)
Size of arable land area	0.1404 (2.1)	0.2131 (3.8)	0.1352 (4.2)
Share of purchase quota total grain output	0.0001 (0.9)	−0.0214 (0.7)	−0.0102 (3.4)
Commodity rate of grain production	0.0614 (2.3)	0.0432 (3.3)	0.0433 (1.9)
Proportion of labour days on off-farm activities	0.0097 (3.5)	0.2525 (6.1)	0.1314 (15.2)
Constant	0.0256 (6.5)	−0.1201 (4.7)	−0.2259 (9.9)
Yearly and provincial dummies (not reported)			
$\bar{R}^2$	0.41	0.58	0.37
Log of the likelihood function	−241.31	−185.66	−225.77

Source: Authors' estimation.
Note: Figures in the parentheses are the t-ratios of the estimates.

similar to those of Table 5 and thus are not reported in this paper.

The results confirmed all the above mentioned hypotheses about the determinants of technical efficiency in grain production. Household's average education level, household head's agricultural experience, the size of arable land area, commodity rate of grain production and the proportion of labour days on off-farm activities all have significant positive effects on technical efficiency for all three crops. The only exception seems to be the case of the state purchase quota. While it has significant negative impact on technical efficiency in wheat production as expected, there is no significant impact on technical efficiency in rice and maize production.

5. Concluding remarks

Some important conclusions can be drawn from the results of this study. First, the short-term potential of grain yield increase in China is still substantial. The current grain output can be increased by a significant margin even by elimination of a part of the technical inefficiency through minimum efforts. For crops, the potential looks higher in maize, while for provinces, the potential is higher in Sichuan. Second, the level of technical efficiency is determined by the household's human capital stock, land size, marketisation and industrialisation process.

These findings have strong policy implications for China's grain production and supply. While investment in scientific research is crucial in determining China's long term grain production potential, there are some short-term potentials which require only limited efforts. Policies should be formulated to (1) encourage human capital accumulation, including formal education, of farmers; and (2) disseminate the 'best practice' methods and their benefits to farmers through extension and other related services.

Some of the determinants of technical efficiency are not included in the empirical investigation due to data availability. For instance, the low technical efficiency of fertiliser application may be related to the availability of the appropriate fertiliser variety, the knowledge of appropriate application methods and the understanding of the local soil condition. These warrant urgent attention by policymakers.

However, the results in this study should be interpreted with caution as it deals with limited samples which may not be considered to represent the entire China. For example, only Shandong data was used for wheat analysis. Unfortunately, due to data errors, wheat data from Sichuan could not be used meaningfully. Therefore, using data from only one province, one cannot provide estimates of production potential for wheat for the entire China. However, our intention is not to provide forecasting of solid estimates of production potential, which require a more detailed study than the present one. What we have attempted is to see whether there is any possibility for improvement for growth in grain production with a minimum cost. With the recent household data, we have attempted that. So, our results should be interpreted as showing the direction of growth rather than the actual magnitude of growth for China.

Acknowledgements

Financial support by the Australian Centre for International Agricultural Research is gratefully acknowledged. The authors benefited from helpful comments by an anonymous referee, the editor of this journal, Ross Garnaut, Christopher Findlay, Ke Bingshen and other participants of an international workshop 'Output growth, marketing system and internationalisation of China's grain sector' between 4–5 October, 1996 in Beijing. Tingsong Jiang provided excellent research assistance for this study.

References

Aigner, D.J., Lovell, C.A.K., Schmidt, P., 1977. Formulation and estimation of stochastic frontier production function models. J. Economet. 6 (1), 21–37.

Breusch, T.S., Pagan, A.R., 1979. A simple test for heteroscedasticity and random coefficient variation. Econometrica 47, 1278–1294.

Brown, L., 1995. Who Will Feed China? Earthscan Publications, London.

Farrell, M.J., 1957. The measurement of productive efficiency. J. R. Stat. Soc. Ser. A 120, 253–281.

Garnaut, R., Ma, G., 1992. Grain in China. Australian Government Publishing Services, Canberra.

Griffiths, W.E., 1972. Estimating actual response coefficients in the Hildreth–Houck random coefficient model. J. Am. Stat. Assoc. 67, 633–635.

Hildreth, C., Houck, J.P., 1968. Some estimators for a linear model with random coefficients. J. Am. Stat. Assoc. 63, 584–595.

Huang, Y., 1995. China's grains and oilseeds sectors: major changes underway. Organisation for Economic Cooperation and Development, Paris.

Kalirajan, K.P., Huang, Y., 1995. Technical efficiency in grain production in China. Paper presented at the workshop Grain in China, 16–19 September, 1995, East–West Center, Honolulu, HI.

Kalirajan, K.P., Obwona, M.B., 1994. Frontier production function: the stochastic coefficients approach. Ox. Bull. Econ. Stat. 56, 85–94.

Kalirajan, K.P., Shand, R.T., 1994. Economics in Disequilibrium: an approach from the frontier. Macmillan, New Delhi.

Lin, J.Y., 1995. Grain yield potential and prospect of grain output increase in China. People's Daily, March 10, 1995, Beijing (in Chinese).

Meeusen, W., van den Broeck, J., 1977. Efficiency estimation from Cobb–Douglas production functions with composed error. Int. Econ. Rev. 18 (2), 435–444.

RIDA (The Research Institute of Development Assistance), 1995. Prospects for grain supply–demand balance and agricultural development policy in China. OECF Discussion Paper No. 6. The Oversease Economic Cooperation Fund, Tokyo.

Rosegrant, M.W., Agcaoili-Sombilla, M., Perez, N.D., 1995. Global food projections to 2020: implications for investment. Food, Agriculture, and the Environment Discussion Paper 5. International Food Policy Research Institute, Washington DC.

Swamy, P.A.V.B., 1971. Statistical Inference in a Random Coefficient Regression Model. Springer, Berlin.

Timmer, P., 1971. Using a probabilistic frontier production function to measure technical efficiency. J. Pol. Econ. 79 (4), 776–794.