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Efficiency and technical progress in traditional and modern agriculture: evidence from rice production in China

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Abstract

Productive efficiency for Chinese hybrid and conventional rice production is estimated using a dual stochastic frontier efficiency decomposition model. Results reveal significant differences in technical and allocative efficiency between conventional and hybrid rice production, and indicate significant regional efficiency differences in hybrid rice production, but not in conventional rice production. © 1998 Elsevier Science B.V.

Keywords: Hybrid rice production; Conventional rice production; Stochastic frontier efficiency

1. Introduction

The continuous creation/introduction of new technology has been used as a standard for distinguishing a modern agricultural system from a traditional system (Schultz, 1964). However, in developing countries, some new agricultural technologies have been only partially successful in improving productive efficiency. This is often attributed to a lack of ability and/or willingness to adjust input levels on the part of producers, due to familiarity with traditional agricultural systems (i.e., Schultz's 'poor but efficient' hypothesis) and/or the presence of institutional and cultural constraints (Ghatak and Ingerset, 1984). These considerations suggest that, in some cases, there may exist a negative relationship between technical progress in conventional agriculture and realized efficiency gains.

This paper examines efficiency for hybrid rice in China. Rice is a very important crop in Chinese agriculture. Since 1976, F_1 hybrid varieties¹ have become increasingly important in Chinese rice production, relative to 'conventional' rice varieties, which are predominantly improved semi-dwarf varieties.² In 1990, approximately 40% of China's rice was planted in hybrid rice (Lin, 1994). While hybrid

¹ F_1 hybrids are a type of high yielding variety of rice. The production of F_1 hybrid seed involves a complicated three-line method (Lin, 1991a). First, a cytoplasmic male-sterile parent plant is located. This plant is then crossed with a maintainer line to produce offspring that, while sterile, have desirable genetic characteristics. These seeds are then crossed with a 'restorer' line to produce F_1 seeds with normal self-fertilizing capabilities.

² Strictly speaking, conventional rice varieties currently being used in China are not traditional in the Schultz sense but are instead post 'green revolution' varieties. Therefore, the newer hybrid rice varieties are 'third generation' varieties.

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rice has been introduced to some other rice producing countries, China is the only country in the world in which hybrid rice is widely used in commercial production.

The Chinese government often influences the diffusion of new agricultural technologies according to its self-sufficiency objective. As a result, the importance of efficiency considerations in the adoption decision regarding hybrid rice at the regional and producer level is uncertain. The measurement of technical and economic efficiency for hybrid rice production, and the relationship of efficiency and producer socioeconomic characteristics would be useful in addressing these issues. While other studies have examined economic issues related to the adoption and production of hybrid rice (e.g., He et al., 1984, 1987; Lin, 1991a,b, 1992, 1994), little attention has been given to the examination of efficiency for hybrid rice production in China.

Most studies that examine efficiency in developing country agriculture have focused on technical efficiency (Bravo-Ureta and Pinheiro, 1993). While physical productivity considerations are important, improvements in economic efficiency will lead to greater benefits to agricultural producers in these countries. Previous studies have examined efficiency in rice production for other developing countries (e.g., Dawson et al., 1991; Kalirajan, 1991). However, few studies have examined the effects of technical change on efficiency.

The primary purpose of this paper is to examine the effects of technical change on efficiencies of traditional and modern agriculture within the context of rice production in China, i.e., to provide a test of Schultz's 'poor but efficient' hypothesis. In doing so, both technical and economic efficiencies are considered within the context of technical change (i.e., adoption of hybrid rice). A secondary objective is to examine the linkage between efficiency in rice production and producer socioeconomic characteristics in order to provide information that may be useful in analysing the effects of policies designed to improve the productivity of new agricultural technologies.

These objectives are achieved through an examination of productive efficiency for conventional and hybrid rice in China. Two frontier production functions are estimated; one for conventional rice and

one for hybrid rice. These functions are then used to measure the degree of efficiency for Chinese rice production.

The remainder of this paper is organized as follows. A brief review of frontier production function methodology is provided in Section 2. This is followed by a discussion of the analytical model used in the study, and a description of the study regions and data. The results of the analysis are then presented and discussed. Section 6 summarizes the study's findings and provides some concluding comments.

2. Efficiency and frontier production functions

Farrell (1957) distinguishes between technical and allocative efficiency (or price efficiency) in production through the use of a 'frontier' production function. Technical efficiency is the ability to produce a given level of output with a minimum quantity of inputs under certain technology. Allocative efficiency refers to the ability of choosing optimal input levels for given factor prices. Economic or total efficiency is the product of technical and allocative efficiency. An economically efficient input–output combination would be on both the frontier function and the expansion path.

Empirical studies of productive efficiency have used a variety of approaches in modelling frontier production functions; parametric vs. nonparametric, deterministic vs. stochastic, and programming methods vs. statistical methods. Battese (1992) provides a review of parametric efficiency methods, both deterministic and stochastic. Bravo-Ureta and Pinheiro (1993) provide a review of empirical studies relating to farm level production efficiency in developing countries.

Given the alternative empirical tools available, the choice as to the 'best' method is unclear. Little rigorous analysis has been done in assessing the sensitivity of efficiency measures to the choice of methodology. Bravo-Ureta and Rieger (1990) compare the results of deterministic (both programming and econometric analyses) and stochastic parametric efficiency models for a sample of US dairy farms. While the estimates from each approach differ quantitatively, the ordinal efficiency rankings of farms

obtained from the different models appear to be quite similar. This would suggest that, to a certain degree, the choice between alternative modelling approaches may be somewhat arbitrary.

3. Analytical model and empirical methods

This study employs a stochastic parametric decomposition and neoclassical duality model to measure the technical, allocative and economic efficiency of hybrid and conventional rice production in China. The stochastic frontier production function model is specified as follows:

$$Y = f(X_a, \beta) + v - u \quad (1)$$

where Y is output (i.e., yield/ha), X_a denotes the actual input vector (i.e., input use/ha), β is the vector of production function parameters, v is a random error term with zero mean and u is a non-negative one-sided error term.

The frontier production function is represented by $f(X_a, \beta)$, and is a measure of maximum potential output for any particular input vector X_a . Both v and u cause actual production to deviate from this frontier. The random variability in production that cannot be influenced by producers is represented by v (e.g., environmental factors such as temperature and moisture); it is identically and independently distributed as $N(0, \sigma_v^2)$ and may be considered as the ‘normal’ error term. The non-negative error term u represents deviations from maximum potential output attributable to technical inefficiency; u is identically and independently distributed ‘half normal’ (i.e., $|N(0, \sigma_u^2)|$).³

The use of stochastic, parametric methodology is consistent with recent agricultural production efficiency studies (e.g., Bravo-Ureta and Evenson, 1994; Kumbhakar, 1994; Parikh and Shah, 1994). There are also some conceptual advantages to using a

stochastic approach, as it allows for statistical noise rather than attributing all deviations to efficiency differences. Finally, this approach is relatively straightforward to implement and interpret.

A Cobb–Douglas functional form is employed to model rice production technology in this study. While more flexible functional forms than the Cobb–Douglas may be chosen for modelling frontier agricultural production technology (e.g., the translog used by Kumbhakar, 1994), Kopp and Smith (1980) suggest that functional form has a limited effect on empirical efficiency measurement. The Cobb–Douglas form has been used in many empirical studies, particularly those relating to developing country agriculture.⁴ The Cobb–Douglas functional form also meets the requirement of being self-dual, allowing an examination of economic efficiency.

The frontier production function model is estimated using Maximum Likelihood procedures. In order to empirically measure technical efficiency, the deviations from the frontier must be separated into a random component (i.e., v) and an inefficiency component (i.e., u). Given the distributional assumptions for u and v , the Maximum Likelihood estimation provides sufficient information to calculate a conditional mean for u (Jondrow et al., 1982). From this calculation, estimates of u and v may be determined.

Technical efficiency is empirically measured using adjusted output (Y^*) for each firm. Adjusted output represents the observed output (Y) adjusted for statistical noise, and is calculated as follows:

$$Y^* = f(X_a; \beta) - u = Y - v \quad (2)$$

where X_a represents actual input use, $f()$ is the ‘deterministic’ frontier output, and u and v are estimates of the random and inefficiency components of overall deviations from the frontier.

Fig. 1 illustrates the difference between observed and adjusted output. For firm i , X_i is the vector of actual input use and Y_i is the observed output. Given the level of input use, the frontier output is represented by A . This is greater than the deterministic frontier output (i.e., $B = f(X_i; \beta)$) due to favourable

³ Recently, the question of the most appropriate distribution for the compound error term has arisen (Bravo-Ureta and Pinheiro, 1993). While more flexible distributional assumptions may be made for u (e.g., Greene, 1990), there is no rigorous evidence that these improve results. Likewise, most empirical stochastic production function studies use the half-normal distribution.

⁴ The review by Battese (1992) of frontier production functions provides an indication of the frequency with which Cobb–Douglas technology is assumed in these studies.

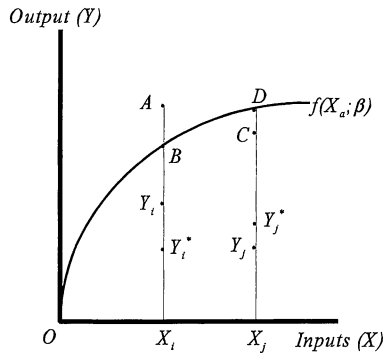


Fig. 1. Stochastic frontier production function.

conditions (i.e., $v_i > 0$). The total deviation from the frontier function for this firm, as defined by Eq. (1) (i.e., $v - u$) is the distance BY_i . This distance may be partitioned into the random component (i.e., $v = AB$) and the inefficiency component (i.e., $u = AY_i$) using the method developed by Jondrow et al. (1982). As indicated by Eq. (2), u_i (i.e., distance AY_i) is subtracted from the deterministic frontier output to obtain the adjusted output for firm i (Y_i^*). Similarly, firm j uses inputs X_j to produce Y_j . Frontier output for this firm is C . The total deviation from the deterministic frontier function (i.e., DY_j) may be partitioned into the random component CD (i.e., $v < 0$) and the inefficiency component CY_j . Adjusted output Y_j^* is equal to the deterministic frontier output minus u_j (i.e., $D - CY_j$).

Adjusted output (Y^*) is used to calculate the technical efficient input vector (X_t). X_t is derived by simultaneously solving Eq. (1) and the input ratios $X_1/X_i = k_i$ ($i > 1$) where k_i is equal to the observed ratio of the two inputs (i.e., from X_a) in the production of Y^* . Battese (1992) provides a detailed explanation of stochastic frontier production function methodology and the calculation of X_t .

Given the assumption of Cobb–Douglas technology, the frontier production function is self-dual. Thus, the corresponding cost frontier can be derived analytically from the stochastic frontier production function estimate. Shephard's lemma is used to determine the set of conditional factor demand functions. These functions provide the economically efficient levels of input use (X_e), given a particular output level and set of input prices. Since the cost

function is derived from the original frontier production function, X_e is both allocatively and technically efficient.

The technically efficient, economically efficient and actual input vectors (X_t , X_e and X_a , respectively) may be combined with the input price vector P to compute technical efficiency (TE), economic efficiency (EE) and allocative efficiency (AE) indices, as follows:

$$TE = (X_t'P)/(X_a'P)$$

$$EE = (X_e'P)/(X_a'P) \quad (3)$$

$$AE = (EE)/(TE) = (X_e'P)/(X_t'P)$$

where $X_t'P$ is the technically efficient cost of production, $X_e'P$ is the economically efficient cost of production, and $X_a'P$ is the actual cost of production for any particular firm's observed level of output. In all cases, efficient production is represented by an index value of 1.0, and lower index values represent less efficient production (i.e., a greater degree of inefficiency).

4. Sample regions and study data

The data used in this study are obtained from a cross-sectional survey of households in Jiangsu province in China. The survey was carried out from July 1985 to January 1986. Jiangsu province is located in the Yangtze River valley and is one of the most important rice producing areas in China, as the region's climate is well suited for rice production. In 1986, the average rice yield in this province was 6.76 metric ton/ha, or 1.56 metric ton more than the national average. The area sown to rice and total rice output of the province, in 1986, represented 7.8 and 9.8%, respectively, of the totals for China.

Jiangsu province can be divided into three rice production regions: north (i.e., north of the Yangtze River valley), central (i.e., along the Yangtze River valley) and south (i.e., south of the Yangtze River valley). While natural agricultural production conditions are similar among these three regions, economic development has been rather unbalanced. In the south, the economy is relatively well developed. Peasants' annual income is approximately two times

Table 1
Economic profile of Jiangsu province, by study region (1986)

	Region ^a		
	South	Central	North
Average level of education for farm labour (yr/person)	6.3	4.8	4.3
Average nonfarm income per household (US\$/yr)	144	90	45
Average capital input into rice production (US\$/ha)	154	127	119
Average labour input into rice production (day/ha ^b)	242	283	293
Average rice yield (ton/ha)	7.39	6.78	6.54

Source: Jiangsu Provincial Statistical Yearbook, 1987.

^aThe locations for the three regions are explained in the main body of the paper.

^bA day is equal to 8 h of labour.

greater in the south than in the north. As shown in Table 1, peasants in the south are better educated than those in the north and central regions. Due to the greater development of non-farm rural industry in the south, farmers in this region also have significantly more off-farm income than those in the north and the central regions (Table 1).

Significant differences also exist among the three regions in terms of relative input use in rice production. As shown in Table 1, the use of capital inputs is highest in the south region (i.e., 29% greater than in the north) and lowest in the north, while labour use on a per hectare basis is lowest in the south (i.e., 17% lower than in the north) and greatest in the north. Given these differences in the characteristics of agriculture between the three rice production regions of Jiangsu province, the north is defined as a traditional agricultural region while the central and the south are classified as more modern agricultural regions, for the purposes of this study.

In establishing the sample for the farm household survey, two counties are selected from each region (i.e., south, central and north) on a random basis. The six counties selected from this process are Wujing and Jurong (south); Taixing and Jiandu (central), and Huaiyin and Dafeny (north). Within each of these counties, 15 conventional rice farmers and 15 hybrid rice farmers are randomly selected as the sample households for the survey. This results in a total sample size of 180 rice households, distributed over 33 villages in the six counties.

Each of these 180 households is surveyed with respect to output levels and input use in rice production, as well as socioeconomic characteristics. Rice

production and input data are collected on a per hectare basis. Rice yield is expressed in terms of metric ton/ha. Data are collected for five productive inputs; labour, chemical fertilizer, manurial fertilizer, machinery and irrigation services, and pesticides. Labour use is expressed as day/ha, with 1 day being equal to 8 h of labour. Chemical fertilizer use is measured as metric tons of pure nutrient per hectare, while manurial fertilizer use is measured in value terms, aggregated by the local price. Machinery and irrigation services are aggregated using tractor service time. Pesticides are measured in terms of kg/ha. In addition to input and output quantities, prices for input and output are collected on a regional average basis.

Socioeconomic characteristics are also collected for the survey sample. These characteristics include household size, total number of years of schooling for household labour, average income from non-rice farm sources, average non-farm income and total area of rice production. These data are used in the analysis to identify important characteristics influencing efficiency of rice production.

5. Empirical results

Cross-sectional data for a sample of 90 hybrid rice (HR) households and 90 conventional rice (CR) households are used to estimate 'average' and frontier rice production functions.⁵ The sample size for

⁵ The average functions are estimated using OLS procedures and represent the results obtained from 'standard' production function analysis.

the CR production function is 100, since some HR households are included in both samples (i.e., produce both hybrid and conventional rice). Dummies are included in the model to represent the south ($D_1 = 1$) and central ($D_2 = 1$) regions. Table 2 presents the maximum likelihood estimates of stochastic frontiers for HR and CR. Standard OLS estimates (i.e., the average functions) are provided for comparison.

Some implications may be drawn from the results shown in Table 2. First, the constant term for the CR function is higher than that for the HR function (5.944 vs. 4.895). This lends credibility to the view that since CR varieties have been adapted over time for use in poor conditions with relatively low capital input use, they have a higher 'basic' yield (Hayami and Ruttan, 1985). Also, the regional yield differences captured by the dummy variables (D_1 and D_2) are much greater for HR production than for CR production, particularly for the south region.

The results in Table 2 also suggest that the response in HR production is much more elastic with respect to chemical fertilizer and pesticides than is the case for CR production. This is also true to a lesser extent for manurial fertilizer and machinery services. The opposite is true for labour input use, however. These results confirm the findings by Fan (1991) that 'modern' inputs (e.g., chemical fertilizers

and machinery services) are becoming more important for Chinese agriculture over time, i.e., with the increase in hybrid rice production. Overall, HR production is more responsive to scale increases in the five inputs modelled in the analysis, i.e., the elasticity of scale for the HR function is 0.804 vs. 0.387 for CR production.

The HR and CR frontier functions are used, in combination with regional average input prices, to derive the frontier cost functions. The resulting cost frontiers are as follows:

$$\begin{aligned} \ln C_{CR} = & -6.005 - 0.134D_1 - 0.269D_2 \\ & + 0.289 \ln P_L + 0.207 \ln P_{CF} \\ & + 0.271 \ln P_{MF} + 0.090 \ln P_{MS} \\ & + 0.142 \ln P_{PE} + 2.584 \ln Y^* \end{aligned} \quad (4)$$

$$\begin{aligned} \ln C_{HR} = & -1.995 - 0.537D_1 - 0.286D_2 \\ & + 0.114 \ln P_L \\ & + 0.383 \ln P_{CF} + 0.199 \ln P_{MF} \\ & + 0.106 \ln P_{MS} + 0.198 \ln P_{PE} \\ & + 1.244 \ln Y^* \end{aligned} \quad (5)$$

where C_{CR} and C_{HR} represent variable costs of CR and HR production per hectare, respectively; Y^* is 'adjusted' rice yield (defined earlier); P_L is labour

Table 2

Average production functions and stochastic frontier functions for hybrid and conventional rice production^{a,b}

Variable	Hybrid rice ($n = 90$)		Conventional rice ($n = 100$)	
	Average	Frontier	Average	Frontier
Constant	4.786 *** (15.56)	4.895 *** (10.31)	5.881 *** (30.79)	5.944 *** (30.91)
D1 (South)	0.459 *** (8.69)	0.432 *** (6.15)	0.057 *** (3.29)	0.052 *** (3.08)
D2 (Central)	0.250 *** (6.20)	0.230 *** (3.69)	0.116 *** (5.38)	0.104 *** (2.64)
Labour	0.082 (1.14)	0.092 (0.85)	0.125* (1.90)	0.112** (2.61)
Chemical fertilizer	0.323 *** (8.72)	0.308 *** (6.30)	0.067 *** (3.14)	0.080 *** (3.89)
Manurial fertilizer	0.163 *** (5.28)	0.160 *** (3.34)	0.104 *** (7.10)	0.105 *** (6.41)
Machinery	0.078** (2.58)	0.085** (2.52)	0.034* (1.41)	0.035* (1.35)
Pesticides	0.156 *** (8.92)	0.159 *** (8.83)	0.056 *** (4.77)	0.055 *** (4.13)
Adjusted R^2	0.80		0.73	
σ_u/σ_v	0.081** (2.09)	2.117** (2.20)		1.619** (2.65)
σ_v^2		0.0034		0.0019
σ_u^2		0.0153		0.0049
Log likelihood		86.9		140

^aThe numbers in parentheses represent t -ratios for the average functions, and asymptotic t -ratios for the frontier functions.

^b*** Represents significance at the 0.01 level; ** Represents significance at the 0.05 level; * Represents significance at the 0.10 level.

cost (Yan/day); P_{CF} and P_{MF} are the unit costs of chemical and manurial fertilizer, respectively; P_{MS} is the of the price of machinery service, measured as the cost of renting tractor services; P_{PS} is the price of pesticides, weighted by the actual use of various pesticides.

Using the cost frontiers, regional average prices and Eq. (3), the economic (EE), technical (TE) and allocative (AE) efficiency indices are computed for each producer. The resulting indices are summarized in Table 3.

One result that may be drawn from Table 3 is that efficiency for HR production is lower than for CR production. This is consistent across regions, and for all three measures of productive efficiency. The relative (i.e., percentage) difference in allocative efficiency is greater than for technical efficiency. Not surprisingly, the greatest difference is in economic

efficiency, since economic efficiency is calculated as the product of technical and allocative efficiencies. The degree of variability in efficiency is also greater for HR production than for CR production, as measured by the standard deviation. This evidence provides support, in the context of Chinese agriculture, to the theory about efficiency and technical progress in traditional agriculture, and supports the ‘poor but efficient’ hypothesis, i.e., farmers are allocatively efficient with traditional varieties.

The other significant result that may be drawn from Table 3 is that productive efficiency is greater in the south than in the north. Efficiency values for the central region lie between those for the north and south. This difference is consistent for both HR and CR production, and for all three measures of productive efficiency. However, the observed differences are greater, on average, for HR production than for CR production.

Relative to previous studies for other rice producing regions, Chinese rice production appears to display greater technical efficiency. For example, average technical efficiency estimates for rice production in the Philippines and Malaysia are 0.50 (Kalirajan and Flinn, 1983) and 0.65 (Kalirajan and Shand, 1986), respectively. These differences are not surprising, as production decisions in China during the relevant time period (i.e., mid-1980’s) were largely controlled by local government, and a goal of the Chinese government at that time was to maximize rice yield. Comparisons for allocative and economic efficiency are not made, as relatively few studies examine these aspects of productive efficiency.

The efficiency calculations reveal significant differences among regions and peasants in HR production. Schumpeterian theory of economic development suggests that technical efficiency is influenced by technical knowledge and understanding, as well as by the socioeconomic environment within which the farmer must make decisions (Kalirajan, 1990). Based on previous studies (Bravo-Ureta and Pinheiro, 1993), three characteristics are chosen as indicators of this socioeconomic environment and are subsequently used as explanatory variables in the analysis of productive efficiency for HR production: (i) education, measured by average years of schooling for household labour; (ii) land size, measured by the total land area cultivated; and (iii) total household

Table 3
Efficiency measures for hybrid and conventional rice, by region^a

			Region ^b		
			South	Central	North
Hybrid rice	TE	Average	0.85	0.78	0.74
		SD	0.11	0.12	0.11
		Maximum	0.90	0.87	0.88
		Minimum	0.64	0.54	0.50
	EE	Average	0.61	0.52	0.49
		SD	0.11	0.11	0.11
		Maximum	0.77	0.76	0.67
		Minimum	0.38	0.33	0.23
	AE	Average	0.72	0.67	0.66
		SD	0.11	0.11	0.13
		Maximum	0.89	0.85	0.79
		Minimum	0.52	0.46	0.45
Conventional rice	TE	Average	0.94	0.91	0.87
		SD	0.05	0.04	0.04
		Maximum	0.98	0.97	0.97
		Minimum	0.87	0.81	0.84
	EE	Average	0.83	0.80	0.74
		SD	0.08	0.08	0.04
		Maximum	0.93	0.93	0.93
		Minimum	0.62	0.64	0.56
	AE	Average	0.88	0.86	0.85
		SD	0.07	0.10	0.10
		Maximum	0.97	0.96	0.96
		Minimum	0.77	0.68	0.53

^aTE, EE and AE refer to technical efficiency, economic efficiency and allocative efficiency, respectively.

^bThe locations for the three regions are explained in the main body of the paper.

Table 4

Statistical analysis of socioeconomic factors influencing efficiency of hybrid rice production^{a,b}

Region ^c		Socioeconomic factors				
		Education	Land size	Non-farm income	R ²	F
South	HREE	0.0127 * (1.17)	0.0152 ** (3.32)	0.0020 * (1.73)	0.63	14.1
	HRTE	0.0093 ** (2.82)	0.0027 * (2.40)	0.0010 ** (2.45)	0.49	7.4
	HRAE	0.0019 (1.34)	0.0141 ** (3.39)	0.0030 ** (2.69)	0.61	11.2
Central	HREE	0.0028 * (1.65)	−0.0129 ** (−2.33)	0.0010 ** (2.20)	0.42	5.2
	HRTE	0.0006 ** (1.18)	0.0031 * (1.92)	0.0010 * (1.74)	0.45	5.7
	HRAE	0.0045 (1.23)	−0.0126 ** (−2.49)	0.0020 * (1.76)	0.46	6.3
North	HREE	0.0012 (1.35)	−0.0041 * (−1.86)	0.0010 * (1.30)	0.36	4.6
	HRTE	0.0161 ** (3.78)	−0.0017 (−1.40)	0.0013 ** (1.83)	0.61	12.7
	HRAE	0.0026 (1.39)	−0.015 ** (3.78)	0.0011 ** (1.75)	0.31	4.4

^aHREE, HRTE and HRAE are estimated economic, technical and allocative efficiency indices, respectively, for hybrid rice production.^bThe numbers in parentheses are *t*-values. * * Represents significance at the 0.05 level; * Represents significance at the 0.10 level.^cThe locations for the three regions are explained in the main body of the paper.

non-agricultural income. OLS procedures are used to estimate the relationship between productive efficiency and these characteristics.

The underlying assumption in this type of procedure is that the explanatory variables are exogenous to the decisions made by producers. While this is likely true for land size and education, it is not normally the case for non-farm income.⁶ Given the differences between regions in terms of off-farm employment opportunities, however, it may be argued that to a certain extent non-farm income is exogenous. Likewise, Kalirajan (1991) argues that since variables such as farm size, education and non-farm income have indirect influences on technical efficiency, it is appropriate to include these in a secondary analysis.

The results of this analysis are presented in Table 4. Overall, the explanatory ability of the three variables included in the analysis is limited (i.e., R^2 values are generally less than 0.5), and not all regressions or parameter estimates are significant. Education appears to be a significant factor in explaining technical efficiency, but not as significant for allocative efficiency. A positive relationship appears to exist between land size, and economic and allocative efficiency in modern agricultural regions (i.e., the south), while the opposite is true for traditional

agricultural areas (i.e., the north). This suggests that the predominantly small farm sizes may pose a constraint to technical change in more modern regions, but not in more traditional agricultural production areas. A similar analysis was conducted for CR production, but no significant relationships were found.

6. Concluding comments and policy implication

This paper uses a stochastic production and cost frontier to derive technical, allocative and economic efficiency of Chinese conventional rice and hybrid rice production. The results suggest that while HR production increases the potential economies of scale for Chinese rice production, observed productive efficiencies are lower than for CR production. The results of this study are consistent with 'poor but efficient' hypothesis; peasants are more efficient in allocating inputs for CR production than for HR production. This is consistent for both modern and traditional agricultural areas.

Facing increasing population pressures, China has adopted policies designed to improve technical efficiency and total productivity. This study reveals a positive relationship between efficiency and education for HR production, thus, emphasizing the importance of considering peasants' abilities to receive and understand information relating to new agricultural technology. This study also determines that land size

⁶ The authors gratefully acknowledge the comments of an anonymous reviewer for raising this issue.

is a positive factor in explaining the efficiency of HR in modern agricultural areas. This suggests that in modern agricultural regions, the predominantly small farm size may pose a restraint to technical change and thus, supports the argument for further liberalization in land markets.

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