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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.

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 Ingersent 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 varieties[1] have become increasingly important in Chinese rice production, relative to "conventional" rice varieties, which are predominantly improved semi-dwarf varieties. In 1990, approximately 40 percent of China's rice was planted in hybrid rice (Lin 1994). China is the only country in the world in which hybrid rice is widely used in commercial production.[2]

Due to the nature of China's economy (i.e., centrally planned), the government often influences the diffusion of new agricultural technologies. 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 socio-economic characteristics would be useful in addressing these issues. To date, little attention has been given to the examination of efficiency for hybrid rice production in China.[3]

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; that is, 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 socio-economic characteristics in order to provide information that may be useful in analyzing 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 organized as follows. A brief review of frontier production function methodology is provided in the next section. 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. The final section summarizes the study's findings and provides some concluding comments.

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 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 using frontier production function methodology to measure productive efficiency can be differentiated on the basis of two criteria. The first of these relates to the use of parametric methods versus nonparametric methods. Parametric methods involve specification of a particular functional form, while nonparametric methods do not have this requirement.

Production efficiency studies may also be differentiated on the basis of whether they utilize deterministic or stochastic methods (i.e., the second criterion). Deterministic methods assume that all deviations from the frontier function result from inefficiency.[4] Stochastic methods allow for some deviation to be attributable to statistical noise.

The vast majority of empirical studies have utilized parametric approaches to measuring production efficiency. Battese (1992) provides a review of parametric efficiency models, both deterministic and stochastic. Deterministic frontier functions can be estimated using two alternative approaches; programming models and statistical models (i.e., econometric analysis). Stochastic frontier functions are estimated through the use of statistical models. Both deterministic and stochastic modelling approaches have received widespread use in the analysis of production efficiency for developing countries.[5]

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 U.S. 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 deterministic and stochastic methods is somewhat arbitrary.

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 use of this 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, it is relatively straightforward to implement and interpret.

The stochastic frontier production function model is specified as follows:

$$\mathbf{Y} = \boldsymbol{f}(\boldsymbol{X_a}, \boldsymbol{\beta}) + \boldsymbol{v} - \boldsymbol{u} \qquad \textbf{(1)}$$

where Y is output, X_a denotes the actual input vector, 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; it is identically and independently distributed as $N(0, \sigma_v^2)$. 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., $|N(0, \sigma_u^2)|$).

In recent studies, the question of the most appropriate distribution for the compound error term has arisen.[6] Greene (1990) proposes a modified frontier model that includes a one-sided error term specified using a Gamma distribution, rather than the half-normal. However, Greene does not provide a test of this specification. While more flexible distributional assumptions can be made for u, most empirical stochastic frontier production function studies use the half-normal distribution. The assumption of a half-normal distribution is also maintained in this study.

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.[7] 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. The technical efficient input vector (X_t) for a given output (Y^0) is derived by simultaneously solving (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 production of Y^0. 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 as the following form:

$$\mathbf{C} = \mathbf{V}(\mathbf{P}, \mathbf{Y}) \qquad \textbf{(2)}$$

where C is the minimum cost of producing output Y, given the vector of factor prices, P. Applying Shephard's lemma, the set of factor demand functions (in vector notation) may be written as follows:

$$\frac{\partial \mathbf{C}}{\partial \mathbf{P}} = \mathbf{X}(\mathbf{P}, \mathbf{Y}) = \mathbf{X_e} \qquad \textbf{(3)}$$

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

$$\begin{aligned} \mathbf{TE} &= (\mathbf{X}_t^{'}\mathbf{P})/(\mathbf{X}_a^{'}\mathbf{P}) \\ \mathbf{EE} &= (\mathbf{X}_e^{'}\mathbf{P})/(\mathbf{X}_a^{'}\mathbf{P}) \\ \mathbf{AE} &= (\mathbf{EE})/(\mathbf{TE}) = (\mathbf{X}_e^{'}\mathbf{P})/(\mathbf{X}_t^{'}\mathbf{P}) \end{aligned} \tag{4}$$

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).

Following the method used by Bravo-Ureta and Evenson (1992), which is based on Jondrow et al (1982), efficiency is empirically measured using adjusted output, as follows:

$$\mathbf{Y}^* = f(X_a ; \beta) - u \tag{5}$$

where u is calculated as:

$$E(u_i/\epsilon_i) = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{f^*(\epsilon_i\lambda/\sigma)}{1-F^*(\epsilon_i\lambda/\sigma)} - \frac{\epsilon_i\lambda}{\sigma}\right] \tag{6}$$

In (6), f*(•) and F*(•) are the standard normal density and cumulative distribution functions, respectively, $\lambda = \sigma_u/\sigma_v$, $\epsilon = v-u$, and $\sigma^2=\sigma_v^2+\sigma_u^2$. Y^* is observed output, adjusted for statistical noise. This adjusted output forms the basis for calculating X_t.

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 tons per hectare, or 1.56 metric tons more than the national average. The area sown to rice and total rice output of the province, in 1986, represented 7.8 percent and 9.8 percent, 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 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 percent 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 percent lower than in the north) and greatest in the north. Given these differences in the characteristics of agriculture between the three rice production

Table 1: Economic Profile of Jiangsu Province, by Study Region (1986)

		Region[a]		
		South	Central	North
Average Level of Education for Farm Labour	years/person	6.3	4.8	4.3
Average Nonfarm Income per Household	US$/year	$144	$90	$45
Average Capital Input into Rice Production	US$/hectare	$154	$127	$119
Average Labour Input into Rice Production	days/hectare[b]	242	283	293
Average Rice Yield	tonnes/hectare	7.39	6.78	6.54

Source: Jiangsu Provincial Statistical Yearbook, 1987.

[a] The locations for the three regions are explained in the main body of the paper.
[b] A day is equal to eight hours of labour.

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.[8] Within each of the six counties chosen using this method, 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 socio-economic characteristics. Rice production and input data are collected on a per hectare basis. Rice yield is expressed in terms of metric tons per hectare. Data are collected for five productive inputs; labour, chemical fertilizer, manurial fertilizer, machinery and irrigation services, and pesticides. Labour use is expressed as days per hectare, with one day being equal to 8 hours 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 servicetime. Pesticides are measured in terms of kilograms per hectare. In addition to input and output quantities, prices for inputs and output are collected on a regional average basis.

Socio-economic 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.

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.[9] The sample size for 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

Table 2: Average Production Functions and Stochastic Frontier Functions for Hybrid and Conventional Rice Production[ab]

	Hybrid Rice (n=90)		Conventional Rice (n=100)	
Variable	Average	Frontier	Average	Frontier
Constant	4.786***	4.895***	5.881***	5.944***
	(15.56)	(10.31)	(30.79)	(30.91)
D1 (South)	0.459***	0.432***	0.057***	0.052***
	(8.69)	(6.15)	(3.29)	(3.08)
D2 (Central)	0.250***	0.230***	0.116***	0.104**
	(6.20)	(3.69)	(5.38)	(2.64)
Labour	0.082	0.092	0.125*	0.112**
	(1.14)	(0.85)	(1.90)	(2.61)
Chemical Fertilizer	0.323***	0.308***	0.067***	0.080***
	(8.72)	(6.30)	(3.14)	(3.89)
Manurial Fertilizer	0.163***	0.160***	0.104***	0.105***
	(5.28)	(3.34)	(7.10)	(6.41)
Machinery	0.078**	0.085**	0.034*	0.035*
	(2.58)	(2.52)	(1.41)	(1.35)
Pesticides	0.156***	0.159***	0.056***	0.055***
	(8.92)	(8.83)	(4.77)	(4.13)
Adjusted R^2	0.80		0.73	
σ_u / σ_v		2.117**		1.619**
		(2.20)		(2.65)
$\sqrt{\sigma_v^2 + \sigma_u^2}$		0.137***		0.081**
		(8.78)		(2.09)
σ_v^2		0.0034		0.0019
σ_u^2		0.0153		0.0049
Log Likelihood		86.9		140

[a] The 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 and * represents significance at the 0.10 level.

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 versus 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; that is, 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 versus 0.387 for CR production) although both functions exhibit decreasing returns to scale.

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:[10]

$$\begin{aligned} LnC_{CR} = & -6.005 - 0.134 D_1 - 0.269 D_2 + 0.289 LnP_L \\ & + 0.207 LnP_{CF} + 0.271 LnP_{MF} + 0.090 LnP_{MS} \\ & + 0.142 LnP_{PE} + 2.584 LnY^{*} \end{aligned} \qquad (7)$$

$$
\begin{aligned}
LnC_{HR} = & -1.995 - 0.537D_1 - 0.286D_2 + 0.114LnP_L \\
& + 0.383LnP_{CF} + 0.199LnP_{MF} + 0.106LnP_{MS} \\
& + 0.198LnP_{PE} + 1.244LnY^* \qquad (8)
\end{aligned}
$$

where C_{CR} and C_{HR} represent variable cost of CR and HR production per hectare, respectively; Y^* is "adjusted" rice yield (defined earlier); P_L is labour 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 (4), 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, that is, farmers are allocatively efficient with traditional varieties.

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
		Std. Dev.	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
		Std. Dev.	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
		Std. Dev.	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
		Std. Dev.	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
		Std. Dev.	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
		Std. Dev.	0.07	0.10	0.10
		Maximum	0.97	0.96	0.96
		Minimum	0.77	0.68	0.53

[a] TE, EE and AE refer to technical efficiency, economic efficiency and allocative efficiency, respectively.

[b] The locations for the three regions are explained in the main body of the paper.

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. The observed differences are greater, on average, for HR production than for CR production, however.

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. Based on previous studies (see Bravo-Ureta and Pinheiro for a review of these studies), three characteristics are chosen as explanatory variables in the analysis of productive efficiency for HR production; education, measured by average years of schooling for household labour; land size, measured by the total land area cultivated; and total household non-agricultural income. OLS procedures are used to estimate the relationship between productive efficiency and these characteristics. The results 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

Table 4: Statistical Analysis of Socio-Economic Factors Influencing Efficiency of Hybrid Rice Production[ab]

		Socio-Economic 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

[a] HREE, HRTE and HEAE are estimated economic, technical and allocative efficiency indices, respectively, for hybrid rice production.

[b] The numbers in parentheses are t-values. ** represents significance at the 0.05 level and * represents significance at the 0.10 level.

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.

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 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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Notes

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. Since the mid-1980's, hybrid rice has been introduced to some other rice producing countries.
3. Other studies have examined economic issues related to the adoption and production of hybrid rice (e.g., He et al 1984, 1987; Lin 1991ab, 1992, 1994).
4. Farrell's original frontier function model is deterministic and nonparametric in nature, and attributes all deviations from the frontier to inefficiency.
5. Bravo-Ureta and Pinheiro (1993) provide a review of empirical studies relating to farm level production efficiency in developing countries. Their review includes information relating to country, commodity, type of approach, type(s) of efficiency measured, and where appropriate, types of socio-economic characteristics considered in explaining efficiency levels.
6. Bravo-Ureta and Pinheiro (1993) provide a discussion of this

methodological issue.

7. Battese's (1992) review of frontier production function studies provides an indication of the frequency with which Cobb-Douglas technology is assumed in these studies.

8. The six counties selected from this process are Wujing and Jurong (south), Taixing and Jiandu (central), and Huaiyin and Dafeny (north).

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

10. The process of deriving a cost function from a Cobb-Douglas production function is relatively straightforward. An example of the derivation is provided by Beattie and Taylor (1985; pp. 239-40).