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Stochastic frontier production function and technical efficiency estimation: A case study on irrigated rice in Myanmar

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Abstract

This paper deals with issues of improving efficiency and productivity on irrigated rice in Myanmar. It uses the stochastic frontier analysis approach to the estimation of production functions from cross-sectional data during the 1997 crop season. The empirical results indicate that in the sample irrigated area seed rate use in rice production would have an important role in increasing total output. In addition, in order to increase efficiency of the rice farms it is required to improve the human resource capability and extension knowledge for the improvement of rice productivity. The significant technical inefficiency effects exist for large farmers who use fertiliser and for small and large farmers who do not use fertiliser.

Key words: irrigated rice production, technical efficiency, stochastic production frontier, Myanmar

1. Introduction

Several recent publications have drawn attention to the problem of current slowing down of the momentum in production of rice to keep pace with the need for the future demand (Crosson and Anderson, 1992; FAO, 1993; Pinstrup-Andersen, 1993; Plucknett, 1993). As one of the rice producing countries in southeast Asia, the importance of rice sub-sector in agriculture plays a principal role in Myanmar's economy in terms of share in the gross domestic product, in employment and in foreign exchange earnings. Rice accounts for about 47% of the total cropped area. Rice farming is the most important source of income for the farmers and determines food security as a whole. Government policies place a high emphasis on the provision of technical and material support for the rice farmers. Until late 1990s, the supply of input such as the improved seed varieties, fertiliser, pesticide and improved farm tools and implements were supported by the government institution. This can be seen as one of the alternative approaches towards improvement of the technical efficiencies of the semi-subsistence farmers. It is argued that there may be an ascertainable relation between the exposure to the production of rice and overall farm technical efficiency. Over the last decade, the yield of rice per acre has not changed so that there was no significant improvement in productivity of rice after the green revolution. In order to analyse the real productivity in rice production in Myanmar it is important to consider the efficiency in the use of resources among farmers. If there are significant opportunities for increasing productivity through more efficient use of resources at farmer's level, improving access to resources (input delivery, infrastructure, irrigation investment) and introducing technological innovations would rather be the right strategy to improve production.

The modelling and estimation of stochastic frontier production functions, originally proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), has been an important area of economic study in the last two decades. Frontier production functions are useful to provide information about the relationship between the amount of output and the inputs of production, given the level of technology involved. In recent years, stochastic frontier models in agricultural economics have been used by Battese and Tessema (1993), Tran, Coelli and Fleming (1993), Kanjilal, Zapata and Heagler (1993), Battese, Malik and Broca (1993), Ajibefun, Battese, and Kada (1996), Battese and Broca (1997), Seyoum, Battese and Fleming (1998), Abdulai and Huffman (1998) and many others. In this study, stochastic production frontier function and the technical inefficiency effects for a cross-sectional data of irrigated rice farmers are modelled in terms of some farmer-specific and inputs variables in the production process. To our knowledge stochastic frontier production function has not previously been estimated using data on irrigated rice production.

The objectives of the analysis are (1) to analyse the level of resource use under different farm sizes given the current technology (2) to estimate frontier production functions of efficient technology (3) to determine technical efficiency scores of respective rice farmers, and (4) to investigate the influence of farm-specific inputs on technical inefficiency.

The paper is organised as follow. Section 2 provides information on data source and sampling method. It also elaborates on the concept of stochastic frontier and technical inefficiency effects. In section 3, the models of stochastic frontier and inefficiency effect are applied in the irrigated rice farmers within the context of a stochastic Cobb-Douglas and Translog production frontier. Section 4 covers the empirical result for frontier and farm level estimates of technical efficiency. Concluding remarks are drawn in section 5.

2. Data and methodology
2.1. Data for farm level rice production studies

The data used in these analyses are based on study of market access to productivity which is a part of Ph. D. Thesis1 by the senior author. Yemethin district in Myanmar was chosen at random as a representative region for irrigated rice to be involved in the survey. Twelve villages were selected by simple random sampling, from which samples of fifteen farmers were selected. The questionnaire was constructed to ask for details about the irrigated rice production at the farms. In particular, there was interest in the area grown, the yields obtained, the use of inputs, such as fertiliser, seed, and pesticides. Information was also obtained on social characteristics of the sample farmers. Data on a total of 180 sample farmers were obtained in the survey. However, to tackle the missing data problem only 162 sample farmers were taken into account in this concern. The output and input data were obtained on a per acre basis in the survey.

2.2. Parametric stochastic frontier and estimation method

The stochastic frontier model was originally proposed for the analysis of the panel data by Battese and Coelli (1995). However, a general stochastic frontier production function for the cross-sectional data, which is considered in this paper, is defined by

$$Y_i = \exp(X_i \beta + V_i - U_i) \qquad (1)$$

where

1 Financial support from the DAAD is gratefully acknowledged.

Y_i denotes the output for the i[th] sample farm

X_i represents a (1 x K) vector whose values are functions of inputs and other explanatory variables for the i[th] farm

β is a (K x 1) vector of unknown parameters to be estimated

V_is are assumed to be independent and identically distributed random errors which have normal distribution with mean zero and unknown variance σ_v^2 and

U_is are non-negative unobservable random variables associated with the technical inefficiency of production, such that for a given technology and levels of inputs, the observed output falls short of its potential output.

Technical inefficiency effect model proposed by Battese and Coelli (1995) is described by

$$U_{it} = \delta_0 + \delta_i Z_{it} \qquad (2)$$

where

Z_{it} is a (1 x M) vector of explanatory variables associated with the technical inefficiency effects in the t[th] time period

δ is an (M x 1) vector of unknown parameters to be estimated

Battese and Coelli (1988) considered the maximum likelihood estimator which involves specification of the distribution of V_i and U_i. The random variables V_i and U_i are assumed to be mutually independent and independent of the input variables in the model. If $U_i = 0$, the assumed distribution is half-normal. Where outputs are expressed in logarithms, the technical efficiency of the i[th] farm is estimated as a ratio of the observed to maximum feasible output, where the latter is provided by the stochastic frontier production. The measure of technical efficiency is given by

$$TE_i = \exp(X_i\beta + v_i - \mu_i) / \exp(X_i\beta + v_i) \qquad (3)$$

$$TE_i = \exp(-\mu_i) \qquad (4)$$

If $U_i = 0$, the farm were 100 percent efficient. Maximum-likelihood estimates of the parameters in the model are obtained using FRONTIER 4.1 which is developed by Coelli, 1994. The parametric model is estimated in terms of the variance parameters, $\sigma_s^2 = \sigma^2 + \sigma_v^2$ and $\gamma = \sigma^2 / (\sigma^2 + \sigma_v^2)$. In case of cross-sectional data, the technical inefficiency model can only be estimated if the inefficiency effects U_i's are stochastic and have particular distributional properties (Battese and Coelli, 1995). Therefore it is of interest to test the null hypotheses that technical inefficiency effects, γ, are non-stochastic. The parameter, γ, has a value between zero and one, in such a way that it is desirable to test the null hypothesis of H_o: $\gamma = 0$ whether traditional production function is a adequate representation of the sample data. If so, the non-negative random variable μ_i is absent from the model. The generalised likelihood-ratio test statistic can be calculated from the logarithms of the likelihood function associated with the unrestricted and restricted maximum likelihood estimates for the special case in which the appropriate parameter is zero by using the program FRONTIER 4.1 (Battese and Tessma, 1993).

Test of hypothesis for the parameters of the frontier model is conducted using the generalised likelihood-ratio statistics, λ, defined by

$$\lambda = -2\log[L(H_1) - L(H_0)] \qquad (5)$$

where $L(H_0)$ is the value of the likelihood function for the frontier model, in which parameter restrictions specified by the null hypothesis, H_0, are imposed; and $L(H_1)$ is the value of the likelihood function for the general frontier model. If the null hypothesis is true, then λ has approximately a chi-square (or mixed square) distribution with degrees of freedom equal to the difference between the parameters estimated under H_1 and H_0, respectively.

3. A stochastic frontier model for irrigated rice farmers

The model proposed for the analysis of rice yields involves a stochastic frontier production function, in which the parameters of the production function are specified to be a function of the variables associated with an input variable, like land, labour, fertiliser, etc. The different factors of production involved may affect the responsiveness of the crop. The models are presented in terms of a Cobb-Douglas and Translog production functions in which the former can only allow constant return to scale and the latter has more flexibility. Two functional forms for the stochastic frontier production function to be estimated are described by

$$LogY_i = \beta_0 + \sum_{j=1}^{7} \beta_j LogX_{ji} + (V_i - U_i) \qquad (6)$$

$$LogY_i = \beta_0 + \sum_{j=1}^{7} \beta_j LogX_{ji} + \Sigma \sum_{j=1}^{6} \beta_j (LogX_{ji})(LogX_{ji}) + (V_i - U_i) \quad (7)$$

These models are separately considered for two categories which are farm size groups and fertiliser utilisation. In the first case three different farm sizes (small, medium, and large) are analysed in order to differentiate any difference in efficiency among farms assuming that there is scale efficiency. In the latter case we will take into consideration for farmers who use fertiliser and for those who do not use fertiliser.

The above models (6 and 7) are production functions, in which the inefficiency effect is subtracted because observed outputs are no larger than their corresponding stochastic frontier, because of the presence of inefficiency use in producing outputs involved. The non-negative random variables U_i in equation (6) implies that the observed input variables for a given level of output and quasi-fixed inputs are not as small as would be possible if the farms were fully efficient in their use of inputs. The flexible functional form of the Translog function is specified in equation (7) so that more general technologies can be accounted for than is possible with the Cobb-Douglas model.

where Log represents the logarithm base 10;
the subscript i represents the i^{th} sample rice farmer
the subscript j represents number of input and farm-specific variables[2]
Y represents yield of the irrigated rice in basket per acre

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2 Farm specific variables are considered for inefficiency effect model.

X_1 represents the land area (in acre) on which irrigated rice were grown on the i^{th} farm
X_2 represents family labour in men equivalent3 on the i^{th} farm
X_3 represents the quantity of seed in kilogram sown on the i^{th} farm
X_4 denotes the amount of urea fertiliser in kilogram applied on land for irrigated rice on the i^{th} farm
X_5 is the cost of hired labour for different farming activities on the i^{th} farm
X_6 is the cost of pesticide in value per unit land area on the i^{th} farm
X_7 is a dummy variable, which has value one if i^{th} farmer used manure for soil fertility improvement and value zero otherwise
β_j j = 0, 1,..., 7 are parameters to be estimated
V_i's are assumed to be independent and identically distributed N (0, σ_v^2) random variables
U_i's are assumed to be independent and identically distributed non-negative truncations of the N (μ, σ^2) distribution

$$U_i = \delta_0 + \sum_{j=1}^{4} \delta_j Z_{ji} \qquad (8)$$

Z_{ji} are values of explanatory variables for the technical inefficiency effects for the i-th farmer,
Z_1 is the age of the i^{th} farmers
Z_2 is the years of farming for the i^{th} farmers
Z_3 is a dummy variable, which has value one if i^{th} farmer has secondary and higher level of education and value zero otherwise
Z_4 is a dummy variable, which has value 1 if i^{th} farmers received extension support from the government institution and value zero otherwise
δ_j j = 0, 1, ..., 4 are unknown scalar parameters

The specification of the model for the inefficiency effects in equation (8) implies that in addition to accounting for the existence of inefficiency effects in the use of inputs in producing output, we assume that the variations in the inefficiency effects are a function of other variables. These are the age of the farmers, farming experience in terms of year, level of education for farmers and extension support from the government's institution. The inefficiency effects are assumed to change in linear function.

5. Empirical results

In this section, the results of summary statistics, the estimates of the parameters of the stochastic Cobb-Douglas and Translog function, and those of the model relating to inefficiency effect are presented and discussed.

3 Men equivalent is calculated using the formula in which one adult male equals one man; one female or one child equals 0.75 or 0.50 male, respectively.

5.1. Summary statistics of input, output and farm-specific variables

Table 1 to 3 describe a detailed summary of the output and input variables involved in the frontier production function for different farm size groups and fertiliser utilisation categories. Sample means and sample standard deviations, along with the minimum and maximum, are given. Mean yields for fertiliser use-farmer vary from 54 basket4 per acre (2.8 ton/ha), with a range of 24 to 80 basket per acre (1.2 to 4.1 ton/ha) for large farm, to 62 basket per acre (3.2 ton/ha) with a range of 36 to 90 basket per acre (1.8 to 4.6 ton/ha) for small farm. The yield gap for large farm between the average and the lowest yield is 30 basket per acre (1.5 ton/ha), and that between the average and the highest is 26 basket per acre (1.3 ton/ha), suggesting that there is a considerable scope for improving average rice yield in the study area. Similar results are also found in small farms. For those who do not use fertiliser irrigated rice has a yield level of 43 basket per acre (2.2 ton/ha) on large farms and of 55 basket per acre (2.8 ton/ha) on small farms. It is well documented that there is a yield difference between farmers who use fertiliser and those who do not use fertiliser. Another finding shows that small farm attains higher yield than large farm.

Table 1. Summary statistics for variables in the stochastic frontier production function for small farms in Myanmar

Variables (unit)	**Mean**		**Minimum**		**Maximum**	
	Fertiliser use	No-fertiliser use	Fertiliser use	No-fertiliser use	Fertiliser use	No-fertiliser use
Output variable						
Yield (bskt /acre)	62.22(15.6)	55.87(15.74)	36.6	40	90	100
Input variables						
Farm size (acre)	2.26(0.66)	2.29(0.76)	1	1	3	3
Family labour(m.e)	1.94(1.13)	1.98(1.16)	1	1	4.5	5.5
Seed rate (kg/ac)	59.59(18.5)	46.34(17.0)	27.12	20.86	104.3	83.4
Urea fertiliser (kg/ac)	45.77(30)		2.5		100	
Cost of hired labour (ks/ac)	3409(1528.8)	3335(1119.1)	690	1350.0	6992.9	6683.3
Manure use (dummy)	0.66(0.48)	0.50(0.51)	0	0	1	1
Variables for inefficiency effect						
Household age (year)	45.7(13.37)	50.3(11.7)	29	32	74	72
Farming year (year)	20.5(12.94)	20.1(8.25)	2	10	50	47
Level of education (dummy)	0.24(0.44)	0.05(0.21)	0	0	1	1
Extension contact (dummy)	0.72(0.45)	0.55(0.51)	0	0	1	1

Figure in parentheses indicate the standard deviation of the corresponding value
Source: based on survey data

4 A basket, which is equal to 20.86 kilograms, is the traditional measure of yield used by farmers

Table 2. Summary statistics for variables in the stochastic frontier production function for medium farms in Myanmar

Variables (unit)	**Mean**		**Minimum**		**Maximum**	
	Fertiliser use	Non-fertiliser use	Fertiliser use	No-fertiliser use	Fertiliser use	No-fertiliser use
Output variable						
Yield (bskt /acre)	59.17(13.16)	50.91(12.45)	28.6	37	87.5	90
Input variables						
Farm size (acre)	5.49(1.15)	5.24(1.01)	3.3	4	7.5	7.15
Family labour(m.e)	1.86(1.07)	2.45(1.31)	0.5	1	5.0	5.5
Seed rate (kg/ac)	54.31(19.2)	45.32(13.47)	20.86	22.53	83.44	62.58
Urea fertiliser (kg/ac)	40.69(27.79)		1.5		100	
Cost of hired labour (ks/ac)	3779(1946.8)	2680.(996.9)	1140	450	8112.2	4945.17
Manure use (dummy)	0.71(0.46)	0.65(0.48)	0	0	1	1
Variables for inefficiency effect						
Household age (year)	49.71(10.6)	52.13(11.59)	29	28	70	67
Farming year (year)	25(11.1)	25.39(11.01)	6	2	55	50
Level of education (dummy)	0.47(0.50)	0.13(0.34)	0	0	1	1
Extension contact (dummy)	0.80(0.40)	0.56(0.51)	0	0	1	1

Figure in parentheses indicate the standard deviation of the corresponding value; Source: based on survey data

Table 3. Summary statistics for variables in the stochastic frontier production function for large farms in Myanmar

Variables (unit)	**Mean**		**Minimum**		**Maximum**	
	Fertiliser use	Non-fertiliser use	Fertiliser use	Non-fertiliser use	Fertiliser use	Non-fertiliser use
Output variable						
Yield (bskt /acre)	54.74(12.34)	43.27(17.36)	24	25	80	91.25
Input variables						
Farm size (acre)	11.85(3.63)	10.62(4.55)	8	8	22	23.82
Family labour(m.e)	1.86(0.79)	1.83(2.07)	0.5	0.5	4	8.25
Seed rate (kg/ac)	51.99(19.24)	46.8(17.26)	20.86	27.74	83.44	83.44
Urea fertiliser (kg/ac)	38.89(28.66)		2		100	
Cost of hired labour (ks/ac)	3201(1219.7)	2783(907.9)	1569.49	1525	5904.76	4550
Cost of pesticide (ks/ac)	108.01(78.44)	7.87(18.42)	26.25	0	325.71	50
Manure use (dummy)	0.67(0.48)	0.50(0.52)	0	0	1	1
Variables for inefficiency effect						
Household age (year)	52.30(12.34)	51.67(13.53)	28	25	72	67
Farming year (year)	29.53(15)	25.75(12.44)	1	5	56	45
Level of education (dummy)	0.50(0.51)	0.33(0.49)	0	0	1	1
Extension contact (dummy)	0.80(0.41)	0.50(0.52)	0	0	1	1

Figure in parentheses indicate the standard deviation of the corresponding value; Source: based on survey data

Every farm size group for fertiliser-use farmers provides average of almost two family labour involved in the farming of rice. For those who do not use fertiliser it varies from 2 to 2.5 men. It appears that family labour use is higher in no-fertiliser user than in fertiliser-use farmers.

In case of fertiliser use farmers the variation in average seed rate use is much smaller across the farm sizes, ranging from 59 kg per acre for small farms to 52 kg per acre for large farms. In medium farms farmers use 54 kg per acre. Those who do not use fertiliser apply lower seed rate as indicated in Table 1 to 3.

There is a considerable variation in the amount of urea use per acre. It ranges from 45 kg per acre for small farms to 39 kg per acre for large farms. In medium farms the fertiliser use is 41 kg per acre.

The average cost of hired labour for different farming activities, which include ploughing, harrowing, transplanting, weeding, intercultivation, harvesting, threshing and winnowing, is the highest in medium farms followed by small and large farms in fertiliser use farmers.

Among the no-fertiliser use farms, small farms have the highest cost than the others. It might reflect that small farms intensify more in labour use other than fertiliser application.

To improve the soil fertility around 65-70% of farmers, who do use fertiliser, are using manure as a nitrogen source. However, these percent is found to be lower in those without fertiliser application.

5.2. Tests of hypotheses

The maximum-likelihood estimates of the parameters for stochastic frontier models are obtained for fertiliser use and no-fertiliser use farmers and for different farm sizes using the FRONTIER 4.1. Two types of hypothesis tests are conducted.

(1) The traditional response function involving no inefficiency effect is examined under the generalised likelihood-ratio statistic, $\lambda = -2\log[L(H_1) - L(H_0)]$ for each category. $L(H_0)$ and $L(H_1)$ are the likelihood functions evaluated at the restricted and unrestricted maximum-likelihood estimators for the parameters of the frontier model. The generalised likelihood-ratio (LR) statistic has approximately chi-square distribution with parameter equal to the number of restrictions less one (Griffiths, Hill and Judge, 1993). Results of LR test mentioned in Table 4 to 6 convinced the preferred frontier models as follows:

Farm size group	Fertiliser use farmer	No-fertiliser use farmer
Small	Traditional average response function	Cobb Douglas stochastic frontier
Medium	Traditional average response function	Traditional average response function
Large	Cobb-Douglas/Translog stochastic frontier	Cobb-Douglas stochastic frontier

Table 4. Maximum-likelihood estimates for parameters of the stochastic frontier production functions for irrigated rice farmers for small farm size

Variables	Parameter	Small farm size (1-3 acre)			
		Fertiliser use farmer (n=29)		No-fertiliser use farmer (n=22)	
		Cobb-Douglas	Translog	Cobb-Douglas	Translog
Stochastic frontier					
Constant	β_0	0.963(1.28)	-9.66(14.03)	1.913(4.83)	-11.85(-2.55)
Holding size	β_1	-0.027(-0.09)	0.005(0.021)	-0.126(-1.35)	-0.47(-1.31)
Permanent family labour	β_2	0.179(1.24)	-0.05(-0.25)	-0.289(-3.7)**	0.013(0.08)
Seed rate	β_3	0.047(0.26)	9.19(10.02)**	0.359(3.44)**	-1.37(-0.86)
Urea fertiliser	β_4	-0.015(-0.31)	-0.66(-4.21)**		
Cost of hired labour	β_5	0.259(1.62)	2.28(5.54)**	-0.129(-1.28)	8.53(3.17)**
Cost of pesticide	β_6				
Manure use	β_7	-0.038(-0.55)	-0.037(-1.05)	-0.154(-3.9)**	-0.083(-1.87)*
(Holding size)2	β_8		-0.55(-1.08)		1.06(1.29)
(Permanent family labour)2	β_9		0.136(0.45)		-0.61(-2.09)*
(Seed rate)2	β_{10}		-2.69(-9.98)**		0.53(1.10)
(Urea fertiliser)2	β_{11}		0.25(3.90)**		
(Cost of hired labour)2	β_{12}		-0.30(-4.84)**		-1.25(-3.22)**
(Cost of pesticide)2	β_{13}				
Inefficiency model					
Constant	δ_0	0.157(1.01)	0.199(2.76)	0.203(2.253)	-0.017(-0.212)
Household age	δ_1	-0.0005(-0.15)	-0.004(-6.6)**	0.0006(0.41)	0.0018(1.26)
Farming year	δ_2	-0.0011(-0.23)	-0.001(-6.6)**	-0.0017(-0.53)	0.00084(0.37)
Level of education	δ_3	-0.043(-0.39)	0.006(0.11)	-0.33(-0.41)	0.021(0.35)
Extension contact	δ_4	0.037(0.28)	0.021(0.57)	-0.126(-4.3)**	-0.068(-2.03)*
Variance parameters					
$\sigma_s^2 = \sigma^2 + \sigma_v^2$	σ_s^2	0.013(1.75)	0.003(1.43)	0.0029(3.31)	0.0019(3.37)
$\gamma = \sigma^2 /(\sigma^2 + \sigma_v^2)$	γ	0.99(177.93)	0.05(1.43)	0.362(0.65)	0.00002(0.32)
Loglikelihood function		28.86	43.97	33.35	37.49
Generalized likelihood ratio statistics for one sided error		3.76	5.98	16.17*	10.20
Iteration		17	50	30	34
χ^2 (0.05)		11.07	18.31	9.49	15.51
Critical t value (α 0.05)		1.70	1.70	1.72	1.72
Critical t value (α 0.01)		2.46	2.46	2.51	2.51
Mean technical efficiency		0.86	0.97	0.88	0.94

Figure in parentheses indicates t value;
*,**, significant at 5% and 1% respectively

Table 5. Maximum-likelihood estimates for parameters of the stochastic frontier production functions for irrigated rice farmers for medium farm size

Variables	Parameter	Medium farm size (>3-8 acre)			
		Fertiliser use farmer (n=45)		No-fertiliser use farmer(n=23)	
		Cobb-Douglas	Translog	Cobb-Douglas	Translog
Stochastic frontier					
Constant	β_0	1.33(4.71)	-6.54(-7.17)	1.93(11.21)	5.52(6.57)
Holding size	β_1	-0.23(-1.49)	0.90(1.09)	-0.15(-0.52)	6.98(8.56)**
Permanent family labour	β_2	-0.58(-0.97)	-0.067(-0.47)	-0.12(-1.26)	-0.068(-0.20)
Seed rate	β_3	-0.081(-0.69)	5.32(5.93)**	0.17(1.14)	1.71(1.93)*
Urea fertiliser	β_4	0.095(2.79)**	0.21(1.00)		
Cost of hired labour	β_5	0.19(3.07)**	2.07(3.34)**	-0.06(-0.54)	-4.95(-8.56)**
Cost of pesticide	β_6				
Manure use	β_7	0.021(0.71)	-0.015(-0.55)	0.079(1.65)	0.14(2.83)**
(Holding size)2	β_8		-0.81(-1.37)		-5.19(-9.11)**
(Permanent family labour)2	β_9		0.031(0.096)		-0.023(-0.046)
(Seed rate)2	β_{10}		-1.63(-5.87)**		-0.48(-1.75)*
(Urea fertiliser)2	β_{11}		-0.061(-0.76)		
(Cost of hired labour)2	β_{12}		-0.28(-3.27)**		0.79(0.89)
(Cost of pesticide)2	β_{13}				
Inefficiency model					
Constant	δ_0	-0.26(-0.40)	0.20(0.94)	0.24(1.03)	-0.22(-1.16)
Household age	δ_1	-0.003(-0.42)	-0.003(-0.43)	0.0009(0.44)	0.004(1.06)
Farming year	δ_2	0.007(0.69)	-0.003(-0.74)	-0.003(-1.7)*	0.0006(0.18)
Level of education	δ_3	0.029(0.33)	-0.0094(-0.14)	0.024(0.39)	0.22(1.81)*
Extension contact	δ_4	0.12(0.63)	0.062(0.74)	0.021(0.50)	-0.025(-0.19)
Variance parameters					
$\sigma_s^2 = \sigma^2 + \sigma_v^2$	σ_s^2	0.023(0.79)	0.011(2.17)	0.0046(3.45)	0.006(3.91)
$\gamma = \sigma^2 / (\sigma^2 + \sigma_v^2)$	γ	0.91(7.98)	0.99(3447.4)	0.99(0.46)	0.99(4.91)
Loglikelihood function		49.76	94.72	29.31	38.78
Generalized likelihood ratio statistics for one sided error	λ	6.28	9.47	5.05	10.19
Iteration		29	20	49	18
χ^2 (0.05)		11.07	18.31	9.49	15.51
Critical t value (α 0.05)		1.67	1.67	1.71	1.71
Critical t value (α 0.01)		2.41	2.41	2.51	2.51
Mean technical efficiency		0.92	0.90	0.81	0.92

Figure in parentheses indicates t value;
*,**, significant at 5% and 1% respectively

Table 6. Maximum-likelihood estimates for parameters of the stochastic frontier production functions for irrigated rice farmers for large farm size

Variables	Parameter	Large farm size (>8 acre)			
		Fertiliser use farmer (n=30)		No-fertiliser use farmer (n=12)	
		Cobb-Douglas	Translog	Cobb-Douglas	Translog
Stochastic frontier					
Constant	β_0	1.03(2.25)	0.51(0.56)	0.66(5.29)	-38.59(-42.88)
Log (Holding size)	β_1	0.077(0.54)	-2.20(-2.80)**	0.20(4.24)**	3.05(3.51)**
Log (Family labour)	β_2	-0.041(-0.39)	0.035(0.095)	0.31(16.63)**	-1.39(-2.70)*
Log (Seed rate)	β_3	0.06(0.41)	-2.19(-2.61)**	-0.009(-0.42)	-13.5(-15.4)**
Log (Urea fertiliser)	β_4	0.05(0.99)	0.43(1.91)*		
Log (Cost of hired labour)	β_5	0.19(1.67)	2.45(3.54)**	0.23(7.01)**	29.95(44.73)**
Log (Cost of pesticide)	β_6	-0.10(-1.89)*	-0.71(-0.86)		
Manure use	β_7	0.089(1.68)	0.03(0.63)	0.019(7.53)**	0.014(0.18)
(Log (Holding size))2	β_8		1.08(2.69)**		-1.80(-4.04)**
(Log (Family labour))2	β_9		-0.27(-0.30)		2.22(4.11)**
(Log (Seed rate))2	β_{10}		0.69((2.59)**		3.81(13.75)**
(Log (Urea fertiliser))2	β_{11}		-0.19(-1.75)*		
(Log (Cost of hired labour))2	β_{12}		-0.31(-2.99)**		-4.4(-40.65)**
(Log (Cost of pesticide))2	β_{13}		0.15(0.73)		
Inefficiency model					
Constant	δ_0	0.025(0.063)	0.21(0.71)	-0.11(-0.94)	-0.34(-1.11)
Household age	δ_1	-0.014(-1.33)	-0.02(-3.23)**	-0.003(-0.62)	0.011(1.01)
Farming year	δ_2	0.023(2.29)*	0.025(3.99)**	0.011(2.56)**	-0.006(-0.43)
Level of education	δ_3	0.054(0.40)	0.11(1.04)	0.076(1.93)*	0.067(1.19)
Extension contact	δ_4	-0.012(-0.12)	0.033(0.25)	-0.21(-4.21)**	-0.079(-0.45)
Variance parameters					
$\sigma_s^2 = \sigma^2 + \sigma_v^2$	σ_s^2	0.0089(2.02)	0.014(3.21)	0.0015(4.0)	0.006(1.67)
$\gamma = \sigma^2 / (\sigma^2 + \sigma_v^2)$	γ	0.70(3.27)	0.99(2876.2)	0.99(641.6)	0.99(5.56)
Loglikelihood function		38.78	41.91	31.14	21.73
Generalized likelihood ratio statistics for one sided error		20.07*	22.62*	34.43*	10.06
Iteration		21	20	96	16
χ^2 (0.05)		12.59	21.0	9.49	15.51
Critical t value (α 0.05)		1.69	1.69	1.79	1.79
Critical t value (α 0.01)		2.46	2.46	2.71	2.71
Mean technical efficiency		0.92	0.88	0.93	0.92

Figure in parentheses indicates t value;
*,**, significant at 5% and 1% respectively

Inefficiency effect is found to be significant for small farmers who do not use fertiliser and large farmers who do use fertiliser and do not use fertiliser.

(2) The other test of hypothesis is related to the functional form. The results of testing various null hypotheses associated with functional forms are presented in Table 7.

Table 7. Generalised likelihood-ratio tests of hypotheses associated with functional form in the stochastic frontier for farmers who use fertiliser and those who do not use fertiliser for different farm size groups

Null hypothesis	Loglikelihood	λ	Critical value	Decision
Small farm size				
Fertiliser use farmers				
H_0: Cobb-Douglas=Translog	28.86			
	43.97	30.22	11.07	Reject H_0
No-fertiliser use				
H_0: Cobb-Douglas=Translog	33.35			
	37.49	8.28	9.49	Accept H_0
Medium farm size				
Fertiliser use farmers				
H_0: Cobb-Douglas=Translog	49.76			
	94.72	89.92	11.07	Reject H_0
No-fertiliser use				
H_0: Cobb-Douglas=Translog	29.31			
	38.78	18.94	9.49	Reject H_0
Large farm size				
Fertiliser use farmers				
H_0: Cobb-Douglas=Translog	38.78			
	41.91	6.26	12.59	AcceptH_0
No-fertiliser use				
H_0: Cobb-Douglas=Translog	31.14			
	21.73	-18.82	9.49	Accept H_0

The null hypothesis of Cobb-Douglas frontier is an adequate representation of data is rejected for small farmers who use fertiliser by calculating the generalised likelihood-ratio statistic. For those who do not use fertiliser, Cobb-Douglas production frontier is an adequate representation of the model.

For medium farms, H_0 is rejected for both farmers with and without fertiliser application. So, functional form is Translog. However, according to LR test in Table 5, the traditional response function is an adequate representation of the irrigated rice production technology given the assumptions of more general stochastic frontier production function. This implies that for the current level of technology, technical inefficiency of production are not significant among the medium farms.

For large farms, Cobb-Douglas production function is a representative model in stochastic frontier either for fertiliser-use farmers or no-fertiliser use farmers. The results are briefly mentioned as follows:

Farm size group	Fertiliser use farmer	No-fertiliser use farmer
Small	Translog frontier function	Cobb Douglas stochastic frontier
Medium	Translog frontier function	Translog frontier function
Large	Cobb-Douglas stochastic frontier	Cobb-Douglas stochastic frontier

5.3. Estimating parameters of explanatory variables in stochastic frontier and technical inefficiency effects

The maximum-likelihood estimates of the parameters in the stochastic production frontier model and those in the technical inefficiency effect model are presented in Table 4 to Table 6. The results obtained indicate that technical inefficiency effects are significant for large farmers who use fertilzer and it holds true for small and large farmers who do not use fertilizer. Thus, for those farmers the traditional average function (Original Least Square) is not an adequate representation of the data involved in the study. The magnitude and significance of the estimate for the variance parameter, γ, also supported the results from the likelihood-ratio tests. The maximum-likelihood estimate for the parameter γ is 0.70 for large farmers who use fertilizer whereas this value is 0.99 and 0.36 for small and large farmers who do not use fertilizer. This indicates the relative magnitude of the variance associated with the inefficiency effect.

5.3.1. Fertiliser use farmers

A discussion of individual estimated coefficients of the production frontier is more relevant to respective preferred model for each of three farm size groups. In the context of the frontier production function, defined by equation (6 and 7), the variables associated with seed rate and cost of hired labour for different farming activities have a positive and significant effect on yield of rice at 1% level for small and medium farms. The similar finding hold true for large farms but is not significant.

The impact of quantity of urea per acre on rice yield shows an expected positive signs in large and medium farms, but the impact is found to be negative in small farms though not significant. This may be explained by the fact that in comparing the use of fertilizer small farmers applied the highest rate (45.7 kg/ac) with a range of 2.5 kg per acre to 100 kg per acre. Using wide range of urea would show the inefficient use of fertilzer. It could be related to poor agronomic management which leads to nitrogen losses through NH_3 volatilization and denitrification. To optimize the nitrogen use efficiency it is recommanded to timly and split application of nitrogen fertilizer which has the large impact on fertilizer efficiency and rice productivity (Riceweb, 1999). A positive relationship between farm size and yield is found to be in all farm groups. The coefficient of family labour indicates the negative impact in explaining the yield of rice. It means even though more family labour are involving in rice production, there is ineffective and inefficient use of labour in rice farming. Manure use is found to be negative in small and medium farms but a positive impact is observed in large farms.

Given the specifications of the preferred model with inefficiency effect, it is noted that the age of farmers has a negative effect on ineffciency. This investigation is consistent with the result by Pitt and Lee (1981) showing that increasing age had a significant contribution to inefficiency. Extension contact measured as dummy gives the expected negative sign explaining that if there is a less extension contact, more inefficiency is observed. Apart from aforementioned variables, Kalirajan (1981), Kalirajan and Shand (1989), Ali and Flinn (1989), Kumbhakar, Biswas and Bailey (1989) and Battese and Coelli (1993) identified farmers' level of education as a determinant of techical inefficiency effects. However, in this study the variables of level of education attained by farmers and the number of farming years could not sufficiently explain the variability of inefficiency level.

5.3.2. No-fertiliser use farmers

For small farms seed rate used by farmers is an important explanatory variable in rice production and significant at 1% level. Farmers overuse the farmily and hired labour showing negative coefficient in explaining yield of rice in small farms. For large farms, the positive and significant coefficients in stochastic frontier production are found in land, family labour, cost of hired labour and manure use. For farmers who do not use fertilizer, because of the scarcity of resource capital, family labour seems to be productive and efficient in production of rice. The positive impact of hired labour cost indicates that increase in investing of seasonal hired labour in different farming activities tends to give higher productivity in rice farming. The coefficient for manure use is positive. It reflects that manure utilization is necessary for non-fertilizer use farmers to sustain the soil fertility in order to achieve the certain yield level. One of the scarce resources, land, which is a constraint factor in determination of the irrigated rice production, has a positive impact on explaining the stochastic frontier prodcution function. The negative impact is found in seed rate. It indicates that the improved seed varieties are highly responsive to nitrogen fertilizer application and without fertilizer utilization higher rate of seed could not turn to increase the yield of rice.

For small and large farms, the inefficiency effect model which cause the actual production to fall short of the corresponding stochastic frontier production, is significant. The result shows that the level of education of the household head has negative impact on inefficiency effect for small farms. The negative sign indicates that higher level of education reduces the inefficiency. Farmers with more education respond more readily in using the new technology and produce closer to frontier output. This finding is consistent with the review of many studies. However, the positive estimate for the coefficient of level of education for large farms indicates that their technical inefficiency effects tend to increase with higher level of education. This result may have resulted in insufficient variability in the data to detect any significant effects on inefficiency level. It means regardless of education the inefficiency is not different.

The coefficient of extension contact variable shows negative and significant for both small and large farms. It indicates that the involvement of extension agent tends to reduce the technical inefficiency for rice production.

The estimated coefficient for age of farmers in the inefficiency models are positive for small farms which indicates that younger farmers are more technically efficient in rice production than the older farmers. However, a negative sign is observed in large farms. It indicates that older farmers have higher technical efficiency than younger farmers. Based on these findings we couldn't draw the conclusion here that age of farmers is a decisive factor in improving the efficiency of farms.

The variable of farming years relative to household head gives expected negative signs for small farms but positive in large farms.

5.4. Technical efficiencies

Figure 1 at the first box illustrates distribution of technical efficiency scores for small farmers who use and do not use fertiliser. Given the specification of the preferred model, no fertiliser use farmers have a range of 0.79 to 0.99 efficiency scores with an average efficiency of 0.88. Under the present technology, most farmers have high technical efficiency in production of rice. However, there is a large proportion (45%) of the sample farmers who have lower levels (<0.85) of technical efficiency score. This suggests that considerable amount of productivity is lost due to inefficiency.

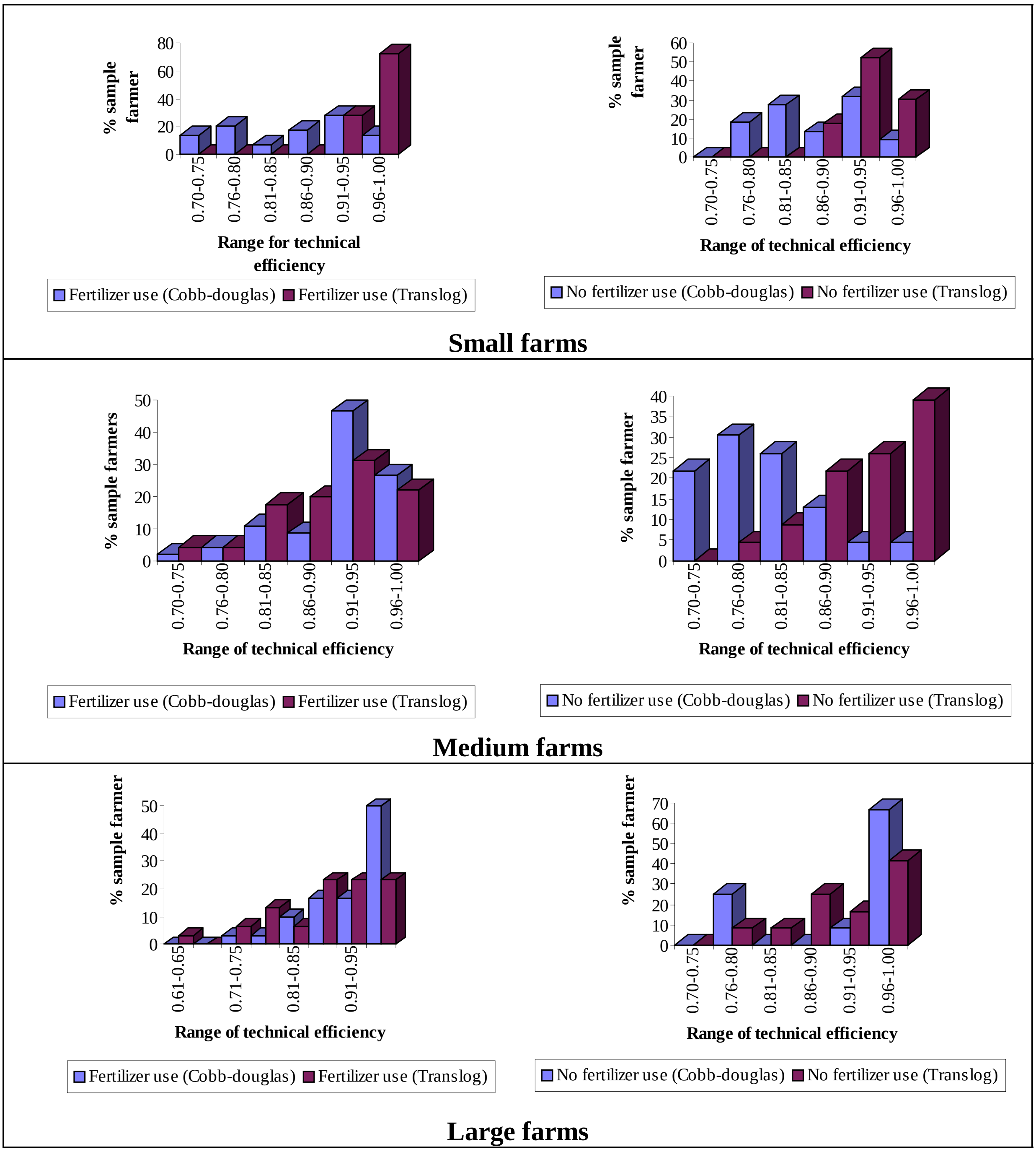

Figure 1. Predicted technical efficiencies distribution for different farms with and without fertiliser application

Because the inefficiency effects for small and medium farmers who use fertiliser and medium farms who do not use fertiliser are not significant, no technical efficiencies are discussed in this issue. In fact, the technical efficiencies of those farmers are reported to be equal to unity, given the present level of technology of rice production.

The technical efficiency distribution for large farms which have a range of technical efficiency of 0.70 to 0.99 with an average efficiency of 0.92 for fertiliser use farmers. For those who do not use fertiliser there is a efficiency score having a range of 0.79 to 0.99 with an average efficiency of 0.93. This result does not support no difference in technical efficiency level between fertiliser use and no-fertiliser use farmers, instead farmers are using the restricted resources to get their respective frontier within the scope of their farm specific variables.

In general, the empirical results show that most farmers have high scores of technical efficiency. The estimated mean technical efficiencies for small, medium and large farmers who use fertiliser are 97, 90 and 92% respectively, i.e. small farmers are more efficient than the large farmers. For farmers not using fertiliser technical efficiency scores are 88, 92 and 93% relative to their respective frontiers associated with different level of technologies respectively. It indicates that there is a lower technical efficiency for the small farmers and it implies that rice farms for small farms operate a bit far to their frontier production function than do their medium and large farm counterparts with respect to their production function. It does not necessarily imply that medium and large farms are more economically viable than small farms.

6. Conclusion and policy implication

Within the limit of partial productivity analysis, the seed rate and cost of hired labour for different farming activities seem to turn out to be important factors of rice production for farmers who use fetilizer in irrigated area. Thus, to increase efficiency of the farms in rice production an increase in seed rate and in more labour intensifying in different farming activities may be appropriate for the improvement of productivity in irrigated rice.

The technical inefficiency effects exist for large farmers who use fertiliser and for small and large farmers who do not use fertiliser. For large farmers who use fertiliser, the inefficiency effect is explained by household age and extension contact. For the medium farms the traditional response function, in which there is no technical inefficiency effect, is a representative production function. The parameter associated with receiving extension services has a significant impact on efficiency of rice production in large and no-fertiliser use farmers. For small farms who do not use fertiliser, the level of education is a decisive factor in determining the inefficiency effect.

The empirical results show that most farmers have high scores of technical efficiency. The estimated mean technical efficiencies for small, medium and large farmers who use fertiliser are 97, 90 and 92% respectively, i.e. small farmers are more efficient than the large farmers. For farmers not using fertiliser technical efficiency scores are 88, 92 and 93% respectively.

The results outlined before have important policy implication

(1) Having higher technical efficiency, 0.93 for those who use fertiliser and 0.91 for those who do not use fertiliser, two things should be considered in the improvement of irrigated rice yield. On one hand, the technological change would be the source of rice productivity growth in

the future. For this the government should continue to increase its support for public investment in infrastructure and technology such as roads, irrigation, and research and extension. On the other hand, since technical efficiency of the small farms who do not use fertiliser, is less than 0.85 for about 45% of the sample farmers, every means, by which increased production and efficiency of production can be achieved.

(2) There exists substantial differences in the efficiency of resource utilisation between fertiliser use and no-fertiliser use farmers in irrigated rice.

(3) The positive estimate for the coefficients of seed in small and medium farms implies that there tended to be an increase in rice yield as the quantity of seed sown increased for the sample of farmers. This indicates that the farmers tended to sow lower seed rate, which resulted in lower stand establishment of the rice plants, which in turn resulted in less rice yield. It would appear that, in general, the farmers need to increase the quantity of the rice seed presently being sown.

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