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RESEARCH NOTES

Estimation of Technical Efficiency in the Stochastic Frontier Production Function Model - An Application to the Tea Industry in Assam

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Tea is the most popular of all the beverages in the world. Tea industry is of considerable importance in the national economy of India. India continues to be one of the leading producers of tea accounting for 28.48 per cent of the global output. In terms of area, it occupies about 18.29 per cent of the world tea area. India remains not only the largest producer but also a largest consumer and a consistent exporter of tea. Assam is the leading state in the country in tea industry. Assam has an area of 2.37 lakh ha which is 55.72 per cent of all-India acreage. During 1993 the production of tea was 0.403 million tonnes accounting for 53.16 per cent of the total production of the country. It produced 15.62 per cent of the total world tea production. But the yield of tea in Assam is 1,702 kg per ha as against an all-India average of 1,784 kg per ha. Assam has been experiencing a production growth rate of 6.23 per cent per annum during the period 1951-1991. The area expansion was 2.56 per cent whereas the productivity growth was 3.58 per cent per annum during the same period.

Although India holds the leading position in production and export the current position of tea trade revealed that it's share in world production and export has been declining steadily over the past three decades. Export during last few decades remained around 200 million kgs. Though India has almost doubled its tea production between 1965 and 1991, still it is not sufficient to maintain India's dominant position in the world tea trade. This necessitates an analysis of production efficiency of the estates to help to formulate policy measures to remove the production constraint in the Indian tea industry particularly in Assam.

Efficiency is an important factor of productivity growth as well as stability of production especially in developing agricultural economies. In view of slow growth and increasing instability in production (Bhuyan and Hazarika, 1997), the tea economy of Assam could be benefited to a great deal from inefficiency studies. Estimates on the extent of inefficiencies could help to decide whether to improve efficiency or to develop new technology to raise tea productivity in Assam.

METHODOLOGY

The prominent tea growing districts in Assam are Sibsagar and Dibrugarh which accounted for 28.29 per cent and 29.02 per cent of the total tea area in Assam during 1992-93 period. The district-wise number of tea estates, area under tea and production of tea in Assam is

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furnished in Table 1. The Tocklai Tea Research Association has also established its research wing in Sibsagar district to assist in increasing productivity of tea plantations. Hence these two districts were selected for detailed study. A three-stage stratified random sampling procedure was followed. A sample of 15 per cent of the total estates in the two selected districts was selected. The sample was distributed among the districts and size groups by probability proportional method. The estates were classified into small and medium (upto 200 ha) and large (above 200 ha) as followed by the Tea Board of India. Thus a total of 67 estates were selected for the present study (Table 2). The estates were selected randomly from the list of tea estates in the district collected from Tocklai Tea Research Station, Jorhat. The primary data were collected through personal interview method using a pre-tested comprehensive interview schedule.

TABLE 1. DISTRICT-WISE NUMBER OF TEA ESTATES, AREA UNDER TEA, PRODUCTION AND PRODUCTIVITY OF TEA IN ASSAM DURING 1992-93

District (1)	Number of estates (2)	Area (ha) (3)	Production (tonnes) (4)	Yield (kg per ha) (5)
Darrang	90	40,425	81,850	2,025
Goalpara	10	3,300	5,260	1,594
Kamrup	12	3,800	4,811	1,266
Lakhimpur	12	4,400	8,622	1,960
Dibrugarh	209	68,715	1,42,785	2,078
Nagaon	23	7,900	12,945	1,639
Sibsagar	239	67,000	96,875	1,446
Cachar	93	35,514	42,439	1,195
Total Assam	688	2,31,054	3,95,587	1,712

Source: Tea Statistics, 1994, J. Thomas and Co. Pvt. Ltd., Calcutta.

TABLE 2. DISTRIBUTION OF SAMPLE SIZE

District	Total number of estates		Number of estates selected		Total sample size
	Small and medium (upto 200 ha)	Large (above 200 ha)	Small and medium (upto 200 ha)	Large (above 200 ha)	
(1)	(2)	(3)	(4)	(5)	(6)
Sibsagar	133	106	20	16	36
Dibrugarh	96	113	14	17	31
Total	229	219	34	33	67

Production Frontiers

Production function represents a maximum possible output for any given set of inputs setting a limit or frontier on the observed values of dependent variable in the sense that no observed value of output is expected to lie above the production function. Any deviation of a farm from the frontier indicates the extent of farm's inability to produce maximum output from its given sets of inputs and hence represent the degree of technical efficiency. A one-sided component captures the effects of inefficiency relative to the stochastic frontier.

A production process may be inefficient in two ways, only one of which can be detected by an estimated production frontier. It can be technically inefficient, in the sense that it fails to produce maximum output from a given input bundle; technical inefficiency results in an equi-proportionate over-utilisation of all inputs. It can also be allocatively inefficient in the sense that the marginal revenue product of input might not be equal to the marginal cost of that input; allocative inefficiency results in utilisation of inputs in the wrong proportions, given input prices. Since estimation of production frontiers is carried out with observations on output and inputs only, such an exercise cannot provide evidence bearing on the matter of allocative inefficiency, and hence cannot be used to draw inferences about total, or economic inefficiency (Schmidt and Lovell, 1979). However, Schmidt and Lovell (1979), extending the analyses of stochastic production frontier of Aigner *et al.* (1977) and Meeusen and Van den Broeck (1977), demonstrate that it is possible to estimate technical and allocative inefficiencies provided an assumption is made that "the firm seeks to minimize the cost of producing its desired rate of output, subject to a stochastic production frontier constraint". If the firm is technically inefficient it operates beneath its stochastic production frontier, and if the firm is allocatively inefficient it operates off its least cost expansion path.

The technical efficiency in production was estimated by using the stochastic frontier production function. The stochastic frontier production function was independently proposed by Aigner *et al.* (1977) and Meeusen and Van den Broeck (1977). The estimation of stochastic frontier production function made it possible to find out whether the deviation in technical efficiencies from the frontier output is due to firm specific factors or due to external random factors. A large number of studies are available on the use of stochastic frontiers for the measurement of technical efficiency in production (Dawson and Lingard, 1989; Kalirajan, 1990; Battese, 1992; Battese and Corra, 1977).

The stochastic frontier model can be represented as:

$$Y_i = f(X_i, \beta)\exp(V_i - U_i) \qquad \text{....(1)}$$

where

Y_i = production of i-th farm

$f(X_i, \beta)$ = is a suitable function of the vector X_i, of inputs for the i-th firm and β is the vector of unknown parameters.

V_i = is the symmetric component of the error term

U_i = is the non-negative random variable which is under the control of the farm.

Given the density function of U_i and V_i, the frontier production function can be estimated by Maximum Likelihood Techniques.

Jondrow *et al.* (1982) has demonstrated that farm specific technical efficiencies can be estimated from the error terms. It is possible because $\varepsilon_i = V_i + U_i$ can be estimated and it obviously contains information on U_i. One can evaluate by considering the conditional distribution of U_i given ε_i. This distribution contains whatever information ε_i yields about U_i. For the commonly used cases of half-normal and exponential U_i, these expressions are easily evaluated. In the case of half-normal model, for each farm the technical efficiency is the expected value of U_i, conditional on ε_i.

$E(U_i/\varepsilon_i) = \sigma_u\sigma_v/\sigma[\phi(\varepsilon_i\lambda/\sigma)/\{1 - \varepsilon_i\lambda\Phi(\varepsilon_i\lambda/\sigma)\} - \varepsilon_i\lambda/\sigma]$ ....(2)

ε_i = $U_i + V_i$, the composed error term,
i = 1, 2, ... n,
ϕ = represent the standard normal density function and Φ represents the cumulative density function, and
λ = is the ratio of standard errors, σ_u/σ_v

The primary advantage of a stochastic frontier production function is that it enables one to estimate U_i and therefore also to estimate farm specific technical efficiencies. The measure of technical efficiency is equivalent to the ratio of the production of the i-th farm to the corresponding production value if the farm effect U_i were zero.

Following Battese and Coelli (1988), when output is measured in logarithms, the farm specific technical efficiency can be estimated as:

$TE_i = Exp(-u_i)$ ....(3)

$i = 1, 2, ..., n, \; 0 \le TE_i \le 1$

The variance ratio γ, explaining the total variation in output from the frontier level of output attributed to technical efficiencies, can be computed as:

$$\gamma = \sigma_u^2/\sigma^2$$

Model Specification

The stochastic frontier production function of the Cobb-Douglas type was specified for this study. Due to its advantages over the other functional forms, it is widely used in the frontier production function studies (Kalirajan and Flinn 1983; Dawson and Lingard 1989; Bravo-Ureta and Evenson 1994).

The model used was:

$$Y_i = \beta_0 + \beta_1 logX_1 + \beta_2 logX_2 + \beta_3 logX_3 + \beta_4 logX_4 + \beta_5 logX_5 + \beta_6 logX_6 + \beta_7 logX_7 + V_i - U_i$$

i = 1, 2, ... n.
Y_i = Total green tea leaf production in kg,
X_1 = Effective area in ha,
X_2 = Total labour in mandays per ha,
X_3 = Total fertiliser in kgs per ha,
X_4 = Proportionate area above 50 years of age,
X_5 = Proportionate area below 50 years of age,
X_6 = Percentage of area under seedjat varieties,
X_7 = Percentage of area under clonal varieties,
U_i = Farm specific technical efficiency related factor, and
V_i = Random variable.

From the residual, using the equation (3), the farm specific technical efficiencies were estimated.

Returns to Scale

The summation of elasticity coefficient (b_i's) indicates returns to scale. Its significance has been tested using F-test as:

$$F_{(1,n-k)} = \frac{(\sum b_i - 1)^2 (n-k)}{[\sum Var(b_i)]\,(k-1)} \quad (i = 1, 2 \ldots. 7)$$

where n = number of observations = 34 for small and medium estates and 33 for large estates.

k = number of parameters = 7.

Var (b_i) = variance of b_i

RESULTS AND DISCUSSION

(A) *Average Size of the Estates and Green Tea Leaf Production*

The average size of holding, effective area and total green tea leaf production of the sample estates in Assam is presented in Table 3. The average size of the estate was 107.79 ha and 502.84 ha for small and medium and large estates respectively. In tea estates what is more important is the effective area. Effective area is the actual area under tea after deducting the vacant area from the total area. The vacancy area formed 6.67 per cent of the total area in small and medium estates and 4.42 per cent in large estates. Productivity is one of the best indicators for the effective utilisation of resources. As could be seen from the table, the productivity of green tea was marginally higher in small and medium estates than that of the large estates. The productivity was 10,372.79 kg per ha and 10,199.68 kg per ha respectively in small and medium and large estates with an overall average of 10,305.17 kg per ha.

TABLE 3. SIZE OF HOLDING AND PRODUCTION OF GREEN TEA LEAF IN THE SAMPLE ESTATES

Category (1)	Average size of holding (ha) (2)	Average effective area (ha) (3)	Green leaf production (kg) (4)	Productivity of green leaf (kg per ha) (5)
Small and medium	107.79	100.60	10,43,503.30	10,372.79
Large	502.84	480.62	49,02,167.70	10,199.68
Pooled	310.66	293.54	30,24,979.60	10,305.17

't' value between groups for productivity of green leaf = 1.35.

(B) *Area under Tea in Different Age Groups*

Age of the bush generally determines the productivity of the crop for a given period of time. The agewise distribution of total area of the sample estates is given in Table 4. It could be observed that 28.34 per cent and 28.69 per cent to total area were above 50 years of age in small and medium and large estates respectively. This age group is considered as the uneconomic bush. The tea starts yielding from the fifth year and the economic yield continues upto 50 years. It could be seen that 67.83 per cent of the total area in small and medium estates and 63.02 per cent in large estates were in the optimum yielding age group. The high proportion of area under the uneconomical group (above 50 years) indicated the failure of the estate owner to replant their estates in time. This requires a detailed study to analyse the causes for not taking up replanting so as to frame strategies to increase the productivity of tea in the long run.

TABLE 4. AVERAGE AREA UNDER TEA IN DIFFERENT AGE GROUPS

(hectares)

Category (1)	Below 5 yrs (2)	5-10 yrs (3)	11-20 yrs (4)	21-30 yrs (5)	31-40 yrs (6)	41-50 yrs (7)	Above 50 yrs (8)	Total area (9)
Small and medium	127.15 (3.83)	316.05 (9.52)	390.08 (11.75)	671.26 (20.22)	493.65 (14.87)	381.11 (11.48)	940.83 (28.34)	3,320.13 (100.00)
Large	1,027.85 (6.29)	1,998.51 (12.23)	2,634.18 (16.12)	2,171.73 (13.29)	2,523.06 (15.44)	1,294.21 (7.92)	4,688.26 (28.69)	16,337.80 (100.00)
Pooled	1,155.00 (5.88)	2,314.56 (11.77)	3,024.26 (15.38)	2,842.99 (14.46)	3,016.71 (15.35)	1,675.32 (8.52)	5,629.09 (28.64)	19,657.93 (100.00)

Figures in parentheses indicate percentages to the total.

(C) *Labour Employment*

Tea industry is labour intensive and hence the study of employment pattern is important from management point of view. The details of employment of labour in different size groups of estates are furnished in Table 5. It was found that on an average 3.57 and 2.76 mandays of labour were employed per ha in small and medium, and large estates respectively. Permanent labour constituted 53.16 per cent and 69.31 per cent of the total labour employed in small and medium, and large estates respectively. Employment of female labour per ha was marginally high in tea estates in general due to the fact that the major operation of plucking is done by women labour. The variation in employment was not much among the different size groups. This might be plausible because as per the plantation Labour Act. 1951 each estate should employ a minimum of two labourers per ha. The productivity of green tea leaf per labour was higher (3,690.09 kg per labour) in large estates as against small and medium estates (2,902.89 kg per labour). This might be because of less employment of labour per ha coupled with higher productivity in large estates.

TABLE 5. LABOUR EMPLOYED PER HECTARE IN THE SAMPLE ESTATES

Category	Permanent			Temporary			Total labour used per farm (man-days)	Average number of labour employed per ha (man-days)	Yield of green tea leaf per labour (kg)
	Male	Female	Child	Male	Female	Child			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Small and medium	84.87 (23.61)	97.73 (27.19)	8.47 (2.36)	61.40 (17.08)	82.87 (23.05)	24.13 (6.71)	359.47 (100.00)	3.57	2,902.89
Large	444.07 (33.43)	448.00 (33.72)	28.73 (2.16)	186.80 (14.06)	175.00 (13.17)	45.87 (3.45)	1,328.47 (100.00)	2.76	3,690.09
Pooled	264.47 (31.35)	272.37 (32.29)	18.60 (2.21)	124.10 (14.71)	128.93 (15.29)	35.00 (4.15)	843.47 (100.00)	2.87	3,586.35

Figures in parentheses indicate percentages to the total.

(D) *Fertiliser Use Pattern*

Fertiliser is an important input for improving the productivity of tea in the short run. It was found that small and medium estates used less quantity of fertiliser (228.98 kg per ha) than that of large estates (258.53 kg per ha). The main component of total fertiliser used was nitrogen, i.e., 124.60 kg per ha in small and medium estates and 141.00 kg per ha in large estates. The small and medium estates used 30.80 kg of phosphorus and 85.00 kg of potash per ha whereas the large estates used 28.47 kg of phosphorus and 94.87 kg of potash per ha. The recommended dose was 135:90: 135 of N: P: K kg per ha. So there existed a gap in the use of phosphorus and potash in the sample estates.

(E) *Production Function*

Estimates of Cobb-Douglas production function for the two groups of the tea estates in Assam are presented in Table 6. The coefficient of multiple determination (R^2) was 0.9728 indicating that 97.28 per cent of the variation in total green tea leaf production was explained by the explanatory variables included in the model for the small and medium estates. All the variables had expected signs. Among the explanatory variables effective area of the estate and total fertiliser used had positive and significant influence on the production of green tea leaf. The coefficient for effective area of estates (X_1) was 0.859 and it implied that one per cent increase in the area will result in 0.859 per cent increase in total green tea leaf production keeping other factors constant at their mean level. Similarly, the coefficient for fertiliser (X_3) showed that for every one per cent increase in fertiliser used will increase the production by 0.262 per cent. The variable "proportionate area under tea production above 50 years age" (X_4) was negative and significant. It implied that one per cent increase in area in this group would reduce production of green leaf tea by 0.092 per cent when other factors are kept at their mean level. This is plausible because tea productivity declined significantly after 50 years of age.

For the large group the coefficient of multiple determination (R^2) was 0.9596 explaining the goodness of fit. The significant variables were area of the estate (X_1) and proportionate area above 50 years of age (X_4). The coefficient of area showed that one per cent increase in the area of estates keeping other variables constant would result in an increase in the production of green leaf tea by 0.685 per cent. Similarly, the coefficient for area above 50 years of age shows that with every one per cent reduction in the area above 50 years of age group keeping other variables constant would result in an increase in the green leaf production by 0.057 per cent.

The regression coefficients in the Cobb-Douglas production function are the production elasticities, and their sum indicates the return to scale. The estimates for return to scale were much higher and significantly different from unity, indicating increasing returns to scale. Returns to scale for small and medium estates was 1.28 and for large estates 1.41, showing overall efficiency of resource use in the sample tea estates. This showed that an increase in the use of the selected variables would result in more than proportionate increase in total production of tea.

TABLE 6. ESTIMATED PARAMETERS OF OLS FOR SMALL AND MEDIUM AND LARGE ESTATES OF ASSAM

Variables	Symbol	Coefficient	
		Small and medium	Large
(1)	(2)	(3)	(4)
Constant term	a_0	7.2119 (0.4316)	8.3777 (1.785)
Effective area under tea (ha)	X_1	0.859* (0.088)	0.685* (0.113)
Total labour (mandays/ha)	X_2	0.057 (0.089)	0.243 (0.103)
Total fertiliser used (kg/ha)	X_3	0.268* (0.047)	0.197 (0.109)
Proportionate area above 50 years of age	X_4	-0.092* (0.021)	-0.057* (0.028)
Proportionate area below 50 years of age	X_5	0.009 (0.044)	0.266 (0.169)
Seedjat area (%)	X_6	0.129 (0.083)	-0.008 (0.153)
Clonal area (%)	X_7	0.052 (0.035)	0.087 (0.057)
R^2		0.9728	0.9596
N		33	34
Return to scale		1.28*	1.41**

Figures in parentheses are standard errors.
* and ** Significant at 1 per cent and 5 per cent probability level respectively.

(F) *Frontier Production Function*

The maximum likelihood estimates of the frontier production function estimates are shown in Table 7. On an average, the sample farmers had 310.66 ha of land with 30.25 lakh kg of green leaf production. The estimates of λ (1379.6) and δ (0.151) were significantly different from zero indicating a good fit and the correctness of the distributional assumption specified. The variance ratio (γ) showed that the farm specific variability contributed more to the variation in yield among the estate owners, which means that the total variation in output from the frontier is attributable to technical inefficiency. This means that about 99 per cent of the differences between the observed and the maximum production frontier outputs were due to differences in farmer's levels of technical efficiency and not related to random variability. These factors are under the control of the farm and the influence of which can be reduced to enhance technical efficiency of the estate owners.

With an upward shift in the constant term the co-efficient of area, total labour, total fertiliser and area under 50 years of age remained significant in the stochastic frontier production function implying that the estate owners could use more of labour, fertiliser and reduce the area under 50 years of age to increase tea production. It was also observed that the farm specific technical efficiency varied between 0.64 to 0.99 with a mean technical efficiency of 0.88. Therefore in the short run it is possible to increase tea production in Assam on an average by 12 per cent by adopting the technology used by the best performers.

TABLE 7. ESTIMATED PARAMETERS OF MLE FOR THE POOLED SAMPLE ESTATES OF ASSAM

Variables (1)	Symbol (2)	Coefficients (3)
Constant	a_0	7.432* (0.587)
Effective area (ha)	X_1	0.758* (0.068)
Total labour used (mandays/ha)	X_2	0.243* (0.061)
Total fertiliser used (kg/ha)	X_3	0.252* (0.066)
Area under above 50 years age	X_4	-0.081** (0.028)
Area under below 50 years age	X_5	0.049 (0.061)
Area under seedjat variety	X_6	0.121 (0.087)
Area under clonal variety	X_7	0.656 (0.036)
λ		1379.6 (103700.0)
γ		0.99
δ		0.151* (0.018)
N		67

Figures in parentheses are standard errors.
* and ** Significant at 1 per cent and 5 per cent probability level respectively.

(G) *Farm Specific Technical Efficiencies*

The farm specific technical efficiencies were estimated by using the equation (3), and the frequency distribution is shown in Table 8. It was found that 29.41 per cent of the total farms who operated large estates belonged to the most efficient category (96 to 99 per cent) and 8.82 per cent in the least efficient group (64 to 70 per cent).

Similarly in small and medium sectors 15.15 per cent were highly efficient and 3.03 per cent were least efficient. So it could be inferred that the variation in the level of technical efficiency in tea estates in Assam was not attributed to the differences in size of estates. Identification of estates, which lead to variation in farm specific technical efficiency, is an important issue for formulating strategies to increase the productivity. So the resource use pattern of some of the most efficient (above 90 per cent technical efficiency) estates were examined. It was found that the most efficient farm employed 3.00 mandays of labour and used 291.33 kgs of fertiliser and produced 11,364.69 kgs of green tea leaf per ha. This showed that by use of more of labour and fertiliser tea production could be increased. Another important dimension is that by reducing the area under above 50 years of age the productivity could be increased. This indicated the need for urgent replanting measures. Strengthening the extension service to enable farmers to follow the resource use pattern of the most efficient farms could help to increase tea production in the short run.

TABLE 8. FREQUENCY DISTRIBUTION OF TECHNICAL EFFICIENCY

Efficiency level (per cent)	Number of estates		
	Small and medium	Large	Total
(1)	(2)	(3)	(4)
64-70	1 (3.03)	3 (8.82)	4 (5.97)
71-75	3 (9.09)	1 (2.94)	4 (5.97)
76-80	6 (18.18)	1 (2.94)	7 (10.45)
81-85	4 (12.12)	5 (14.71)	9 (13.43)
86-90	6 (18.18)	9 (26.47)	15 (22.39)
91-95	8 (24.24)	5 (14.71)	13 (19.40)
96-99	5 (15.15)	10 (29.41)	15 (22.39)
Total estates	33 (100.00)	34 (100.00)	67 (100.00)

Figures in parentheses indicate percentages to the total.

POLICY IMPLICATIONS

1. The result showed that even under the existing technology potentials exists for improving the productivity with proper allocation of the existing resources. Hence proper extension strategies needs to be taken to educate the estate owners about rational use of inputs.
2. The existence of obsolete tea bushes is one of the factors that inhibited the growth of the industry. The high percentage of vacancy and old age bushes weakened the productivity of the plantations. So the estate owners should be educated on the need for undertaking infilling, replanting and replacement planting.

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REFERENCES

Aigner, D.J.; C. Lovell and P. Schmidt (1977), "Formulation and Estimation of Stochastic Frontier Production Function Models", *Journal of Econometrics*, Vol. 6, No. 1, pp. 21-37.

Battese, G.E. (1992), "Frontier Production Functions and Technical Efficiency - A Survey of Empirical Applications in Agricultural Economics", *Agricultural Economics*, Vol. 7, pp. 185-208.

Battese, G.E. and G.S. Corra (1977), "Estimation of a Production Frontier Model: With Application to the Pastoral Zone of Eastern Australia", *Australian Journal of Agricultural Economics*, Vol. 21, No. 3, pp. 169-179.

Battese, G.E. and T.J. Coelli (1988), "Prediction of Firm-Level Technical Efficiencies with a Generalised Frontier Production Function and Panel Data", *Journal of Econometrics*, Vol. 38, pp. 387-399.

Bhuyan, R.P. and C. Hazarika (1997), "An Analysis of Growth and Instability in Tea Production in Assam", *Journal of Interacademicia*, Vol. 1, No. 3, pp. 248-254.

Bravo-Ureta, B.E. and R.E. Evenson (1994), "Efficiency in Agricultural Production - The Case of Peasant Farmers in Eastern Paraguay", *Agricultural Economics*, Vol. 10, No. 1, pp. 27-37.

Dawson, P.J. and J. Lingard (1989), "Measuring Farm Efficiency Over Time on Philippine Rice Farms", *Journal of Agricultural Economics*, Vol. 40, No. 2, pp. 168-177.

Jondrow, J., C.A.K. Lovell, I.S. Materov and P. Schmidt (1982), "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model", Journal of Econometrics, Vol. 19, pp. 233-238.

Kalirajan, K.P. and J.C. Flinn (1983), "The Measurement of Farm-Specific Technical Efficiency", *Pakistan Journal of Applied Economics*, Vol. 11, No. 2, pp. 167-180.

Kalirajan, K.P. (1990), "On Measuring Economic Efficiency", *Journal of Applied Econometrics*, Vol. 5, pp. 75-85.

Meeusen, N. and J. Van den Broeck (1977), "Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error", *International Economic Review*, Vol. 18, No. 2, pp. 435-444.

Schmidt, P. and C.A.K. Lovell (1979), "Estimating Technical and Allocative Efficiency Relative to Stochastic Production and Cost-Frontiers", *Journal of Econometrics*, Vol. 9, No. 3, pp. 343-366.