Australian Journal of Agricultural Economics, Vol. 40, No. 2 (August 1996), pp.103-128

IDENTIFICATION OF FACTORS WHICH INFLUENCE THE TECHNICAL INEFFICIENCY OF INDIAN FARMERS

TIM COELLI and GEORGE BATTESE
Department of Econometrics, University of New England,
Armidale, NSW, 2351

The agricultural production of Indian farmers is investigated using a stochastic frontier production function which incorporates a model for the technical inefficiency effects. Farm-level data from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are used. Variables considered in the model for the inefficiency effects include the age and level of education of the farmers, farm size and the year of observation. The parameters of the stochastic frontier production function are estimated simultaneously with those involved in the model for the inefficiency effects. This approach differs from the usual practice of predicting farm-level inefficiency effects and then regressing these upon various factors in a second-stage of modelling. The results indicate that the above factors do have a significant influence upon the inefficiency effects of farmers in two of the three villages considered.

Introduction

The measurement of the productive efficiency of a farm relative to other farms or to the "best practice" in an industry has long been of interest to agricultural economists. Much empirical work has centred on imperfect, partial measures of productivity, such as yield per hectare or output per unit of labour. Farrell (1957) suggested a method of measuring the technical efficiency of a firm in an industry by estimating the production function of firms which are "fully-efficient" (i.e., a frontier production function).

Many subsequent papers have applied and extended Farrell's ideas. This literature may be roughly divided into two groups according to the method chosen to estimate the frontier production function, namely, mathematical programming versus econometric estimation. Debate continues over which approach is the most appropriate method to use. The answer often depends upon the application considered. The mathematical programming approach to frontier estimation is usually termed Data Envelopment Analysis (DEA). Coelli (1995a) outlines some of the literature on this approach.

The primary criticism of the DEA approach is that measurement errors can have a large influence upon the shape and positioning of the estimated frontier. Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) independently proposed the stochastic frontier production function to account for the presence of measurement error in production in the specification and estimation of frontier production functions. Stochastic frontier production functions have two error terms, one to account for the existence of technical inefficiency of production and the other to account for factors such as measurement error in the output variable, luck, weather, etc. and the combined effects of unobserved inputs on production. This favourable property of stochastic frontiers comes with a price, namely, that the functional form of the production function and the distributional assumptions of the two error terms must be explicitly specified. Bauer (1990) and Greene (1993) present comprehensive reviews of the econometric estimation of frontiers. Coelli (1995a) also outlines models and applications of stochastic frontier production functions.

In the agricultural economics literature the stochastic frontier (econometric) approach has generally been preferred. This is probably associated with a number of factors. The assumption that all deviations from the frontier are associated with inefficiency, as assumed in DEA, is difficult to accept, given the inherent variability of agricultural production, due to weather, fires, pests, diseases, etc. Furthermore, because many farms are small family-owned operations, the keeping of accurate records is not always a priority. Thus much available data on production are likely to be subject to measurement errors.

There have been many applications of frontier production functions to agricultural industries over the years. Battese (1992) and Bravo-Ureta and Pinheiro (1993) provide surveys of applications in agricultural economics, the latter giving particular attention to applications in developing countries. Bravo-Ureta and Pinheiro (1993) also draw attention to those applications which attempt to investigate the relationship between technical efficiencies and various socio-economic variables, such as age and level of education of the farmer, farm size, access to credit and utilisation of extension services. The identification of those factors which influence the level of technical efficiencies of farmers is, undoubtedly, a valuable exercise. The information provided may be of significant use to policy makers attempting to raise the average level of farmer efficiency. Most of the applications which seek to explain the differences in technical efficiencies of farmers use a two-stage approach. The first stage involves the estimation of a stochastic frontier production function and the prediction of farm-level technical inefficiency effects (or technical efficiencies). In the second stage, these predicted technical inefficiency effects (or technical efficiencies) are related to farmer-specific factors using ordinary least-squares regression. This approach appears to have been first used by Kalirajan (1981) and has since been used by a large number of agricultural economists, a recent example being Parikh and Shah (1994).

Kumbhakar, Ghosh and McGuckin (1991), Reifschneider and Stevenson (1991), Huang and Lui (1994) and Battese and Coelli (1995) specify stochastic frontiers and models for the technical inefficiency effects and simultaneously estimate all the parameters involved. This one-stage approach is less objectionable from a statistically point of view and is expected to lead to more efficient inference with respect to the parameters involved. The Battese and Coelli (1995) stochastic frontier is specified for panel data where the model for the technical inefficiency effects involves farmer-specific variables and the year of observation. Battese and Coelli (1995) apply their model in the analysis of a small sample of fourteen paddy farmers observed over ten years in the village of Aurepalle in India. In this paper, a variant of the Battese and Coelli (1995) model is applied in the analysis of data for 34 farmers from this village and also in the analysis of data for farmers from two other Indian villages.

The remainder of this paper consists of four sections. In Section 2, the data on the farmers from the three Indian villages are briefly described. The proposed stochastic frontier and inefficiency model is discussed in Section 3. Section 4 contains the empirical results. Some conclusions are made in the final section.

Panel Data on Indian Agriculture

During the decade from 1975-76 to 1984-85, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) collected farm-level data on the agricultural operations of a sample of farmers in three different regions in India. These Village Level Studies (VLS) were designed to obtain reliable data on the broad agro-climatic sub-regions in the semi-arid tropics of India, in order to better understand traditional agriculture in the region, with a view to encouraging improved methods of agricultural production.

The three villages of Aurepalle, Kanzara and Shirapur were selected by ICRISAT for the in-depth study of the farming operations involved because they were considered broadly representative of the semi-arid tropics of India. These villages are located in the districts of Mahbubnagar, Akola and Sholapur, respectively, and are approximately 70 km south, 550 km north and 336 km west of the Headquarters of ICRISAT at Patancheru, near Hyderabad in the State of Andhra Pradesh. The three districts were selected because they represented the major soil types, rainfall and cropping patterns in the semi-arid tropics of India. Within each of the selected villages, farmers were stratified into small, medium and large farming operations. Samples of ten farmers were then selected from each of the three groupings in each of the three villages. The numbers of farmers involved in the three villages are 34, 33 and 35 for Aurepalle, Kanzara and Shirapur, respectively. These numbers exceed 30 because some farmers withdrew from the survey program and were replaced by other farmers from the appropriate size category. The total numbers of yearly observations involved in our analyses are 273, 289 and 268, for Aurepalle, Kanzara and Shirapur, respectively.

Walker and Ryan (1990) present a detailed discussion of the regions and the VLS data. We present only a brief description of the agro-climatic conditions in the three districts involved. Aurepalle is characterised by red soils of shallow-to-medium depth which generally have low water-retention capacities. Kanzara and Shirapur have black soils, which are deeper and have higher water-retention qualities than Aurepalle's red soils. The soils in Shirapur are regarded as better than the soils in Kanzara. Mean annual rainfalls over the ten-year period were 611 mm in Aurepalle, 629 mm in Shirapur and 850 mm in Kanzara, with year-to-year variation between 400 and 1200 mm. The majority of rain falls in the period from June to October. The predominant crops in the three villages are castor, sorghum and paddy in Aurepalle; cotton, pigeon pea and sorghum in Kanzara; and sorghum, chickpea, wheat and vegetables in Shirapur.

The Stochastic Frontier and Inefficiency Model

The stochastic frontier production function model which we specify for the farming operations in a given village is

$$(1)\quad \ln(Y_{it}) = \beta_0 + \beta_1\ln(Land_{it}) + \beta_2(IL_{it}/Land_{it}) + \beta_3\ln(Labour_{it}) + \beta_4(HL_{it}/Labour_{it}) + \beta_5\ln(Bullocks_{it}) + \beta_6\ln(Costs_{it}) + \beta_7(Year_{it}) + V_{it} - U_{it}$$

where the subscripts i and t refer to the i-th farmer and the t-th observation, respectively;

ln represents the natural logarithm (i.e., to base e);

Y represents the total value of output (in Rupees, in 1975-76 values) from the crops which are grown;

Land represents the total area of irrigated and unirrigated land (in hectares);

IL represents the area of irrigated land that is operated (in hectares);

Labour represents the total quantity of human labour for family members and hired labourers (in man hours)[1];

HL represents the amount of hired labour employed (in man hours);

1 Labour hours were converted to male equivalent units according to the rule that female and child hours were considered equivalent to 0.75 and 0.50 male hours, respectively. These ratios were obtained from ICRISAT.

Bullocks represents the total amount of bullock labour for owned or hired bullocks (in hours for pairs of bullocks);

Costs represents the total value of other input costs involved (fertiliser, manure, pesticides, machinery, etc.)[2];

Year represents the year of observation (expressed in terms of 1,2,..., 10);

the $V_{it}s$ are assumed to be independently and identically distributed random errors, having $N(0, \sigma_v^2)$-distribution; and

the $U_{it}s$ are non-negative random variables, called technical inefficiency effects, associated with the technical inefficiency of production of the farmers involved.[3]

It is assumed that the inefficiency effects are independently distributed and U_{it} arises by truncation (at zero) of the normal distribution with mean, μ_{it}, and variance, σ^2, where μ_{it} is defined by

$$(2) \quad \mu_{it} = \delta_0 + \delta_1(Age_{it}) + \delta_2(Schooling_{it}) + \delta_3(Land_{it}) + \delta_4(Year_{it})$$

where *Age* and *Schooling* are the age and years of formal schooling of the farmer who is the principal decision maker; and *Land* and *Year* are as defined above.

The β- and δ-coefficients are unknown parameters to be estimated, together with the variance parameters which are expressed in terms of

$$(3) \quad \sigma_S^2 = \sigma_v^2 + \sigma^2 \text{ and}$$

$$(4) \quad \gamma = \sigma^2 / \sigma_S^2$$

where the γ-parameter has value between zero and one. The parameters of the stochastic frontier production function model are estimated by the method of maximum likelihood, using the computer program, FRONTIER Version 4.1 (see Coelli, 1992,1994).

The stochastic frontier production function, defined in equation (1), is a linearised approximation of a Cobb-Douglas production function in which the land and labour variables are linear combinations of irrigated and unirrigated land and hired and family labour, respectively. For more on this particular specification, see Battese, Coelli and Colby (1989) and Battese and Coelli (1992). A test of the hypothesis

2 For the *Costs* of other inputs, zero values were obtained for some farmers. Hence the *Costs* variable is actually defined as *Costs* = Maximum(Costs, 1-D), where the dummy variable, D, is defined to have values 0 or 1 if Costs of other inputs were zero or positive, respectively.

3 Because the output variable in the stochastic frontier production function is *value of total output*, the measures of technical efficiencies obtained below will, in fact, be measures of the total economic efficiencies of the farmers. Hence the $U_{it}s$ are hereafter referred to as "inefficiency effects" rather than technical inefficiency effects in this paper.

that hired and family labour are equally productive is obtained by testing the null hypothesis that the coefficient, β_4, of the labour-ratio variable, *HL/Labour*, is zero. This hypothesis is of particular interest in Indian agriculture, cf. Bardhan (1973). The *Costs* variable which is included in the production function is a composite of the costs of other inputs, such as fertiliser, pesticides, etc. It would be desirable to have data on some these individual inputs because they obviously have different influences on crop production. However, there would have been significant proportions of the sample farmers having zero values for these inputs.[4] The inclusion of the year of observation in the production function (1) assumes the possibility of Hicks-neutral technical change.

The expected signs on the δ-parameters in the inefficiency model, defined by equation (2), are not clear in all cases. The *Age* of the farmers could be expected to have a positive or a negative effect upon the size of the inefficiency effects. The older farmers are likely to have had more farming experience and hence have less inefficiency. However, they are also likely to be more conservative and thus be less willing to adopt new practices, thereby perhaps having greater inefficiencies in agricultural production.

Schooling is expected to have a negative effect upon the inefficiency effects. That is, we expect that greater levels of formal education will be associated with smaller values for the inefficiency effects.

The sign of the coefficient of the *Land* variable in the model for the inefficiency effects is expected to be negative. This expectation is partially based upon the likelihood that the farmers with smaller operations may have alternative income sources which are more important and hence put less effort into their farming operations compared with the larger farmers. It is also possible that the modified Cobb-Douglas form used in this analysis does not appropriately accommodate a range of scale economies and hence that some scale inefficiency may be included in the estimated inefficiencies of production.

The coefficient of the *Year* variable in the model for the inefficiency effects (2) is expected to be negative. This implies that the levels of the inefficiency effects of the farmers in the three villages tend to decrease over time. That is, the farmers are expected to become more efficient over time. This time-trend variable is expected to pick up the influence of factors which are not included in the inefficiency model which vary systematically through time. For example, it may reflect

4 If the dummy variable, D, defined above, is included as an explanatory variable in the stochastic frontier (1), then different intercepts are permitted for farmers with positive and zero values of Costs of other inputs. Further, the estimate for the elasticity of Costs from such a model would be equivalent to that obtained if only data with positive costs are used (see Battese, 1996).

the influence of government agricultural extension programs over the sample period.

Variables such as contact with extension advisers, credit availability, etc., would be useful in modelling the inefficiency effects, but data on these variables are not available. The inefficiency effects could be modelled in terms of quadratic time effects or different intercepts could be specified for different time periods.

It is important to note that the above model for the inefficiency effects can only be estimated if the inefficiency effects are stochastic and have a particular distributional specification. Hence there is interest to test the null hypotheses that the inefficiency effects are not present, H_0: $\gamma = \delta_0 = \ldots = \delta_4 = 0$; the inefficiency effects are not stochastic, H_0: $\gamma = 0$; and the coefficients of the variables in the model for the inefficiency effects are zero, H_0: $\delta_1 = \ldots = \delta_4 = 0$. These and other null hypotheses of interest are tested using the generalised likelihood-ratio statistic, λ, defined by

(5) $\lambda = -2 \ln[L(H_0) / L(H_1)]$

where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the specifications of the null and alternative hypotheses, H_0 and H_1, respectively. If the given null hypothesis is true then λ has approximately a Chi-square (or a mixed Chi-square) distribution. If the null hypothesis involves $\gamma = 0$, then the asymptotic distribution involves a mixed Chi-square distribution (see Coelli, 1995b).

The technical efficiency of a farmer at a given period of time is defined as the ratio of the observed output to the frontier output which could be produced by a fully-efficient firm, in which the inefficiency effect is zero. Given the specifications of the stochastic frontier model (1)-(2), the technical efficiency of the i-th farmer in the t-th year of observation, can be shown to be equal to

(6) $TE_{it} = \exp(-U_{it})$.

Thus the technical efficiency of a farmer is between zero and one and is inversely related to the inefficiency effect. The efficiencies are predicted using the predictor that is based on the conditional expectation of $\exp(-U_{it})$, presented in Battese and Coelli (1993), which is programmed in FRONTIER Version 4.1.

Results and Discussion

A summary of the sample data on the different variables in the stochastic frontier and inefficiency model, defined by equations (1) and (2), is presented in Table 1. The sizes of the holdings are small relative to those seen in modern western agriculture. The average farm sizes vary from 4.29 ha in Aurepalle to 6.68 ha in Shirapur. The smaller holdings in Aurepalle could be attributed to the greater use of irrigation

TABLE 1

Summary Statistics for Variables in the Stochastic Frontier Production Functions for Farmers in Three Indian Villages

Variable	Sample Mean	Standard Deviation	Minimum Value	Maximum Value
Value of Output (Rupees)				
Aurepalle	3679.6	4559.2	10.15	18094
Kanzara	5231.3	7226.5	121.58	39168
Shirapur	3270.7	3482.7	22.00	26423
Land (hectares)				
Aurepalle	4.29	3.87	0.20	20.97
Kanzara	6.02	7.40	0.40	36.34
Shirapur	6.68	5.49	0.61	24.19
Irrigated Land (hectares)				
Aurepalle	0.95	1.41	0	7.09
Kanzara	0.51	1.22	0	9.79
Shirapur	0.64	1.07	0	4.96
Labour (hours)				
Aurepalle	2206.2	2744.1	26	12916
Kanzara	2578.5	3145.7	58	15814
Shirapur	1674.8	1576.9	40	11146
Hired Labour (hours)				
Aurepalle	1468.3	2349.6	0	11662
Kanzara	1841.2	2852.3	6	14130
Shirapur	719.1	768.4	24	4823
Bullock Labour (hours)				
Aurepalle	528.2	604.6	8	4316
Kanzara	570.6	765.1	12	3913
Shirapur	342.3	282.2	14	1240
Cost of Other Inputs (Rupees)				
Aurepalle	651.02	981.06	0	6205.0
Kanzara	628.96	978.49	0	5344.3
Shirapur	464.49	1038.00	0	6746.0
Age of Farmer (years)				
Aurepalle	53.9	12.6	26	90
Kanzara	43.7	9.6	23	67
Shirapur	48.2	10.2	24	72
Schooling of Farmer (years)				
Aurepalle	2.01	2.87	0	10
Kanzara	4.03	4.10	0	12
Shirapur	2.94	3.35	0	16

* Sample sizes are 273, 289 and 268 for Aurepalle, Kanzara and Shirapur, respectively.

in Aurepalle (an average of 0.95 ha per farm in Aurepalle versus approximately 0.5 ha per farm in the other two villages). Labour use is higher in Aurepalle and Kanzara where paddy planting and cotton picking are labour-intensive activities. The use of bullock labour and costs of other inputs in Aurepalle and Kanzara are higher than in Shirapur. Much of this is due to the high input use required with the above two crops. The average age of farmers vary from 43.7 years in Kanzara to 53.9 years in Aurepalle, while average education levels are quite low, varying from about two years in Aurepalle to about four years in Kanzara.

The maximum-likelihood estimates for the parameters in the stochastic frontier and inefficiency model for the three villages involved are presented in Table 2. The estimated β-coefficients of the stochastic frontier have signs and sizes which generally conform with our expectations. The estimated coefficients of *Land* and *Labour* are positive for all of the three villages. The coefficient of *IL/Land* is estimated to be positive for Aurepalle and Kanzara, reflecting the higher productivity of irrigated land. However, for Shirapur the coefficient of the proportion of irrigated land is estimated to be negative and significantly different from zero. This is a surprising result which requires further investigation to satisfactorily explain.

The coefficient of the ratio of hired labour to total labour, *HL/Labour*, is estimated to be negative for Aurepalle and Kanzara, indicating that hired labour is less productive than family labour. Generalised likelihood-ratio tests of the null hypothesis that the coefficient of the hired-labour ratio is zero are presented in Table 3 for the three villages. The null hypothesis, H_0: $\beta_4 = 0$, is rejected for farming operations in Aurepalle, but accepted for Kanzara and Shirapur. The conclusion that hired and family labour are not equally productive in Aurepalle may be associated with the labour-intensive operations required in paddy production and the nature of the well-developed labour market in that region.

The estimated coefficients of bullock labour are negative for all three villages, but only the estimate for Aurepalle is significantly different from zero. This negative influence is contrary to what one would expect, but conforms with earlier analyses, reported by Saini (1979) and Battese and Coelli (1992, 1995). A possible explanation for this result is that the bullocks are often used for weed control and repairs of irrigation banks in poor seasons when the land is less water-logged. Thus the quantity of bullock labour may be acting as an inverse proxy for rainfall.

The coefficient of the cost of other inputs is estimated to be positive for all three villages. In Table 3, the null hypothesis, H_0: $\beta_6 = 0$, is accepted for Aurepalle and Shirapur, but for Kanzara it is strongly rejected. This result may be due in part to the importance of cotton production in Kanzara. The cotton plant is susceptible to a number of

TABLE 2

*Maximum-Likelihood Estimates for Parameters of the Stochastic Frontier and Inefficiency Models for Three Indian Villages**

Variable	Parameter	Aurepalle	Kanzara	Shirapur
Stochastic Frontier				
Constant	β_0	–5.62	–4.90	–4.69
		(0.33)	(0.37)	(0.32)
Land	β_1	0.264	0.066	0.012
		(0.070)	(0.066)	(0.061)
IL/Land	β_2	0.093	0.083	–0.076
		(0.058)	(0.038)	(0.030)
Labour	β_3	1.212	0.785	0.905
		(0.076)	(0.079)	(0.060)
HL/Labour	β_4	–0.00047	–0.000019	0.00020
		(0.00012)	(0.000091)	(0.00040)
Bullocks	β_5	–0.430	–0.006	–0.086
		(0.056)	(0.060)	(0.060)
Costs	β_6	0.009	0.098	0.002
		(0.014)	(0.011)	(0.010)
Year	β_7	0.0279	–0.0182	0.016
		(0.0088)	(0.0081)	(0.012)
Inefficiency Model				
Constant	δ_0	–1.8	0.80	1.37
		(1.5)	(0.35)	(0.50)
Age	δ_1	–0.0150	–0.015	0.0133
		(0.0092)	(0.010)	(0.0099)
Schooling	δ_2	–0.064	0.039	–0.217
		(0.046)	(0.033)	(0.088)
Size	δ_3	–0.29	–0.083	–0.208
		(0.14)	(0.056)	(0.082)
Year	δ_4	–0.36	–0.077	–0.39
		(0.15)	(0.046)	(0.12)
Variance Parameters				
	σ_S^2	2.19	0.39	0.96
		(0.92)	(0.20)	(0.35)
	γ	0.9826	0.915	0.944
		(0.0069)	(0.040)	(0.023)
Log–likelihood Function		**–99.51**	**–80.29**	**–128.81**

* Estimated standard errors are given below the parameter estimates, correct to at least two significant digits. The parameter estimates are given correct to the corresponding number of digits behind the decimal places.

TABLE 3

Statistics for Tests of Hypotheses Involving Some Coefficients of the Stochastic Frontier Production Functions for Three Indian Villages

Null Hypothesis	Log–Likelihood Function	Test Statistic λ	Critical Value	Decision
H_0: $\beta_4 = 0$				
Aurepalle	−104.90	10.78	3.84	Reject H_0
Kanzara	−80.31	0.04	3.84	Accept H_0
Shirapur	−128.97	0.32	3.84	Accept H_0
H_0: $\beta_6 = 0$				
Aurepalle	−99.69	0.36	3.84	Accept H_0
Kanzara	−111.28	61.98	3.84	Reject H_0
Shirapur	−128.81	0.00	3.84	Accept H_0
H_0: $\beta_7 = 0$				
Aurepalle	−103.32	7.62	3.84	Reject H_0
Kanzara	−83.04	5.50	3.84	Reject H_0
Shirapur	−129.80	1.98	3.84	Accept H_0

insect pests and so the regular use of pesticides in cotton production appears to be a highly significant factor in the agricultural production in Kanzara.

The coefficient of year of observation in the stochastic frontier, β_7, is estimated to be positive for Aurepalle and Shirapur, which indicates technical progress in these villages. However, for Kanzara, a negative estimate is obtained, which indicates technical regress. The null hypothesis of no technical change, H_0: $\beta_7 = 0$, is the last considered in Table 3. The test statistics indicate that the null hypothesis of no technical change is rejected in Aurepalle and Kanzara, but is accepted for Shirapur. One possible reason for technical regress is the situation where intensive cropping practices reduce the nutrient content of the soil at a faster rate than it is replenished by fertiliser applications. A closer inspection of the farming practices in Kanzara is required before any firm conclusions can be made.

It is interesting to note that the conclusions of the generalised likelihood-ratio tests listed in Table 3 are the same as those that would have been made if asymptotic t-tests had been used. Thus, in this application, the standard errors of the maximum-likelihood estimators appear to be well estimated using the Davidon-Fletcher-Powell algorithm which is used in the FRONTIER program.

The estimated δ-coefficients in Table 2 associated with the explanatory variables in the model for the inefficiency effects are worthy of particular discussion. We observe that age of the farmers has a negative effect upon the inefficiency effects in Aurepalle and Kanzara. That is, the older farmers tend to have smaller inefficiencies (i.e., are more efficient) than younger farmers in Aurepalle and Kanzara, but the reverse is true in Shirapur. This mixture of signs is not unexpected, given the various effects that farmer age may have upon efficiency, as discussed in Section 3.

The coefficient of *Schooling* is estimated to be negative in Aurepalle and Shirapur, but positive in Kanzara. That is, in the villages of Aurepalle and Shirapur, farmers with greater years of formal education tend to be more efficient in agricultural production. The positive value obtained for Kanzara is unexpected, but it is not significantly different from zero.

The coefficient of the *Land* variable in the model for the inefficiency effects is estimated to be negative in all villages, as expected. This indicates that farmers with larger farms tend to have smaller inefficiency effects than farmers with smaller operations. This contradicts the claim which is frequently made for developing country agriculture, that smaller farmers tend to be more efficient in production than larger farms.

The coefficient of *Year* of observation in the model for the inefficiency effects is also estimated to be negative in all three villages. This implies that the levels of the inefficiency effects of farmers in the three villages tend to decrease over time. That is, farmers tend to become more efficient over time. This time-trend variable may be picking up the influence of factors which are not included in the inefficiency model, such as government extension programmes.

The γ-parameter associated with the variances in the stochastic frontier is estimated to be greater than 0.9 in all of the three villages. Although this parameter cannot be interpreted as the proportion of the variance of the inefficiency effects relative to the sum of the variances of the inefficiency effects and the random variation, it indicates that the random component of the inefficiency effects does make a significant contribution in the analysis of agricultural production in the Indian villages involved.

Formal tests of hypotheses associated with the inefficiency effects are presented in Table 4. The first three null hypotheses are strongly rejected by the data for all of the three villages involved.[5] Thus the traditional average response function is not an adequate representation for the agricultural production in the three villages, given the specification of the stochastic frontier and inefficiency model, defined by equations (1) and (2).

[5] The critical values for the two null hypotheses involving $\delta = 0$ are less than the 95-th percentiles for the Chi-square distributions with six and three degrees of freedom for the first and second null hypotheses, respectively. The correct critical values are obtained from Table 1 of Kodde and Palm (1986, p.1246) for degrees of freedom 6 and 3, respectively.

TABLE 4

Tests of Hypotheses for Coefficients of the Explanatory Variables for the Technical Inefficiency Effects in the Stochastic Frontier Production Functions for Three Indian Villages

Null Hypothesis	Log–likelihood Value	Test Statistic λ	Critical Value	Decision
H_0: $\gamma = \delta_0 = ... = \delta_4 = 0$				
Aurepalle	−138.02	77.02	11.91	Reject H_0
Kanzara	−106.03	51.48	11.91	Reject H_0
Shirapur	−183.68	109.74	11.91	Reject H_0
H_0: $\gamma = 0$				
Aurepalle	−137.86	76.70	7.05	Reject H_0
Kanzara	−100.18	39.78	7.05	Reject H_0
Shirapur	−177.54	97.46	7.05	Reject H_0
H_0: $\delta_0 = ... = \delta_4 = 0$				
Aurepalle	−113.12	27.22	11.07	Reject H_0
Kanzara	−93.27	25.96	11.07	Reject H_0
Shirapur	−161.58	65.54	11.07	Reject H_0
H_0: $\delta_1 = ... = \delta_4 = 0$				
Aurepalle	−101.92	4.82	9.49	Accept H_0
Kanzara	−91.13	21.68	9.49	Reject H_0
Shirapur	−151.98	46.34	9.49	Reject H_0

The last null hypothesis considered in Table 4, H_0: $\delta_1 = ... = \delta_4 = 0$, specifies that all the coefficients of the explanatory variables in the inefficiency model are equal to zero (and hence that the technical inefficiency effects have the same truncated-normal distribution). This null hypothesis is rejected for the villages of Shirapur and Kanzara, but it is accepted for Aurepalle. Thus for Aurepalle, it could be concluded that the inefficiency effects are not significantly influenced by the age and education of the farmers, the size of the farming operation, and that they are not time-varying. Hence it appears that, given the specifications of the stochastic frontier and inefficiency model, defined by equations (1) and (2), the inefficiency effects for Aurepalle farmers can be regarded as independent and identically distributed random variables which arise from the truncation of a normal distribution with non-zero mean.

The (technical) efficiencies of farmers, defined by equation (6), are predicted for each year in which they were observed. These predictions are derived from the estimated models presented in Table 2. The predicted efficiencies of the farmers in Aurepalle, Kanzara and Shirapur are presented in Tables 5, 6 and 7, respectively. Also presented in these tables are estimates for the mean efficiencies of each farmer (over the ten-year period) and the mean efficiencies for farmers in each of the years involved. The predicted efficiencies differ substantially within each village. They range from quite small values of less than 0.1 to values in excess of 0.9. The mean efficiencies of the farmers in the three villages do not appear to differ substantially. They are 0.747 for Aurepalle, 0.738 for Kanzara and 0.711 for Shirapur.

To give a better indication of the distribution of the individual efficiencies, frequency distributions of the efficiencies are plotted for Aurepalle, Kanzara and Shirapur in Figures 1, 2 and 3, respectively. The plots are quite similar, with a thin tail in the left of the distribution, gradually rising to a maximum in the 0.8 to 0.9 interval, and then dropping sharply in the 0.9 to 1.0 interval. The fact that the mode of the distribution is not in this final interval offers support for the use of more general distributions (than the often considered half-normal distribution) for the inefficiency effects, such as the general truncated-normal distribution used in this study.

The annual mean efficiencies, which are presented in the bottom row of each of Tables 5, 6 and 7, are plotted in Figure 4. A general upward trend in the levels of mean efficiency is observed over the sample period in all three villages. The mean efficiencies in Shirapur tend to follow a rather smooth upward trend, in comparison with the more volatile results for Aurepalle and Kanzara. There is also a suggestion of a reduction in the variability of the mean efficiencies in the three villages towards the end of the ten-year period, relative to the greater divergence in the values in the earlier part of the sample period. This could reflect an improvement in the ability of the farmers to adjust their production methods to the year-to-year changes in the agro-climatic environments in the regions involved.

Conclusions

Stochastic frontier production functions are estimated for each of three villages from diverse agro-climatic regions of the semi-arid tropics of India. The production frontiers involve the inputs of land, labour, bullock labour and cost of other inputs. The ratios of irrigated land to total land and hired labour to total labour are included in the functions to permit the productivities of irrigated versus unirrigated land and hired versus family labour to differ. A time trend is used to proxy the influence of technical change. All estimates have the expected signs, with the exception of the coefficients of the ratio variables in the case of Shirapur and the coefficient of year of observation in the case of Kanzara. The results for Shirapur may be a consequence of there being no important labour-intensive irrigated crop grown in that village.

The model for the inefficiency effects in the production frontier includes the age and years of formal schooling of the farmer, size of the farm and the year of observation as explanatory variables. A number of tests of hypotheses are conducted to assess the relative influence of these factors and other random effects. The results indicate a significant random component in the inefficiency effects in all three villages and that the above four factors have a significant influence upon the size of the inefficiencies of farmers in Kanzara and Shirapur, but not in Aurepalle. Farm size and year of observation are estimated to be inversely related to the level of technical inefficiency in all villages. In two of the three villages, the effects of age and education of the farmers are found to be negatively related to the level of the inefficiency effects.

An important feature of our frontier model is that it is possible to separately estimate technical change and changes in the inefficiency effects over time. For the village of Aurepalle, significant technical progress was evident, but the inefficiency effects were time-invariant. However, in Kanzara, there was evidence of technical regress, but also of decreasing inefficiency effects over time.

The analyses reported in this paper indicate that there are significant differences in the behaviour of value of output and inefficiencies of production in the different regions from which data were obtained in ICRISAT's Village Level Studies. Although this empirical study does not include some variables which might be important in modelling output and inefficiency effects, such as rainfall data, use of agricultural extension services and access to credit, it indicates the potential for more refined analysis, if such data were readily available. It is evident that, in order to be able to draw conclusions of significance for policy purposes, future studies need to be devised to obtain extensive data sets on relevant variables for production frontiers and models for the inefficiency effects which are consistent with such policy orientations.

TABLE 5

Predicted Efficiencies for Farmers in Aurepalle

Farm	75-76	76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85	Mean
1	–	–	–	–	–	.554	.590	.909	.764	.867	.737
2	–	–	–	–	–	.558	.573	–	.721	.351	.551
3	–	–	–	–	–	–	.323	.879	–	–	.601
4	–	–	–	–	–	.586	.790	.890	.805	.756	.765
5	.756	.772	.928	.587	.818	.700	.642	.918	.700	.550	.737
6	.745	.804	.908	.606	.825	.674	.651	.922	.702	.707	.754
7	.894	.837	–	.543	.664	.850	.388	.873	.826	.865	.749
8	.841	.154	.802	.800	.618	.582	.615	.846	.785	.847	.689
9	.767	.825	.472	–	.880	–	.664	.938	.709	.875	.766
10	.919	.749	.836	.887	.828	–	.607	.896	.905	.914	.838
11	.454	.599	.702	.795	.813	–	.475	.929	.681	.758	.689
12	.939	–	.811	.779	.680	.486	.304	.842	.045	.538	.603
13	.715	.778	.834	.834	.375	–	.604	.932	.563	.850	.721
14	.648	–	.809	.799	.835	.860	–	–	–	–	.790
15	.411	.372	.931	.750	.834	.758	–	–	–	–	.676
16	.705	.220	.826	.846	.908	.647	–	–	–	–	.692
17	.358	–	–	–	.487	.595	–	–	–	–	.480
18	.752	.452	.903	.890	.777	.799	.697	.869	.859	.851	.785
19	.665	.393	.662	.650	.704	.506	.676	.852	–	–	.638
20	.673	.365	.757	.906	.790	.588	.769	.843	.819	.874	.739
21	.620	.813	.888	.779	.825	.847	.890	.878	.905	.872	.832
22	.903	.452	.878	.879	.880	.456	.845	.837	.864	.874	.787
23	.890	.478	.800	.803	.707	.465	.649	–	–	–	.685
24	.875	.767	.933	.897	.847	.822	.805	.887	.848	.847	.853
25	.934	.231	.901	.869	.754	.583	.696	.716	.825	.690	.720

26	.654	.423	.930	.838	.764	.788	.827	.890	.749	–	.763
27	.833	.610	.802	–	.827	.653	.885	.920	.841	.847	.802
28	.748	.254	.785	.776	.781	.704	.702	.863	.823	.868	.730
29	.864	.765	.853	.800	.888	.826	.747	.829	.877	.887	.834
30	.807	.891	.913	.848	.926	.838	.932	.935	.874	.929	.889
31	.834	.505	.855	.857	.871	.728	.854	.859	.797	.905	.807
32	.694	.555	.895	.791	.741	.716	.881	.925	.869	.899	.796
33	.504	.463	.905	.822	.793	.312	.636	–	–	–	.634
34	–	.428	.894	.833	.844	–	–	–	–	–	.750
Mean	**.738**	**.554**	**.836**	**.795**	**.776**	**.660**	**.680**	**.880**	**.766**	**.801**	**.747**

TABLE 6

Predicted Efficiencies for Farmers in Kanzara

Farm	**75-76**	**76-77**	**77-78**	**78-79**	**79-80**	**80-81**	**81-82**	**82-83**	**83-84**	**84-85**	**Mean**
1	–	–	.526	.558	.683	.378	.493	.774	–	–	.569
2	–	–	–	–	.596	.353	.737	.670	.690	–	.609
3	–	–	–	.552	.847	.596	–	–	.824	.790	.722
4	.832	.794	.598	.740	.729	.506	.881	.819	.896	.883	.768
5	.871	.750	.819	.309	.591	.440	.649	.875	.900	.885	.709
6	.916	.596	.653	.378	.614	.372	.738	.741	.883	.674	.657
7	.904	.460	.841	.602	.652	.458	.825	.817	.889	.852	.730
8	.856	–	–	.414	.425	.498	.530	.690	–	–	.569
9	.740	.523	.843	–	.669	.679	.915	.883	.675	.904	.759
10	.906	.844	.757	.602	.900	.640	.909	.773	–	–	.792
11	.919	.708	.735	.654	.843	.466	.585	.837	.947	.777	.747
12	.695	.365	.629	.687	.773	.754	.704	.860	.886	.879	.723

13	.847	–	–	–	–	–	–	–	.853	–	.850
14	.372	.880	.470	.132	.782	.617	–	.593	.897	.688	.603
15	.873	.809	.791	.565	.699	.625	.860	.866	.914	.820	.782
16	.739	.792	.415	.337	.804	.461	.606	–	.878	.908	.660
17	.702	–	–	–	–	.765	.597	.810	.826	.785	.748
18	.844	.793	.910	.819	.837	.639	.920	.924	.910	.851	.845
19	.867	.863	.605	.427	.249	.692	.534	.762	.660	.866	.652
20	.585	.908	.727	.830	.886	.551	.746	.793	.876	.767	.767
21	.768	.864	.431	.593	.706	.329	.783	.579	.896	.796	.674
22	.435	.654	.611	.686	.845	.464	.712	.759	.849	.847	.686
23	.863	.720	.479	.393	.709	.408	.740	.756	.721	.853	.664
24	.942	.848	.838	.891	.850	.635	.794	.811	.835	.851	.830
25	.854	.923	.855	.860	.823	.792	.867	.901	.932	.838	.864
26	.625	.553	.387	.452	–	–	–	–	–	–	.504
27	.805	.631	.606	.545	.783	.449	.733	.657	.812	.798	.682
28	.947	.934	.895	.867	.930	.901	.933	.944	.942	.918	.921
29	.754	.908	.808	.722	.780	.562	.842	.883	.883	.874	.802
30	.836	.777	.681	.402	.794	.458	.818	.773	.824	.850	.721
31	.903	.827	.653	.837	.756	.660	.902	.870	.881	.876	.817
32	.792	.815	.659	.626	.454	.855	.908	.925	.870	.862	.777
33	.856	.908	.872	.868	.898	.747	.902	.925	.939	.936	.885
Mean	**.795**	**.757**	**.682**	**.598**	**.730**	**.573**	**.764**	**.802**	**.855**	**.838**	**.738**

TABLE 7

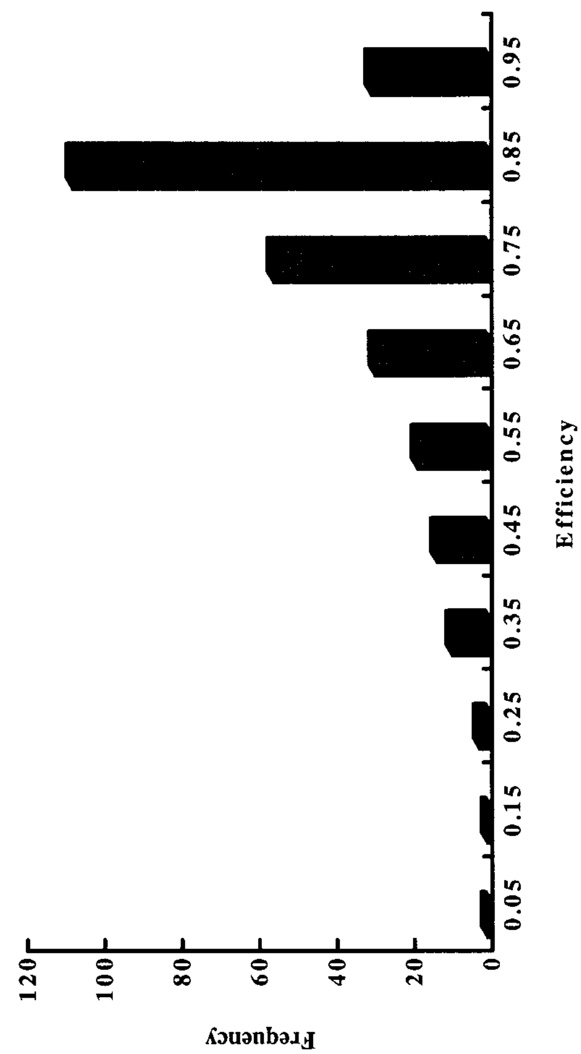
Predicted Efficiencies for Farmers in Shirapur

Farm	75-76	76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85	Mean
1	–	.613	.629	.679	.715	.869	.800	.890	.910	.874	.775
2	–	.375	.670	.328	.181	–	–	–	–	–	.389
3	–	.749	.882	.727	.916	.867	.903	.712	.633	.392	.754
4	–	–	–	–	–	.707	.761	.802	.611	.821	.740
5	.568	.192	.340	.404	.608	.827	.721	.696	.599	–	.551
6	.352	.833	.811	.850	.885	.917	.770	.742	.463	.549	.717
7	.276	.739	.606	.781	.575	–	–	–	–	–	.595
8	.100	.298	.338	.764	.762	.637	.888	.900	.818	.877	.638
9	.022	–	–	–	.427	.099	.443	.556	.661	.468	.382
10	.361	.709	.523	.778	.629	.626	–	.806	.482	.450	.596
11	.390	.727	.496	.767	.872	.836	.897	.919	.896	.554	.735
12	.865	.859	.552	–	–	–	–	–	–	–	.759
13	.479	.737	.801	.789	.819	.839	.798	.567	.862	.880	.757
14	.345	.806	.454	.721	.721	.886	.722	.855	.760	–	.697
15	.180	.601	.885	.636	.936	.922	.903	.926	.765	.855	.761
16	.297	.445	.511	.346	.690	.700	.869	.900	–	–	.595
17	.316	.528	.743	.503	.685	.884	–	–	–	–	.610
18	.400	.688	.668	.586	.588	.847	.871	.892	.765	.877	.718
19	.178	.588	.745	.695	.843	.696	.864	.887	.893	.712	.710
20	.471	.882	.773	.845	.943	.910	.919	–	–	–	.820
21	.224	–	–	.464	–	.360	.778	.826	.864	.876	.628
22	.647	.756	.854	.787	.829	.859	.558	.891	.641	.912	.774
23	.152	–	–	–	.416	–	–	–	–	–	.284
24	.341	.718	.818	.780	.855	.848	.872	.876	.852	.859	.782

25	.700	.623	.828	.781	.928	.861	.905	.886	.804	.806	.812
26	.416	.700	.565	.731	.808	.717	.804	.838	.796	.867	.724
27	.776	.865	.926	.889	–	.599	.897	.905	.905	.460	.802
28	.735	.808	.855	.660	.769	.710	.901	.911	.893	.890	.813
29	.376	.813	.791	.849	.808	.833	.799	.891	.845	.834	.784
30	.892	.904	.812	.873	.888	–	–	–	–	–	.874
31	.932	.852	.827	–	–	–	–	–	–	–	.870
32	.353	–	–	–	–	–	–	–	–	–	.353
33	–	.195	.501	.523	.689	.768	–	–	–	–	.535
34	–	.713	.651	.530	.851	–	–	.830	.900	.867	.763
35	–	.892	.853	.863	.910	.883	.888	.933	.889	.893	.889
Mean	**.434**	**.674**	**.690**	**.687**	**.743**	**.760**	**.814**	**.833**	**.771**	**.753**	**.711**

FIGURE 1

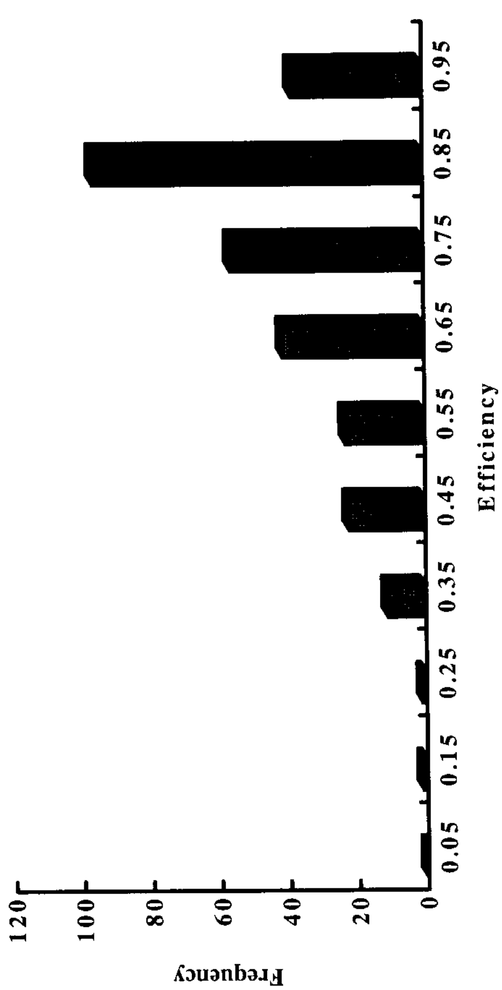
Frequency Distribution of Predicted Efficiencies of Farmers in Aurepalle



(Note that numbers on the horizontal axis refer to the mid-point of the interval.)

FIGURE 2

Frequency Distribution of Predicted Efficiencies of Farmers in Kanzara



(Note that numbers on the horizontal axis refer to the mid-point of the interval.)

FIGURE 3

Frequency Distribution of Predicted Efficiencies of Farmers in Shirapur

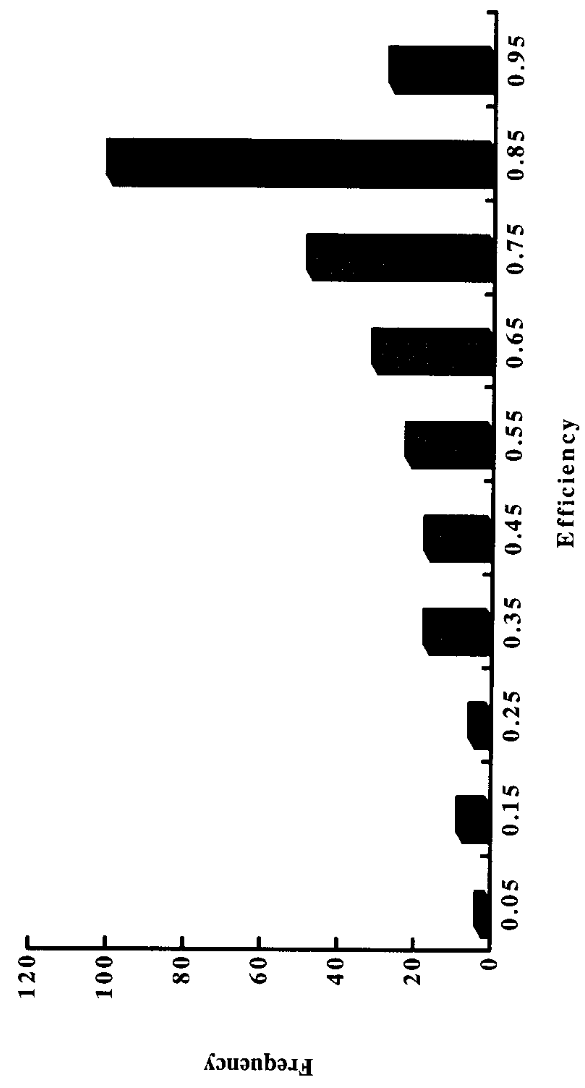
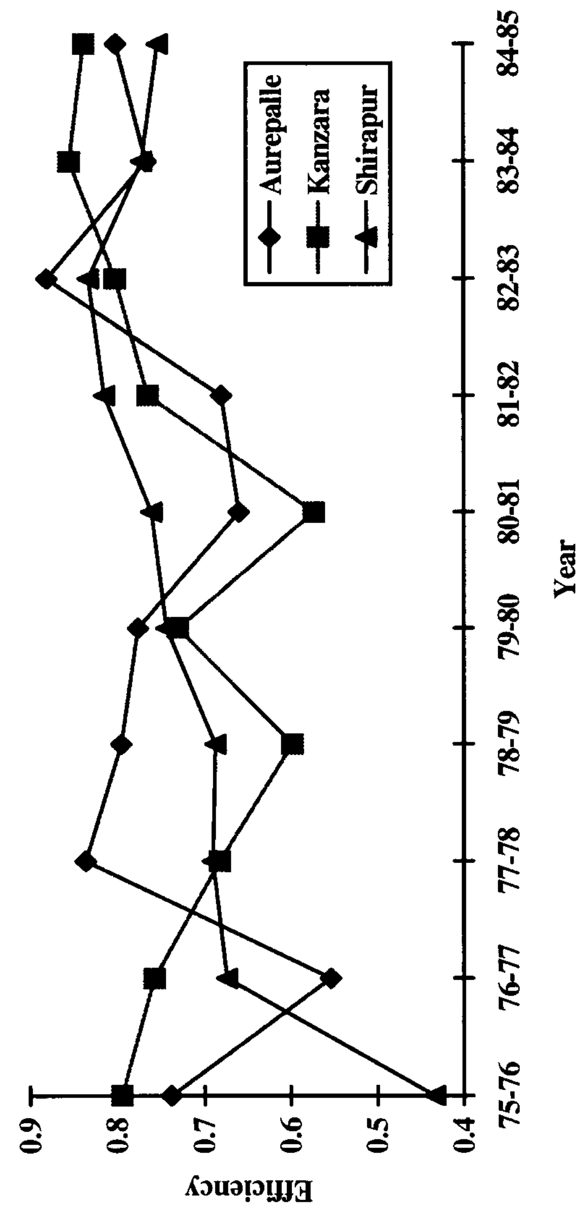


FIGURE 4
Mean Efficiencies of the Three Indian Villages



References

Aigner, D., C.A.K. Lovell, and P. Schmidt (1977), 'Formulation and Estimation of Stochastic Frontier Production Function Models', *Journal of Econometrics*, 6, 21-37.

Bardhan, P.K. (1973), 'Size, Productivity and Returns to Scale: An Application of Farm-level Data in Indian Agriculture', *Journal of Political Economy*, 81, 1370-1386.

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

Battese, G.E. (1996), 'On the Estimation of Production Functions Involving Explanatory Variables with have Zero Values', *Working Papers in Econometrics and Applied Statistics, No. 86*, Department of Econometrics, University of New England, Armidale, pp.6.

Battese, G.E. and T.J. Coelli (1992), 'Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India', *Journal of Productivity Analysis*, 3, 153-169.

Battese, G.E. and T.J. Coelli (1993), 'A Stochastic Frontier Production Function Incorporating a Model for Technical Inefficiency Effects', *Working Papers in Econometrics and Applied Statistics*, No. 69, Department of Econometrics, University of New England, Armidale, pp. 22.

Battese, G.E. and T.J. Coelli (1995), 'A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data', *Empirical Economics*, 20, 325-332.

Battese, G.E., T.J. Coelli and T.C. Colby (1989), 'Estimation of Frontier Production Functions and the Efficiencies of Indian Farms Using Panel Data From ICRISAT's Village Level Studies', *Journal of Quantitative Economics*, 5, 327-348.

Bauer, P.W. (1990), 'Recent Developments in the Econometric Estimation of Frontiers', *Journal of Econometrics*, 46, 39-56.

Bravo-Ureta, B.E. and A.E. Pinheiro (1993), 'Efficiency Analysis of Developing Country Agriculture: A Review of the Frontier Function Literature', *Agricultural and Resource Economics Review*, 22, 88-101.

Coelli, T.J. (1992), 'A Computer Program for Frontier Production Function Estimation: FRONTIER, Version 2.0', *Economics Letters*, 39, 29-32.

Coelli, T.J. (1994), *A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation*, mimeo, Department of Econometrics, University of New England, Armidale, pp. 32.

Coelli, T.J. (1995a), 'Recent Developments in Frontier Estimation and Efficiency Measurement', *Australian Journal of Agricultural Economics*, 39, 219-245.

Coelli, T.J. (1995b), 'A Monte Carlo Analysis of the Stochastic Frontier Production Function', *Journal of Productivity Analysis*, 6, 247-268.

Farrell, M.J. (1957), 'The Measurement of Productive Efficiency', *Journal of the Royal Statistical Society*, Series A, 120, 253-290.

Greene, W.H. (1993), 'The Econometric Approach to Efficiency Analysis', in Fried, H.O., C.A.K. Lovell and S.S. Schmidt (eds), *The Measurement of Productive Efficiency: Techniques and Applications*, Oxford University Press, New York, pp. 68-119.

Huang, C.J. and J-T. Liu (1994), 'Estimation of a Non-neutral Stochastic Frontier Production Function', *Journal of Productivity Analysis*, 4, 171-180.

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

Kalirajan, K.P. (1981), 'An Econometric Analysis of Yield Variability in Paddy Production', *Canadian Journal of Agricultural Economics*, 29, 283-294.

Kodde, D.A. and F.C. Palm (1986), 'Wald Criteria for Jointly Testing Equality and Inequality Restrictions', *Econometrica*, 54, 1243-1248.

Kumbhakar, S.C., S. Ghosh and J.T. McGuckin (1991), 'A Generalised Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Dairy Farms', *Journal of Business and Economic Statistics*, 9, 279-286.

Meeusen, W. and J. van den Broeck (1977), 'Efficiency Estimation from Cobb-Douglas Production Functions With Composed Error', *International Economic Review*, 18, 435-444.

Parikh, A. and K. Shah (1994), 'Measurement of Technical Efficiency in the North West Frontier Province of Pakistan', *Journal of Agricultural Economics*, 45, 132-138.

Reifschneider, D. and R. Stevenson (1991), 'Systematic Departures from the Frontier: A Framework for the Analysis of Firm Inefficiency', *International Economic Review*, 32, 715-723.

Saini, G.R. (1979), *Farm Size, Resource-Use Efficiency and Income Distribution*, Allied Publishers, New Delhi.

Walker, T.S. and J.G. Ryan (1990), *Village and Household Economies in India's Semi-arid Tropics*, The John Hopkins University Press, Baltimore.