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Measuring and Explaining Technical Efficiency in Crop Production in Andhra Pradesh

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I

INTRODUCTION

In India, foodgrain production increased by nearly four times since Independence and is ahead of growth rate of population. Not only has the dependence on imports of farm products, especially of foodgrains declined, but also the exports have been increasing. India's capabilities for management of droughts and famines have also been creditable. The growth in agriculture has also contributed to the reduction in the incidence of rural poverty (Parthasarathy, 1994).

However, India's average growth rate of 2.3 per cent per annum of gross domestic product (GDP) originating in agriculture over the two decades of green revolution (1968-1988) compares very modestly with the growth rates for green revolution crops (rice and wheat) in most other Asian countries over that period (Ahluwalia, 1991). International comparisons reveal a wide gulf in India's performance between achievements in output and productivity. While India compares favourably in terms of total output, it compares poorly in terms of yield per hectare.[1]

Evidences show a plateau in crop yield levels, especially during the 1990s, even in well-endowed regions.[2] Such a slow down or stagnation in yield levels is attributed, among other things, to low efficiencies in the production process, non-availability of new technologies, and resource degradation associated with input intensification.

Economic efficiency is composed of technical efficiency and allocative efficiency. While a number of studies established that allocative efficiency was quite high, only a few studies attempted to examine the technical efficiency in Indian agriculture (Vidya Sagar, 1992). It was shown that technical efficiency determines the allocative efficiency (Kalirajan and Shand, 1994). The under-pricing of inputs, through subsidies, was perhaps one of the reasons why farmers used inputs up to or more than allocatively efficient levels, without bothering for their efficient use (Jayaram *et al.*, 1992). Thus, improvement in technical efficiency is a potential source of further productivity growth. Improving the technical efficiency is also important for the reason that without using the

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existing technology to its full potential, embarking on introducing new technologies is not meaningful (Kalirajan *et al.*, 1996).

This paper is an attempt to examine the levels of technical efficiency in the production of three major crops, viz., rice, groundnut and cotton, in the state of Andhra Pradesh in India. The paper also attempts to identify the factors associated with technical efficiency.

II

ESTIMATION AND EXPLANATION OF TECHNICAL EFFICIENCY

The review of literature[3] suggests that stochastic frontier production function with a composed error term is a more appropriate model to estimate technical efficiency. The general form of the stochastic frontier production function is

$$Ln(Y_i) = x_i \alpha + v_i - u_i,$$

where Y is the dependent variable (output) and X_is are the independent variables. In this model, the dependent variable is bounded by above by the stochastic variable, $v_i - u_i$. The random error, v_I, can be positive or negative and so the stochastic outputs vary about the deterministic part of the frontier model. The v_i "accounts for the measurement error and other random factors, such as the effects of weather, etc., on the output variable together with the combined effects of unspecified input variables in the production function" (Coelli *et al.*, 2000). The u_i represents the firm-specific technical inefficiency. Unlike the deterministic frontier model,[4] the stochastic frontier function permits the estimation of standard errors and tests of hypotheses using traditional maximum-likelihood methods. However, the estimates of firm-specific inefficiencies may be sensitive to the distributional assumptions with regard to the u_is.

It was also observed that examination of factors affecting technical efficiency is better done in a single step procedure rather than in a two-step procedure[5] (Wilson *et al.*, 1998; Battese and Coelli, 1995). Therefore, the following functional form was used to estimate the individual technical efficiencies and to examine the factors affecting them.

$$Ln\ Yi = \alpha_0 + \sum_{k=1}^{5} \alpha_k\ Ln\ X_{ki} + v_i - u_i \qquad \text{.... (1a)}$$

$$\mu_i = \delta_o + \sum_{m=1}^{4} \delta_m\ Z_m \qquad \text{.... (1b)}$$

where Y_i : Output of the i-th farmer (q ha^{-1})

X_{ki} : Use of k-th input by the i-th farmer

v_i : random error assumed to be identically and independently distributed $N(0, \sigma^2_v)$

u_i : Firm-specific inefficiency effect assumed to follow a truncated (at zero) normal distribution $N(\mu_I, \sigma^2_u)$, and

Z_m are the factors affecting technical inefficiency,

α's and δ's are the regression coefficients to be estimated.

The technical efficiency of the i-th farmer ($TE_i = \mu_i$) is derived from the density function of U and V which can be written as

$F_u (u) = 1 / \sqrt{(½*\Pi)} . 1/ \sigma_u . \exp [-u^2/2\sigma^2_u]$ for $u \leq 0$
$= 0$ otherwise .... (2a)

$F_v (v) = 1 / \sqrt{(½*\Pi)}. 1/ \sigma_v . \exp [-v^2/2\sigma^2_v]$ for $-\infty \leq u \leq \infty$ .... (2b)

The density function of Y is the joint density function of (U + V) and is given by

$F_v (Y) = \Pi. 1 / \sqrt{(½*\Pi)} . 1/ \sigma. \exp \{(u + v)^2/2\sigma^2\}$
$[1 - F \{((u + v)/\sigma) (\gamma/(1+ \gamma))]$ .... (3)

where

$\sigma^2 = \sigma^2_u + \sigma^2_v$ .... (4a)

$\gamma = \sigma^2_u /\sigma^2, \quad 0 \leq \gamma \leq 1$ .... (4b)

Finally, μ_i is given by

$e^{ui} = - \sigma_u \sigma_v /\sigma [\{\varphi (.) /1-\phi (.)\} - \{((u+v)/ \sigma) \sqrt{(\gamma/(1-\gamma))})]$ .... (5)

where φ (.) and ϕ (.) are standard density and distribution functions, respectively.

The model was estimated using the computer programme FRONTIER 4.1 (Coelli, 1996) to estimate simultaneously the parameters of the stochastic production frontier and the technical inefficiency effects.

Specification of Variables

Y : Output of crop (rice, groundnut or cotton) in q ha^{-1}
X_1 : Total (family + hired) human labour used (hours ha^{-1})
X_2 : Seed rate (kg ha^{-1})
X_3 : Quantity of fertiliser (N + P + K) used (kg ha^{-1})
X_4 : Quantity of farm yard manure applied (q ha^{-1})
X_5 : Expenditure on plant protection measures (Rs. ha^{-1})
Z_1 : Age of the farmer (years)
Z_2 : Education of the farmer (Number of years of schooling)
Z_3 : per cent area under the crop concerned
Z_4 : farm size (ha).

DATA

The crops selected, viz., rice, groundnut and cotton not only represent three important crop groups, but also occupy a substantial proportion (about 62 per cent) of the cropped area in the state. The average production elasticities and the technical efficiency were examined using the farm level data collected by the Comprehensive Scheme on Cost of Cultivation of Crops.[6] The data were obtained for three representative districts – one each for the crops selected – for the agricultural year 1996-97. The villages selected received normal rainfall during this year. Thus, three districts, viz., West Godavari, Anantapur and Prakasam were selected for rice, groundnut and cotton, respectively. These districts were selected considering that the proportion of the area under the crop concerned was one of the highest in the state.

Further, it may be noted that rice is grown as an irrigated crop, and groundnut and cotton under rainfed conditions.

III

RESULTS AND DISCUSSION

Average Production Functions

An understanding of the average output response to the changes in inputs is useful before examining the levels of technical efficiency. Therefore, a Cobb-Douglas production function was estimated following the Ordinary Least Squares (OLS) procedure to estimate the output elasticities with respect to key inputs in the production of selected crops.

Rice

A perusal of the production function (Table 1) indicates that yield responded significantly to all the inputs, except to the fertiliser nutrients. The response was relatively high to the seed and human labour, with output elasticities of 0.14 and 0.26, respectively. Compared to this, the output elasticities with respect of FYM and plant protection chemicals were only 0.04 and 0.02, respectively. A significant proportion of variability in yield was explained by these variables as indicated by an R^2 of 0.73.

TABLE 1. ESTIMATED COBB-DOUGLAS PRODUCTION FUNCTION FOR RICE, GROUNDNUT AND COTTON IN ANDHRA PRADESH, 1996-97 (N=40)

Variable	Regression Coefficients		
	Rice	Groundnut	Cotton
(1)	(2)	(3)	(4)
Constant	1.3086@ (0.6891)	1.4280** (0.3650)	0.7557 (0.6987)
Human labour	0.2634** (0.0917)	0.1026** (0.0483)	1.4332** (0.3093)
Seed	0.1372* (0.0596)	0.1647** (0.0187)	0.3891* (0.1574)
Fertiliser nutrients	0.0394 (0.0481)	0.1720** (0.0241)	0.0669** (0.0207)
Farm yard manure (FYM)	0.0373* (0.0156)	0.0991** (0.0194)	0.0542** (0.0193)
Plant protection chemicals	0.0163@ (0.0097)	0.0217* (0.0072)	-0.0837* (0.0334)
R^2	0.73	0.69	0.88

**, * and @ indicate level of significance at 1, 5 and 10 per cent, respectively.
Figures in parentheses are standard errors.

The insensitivity of yield to the changes in fertiliser nutrients could in part be due to the high levels of fertiliser use (190 kg ha^{-1}) and the resultant soil degradation.

Also, deficiencies of micronutrients and soil salinity that are reported in this region (APAU, 1995) might have affected the nutrient uptake by the crop. The integrated pest management and crop management (weed and water management) are more labour using technologies, which was reflected in the positively significant co-efficient for human labour. Whether the small but significant response to the use of plant protection chemicals was due to adoption of pest resistant crop varieties or due to use of inappropriate chemicals can only be ascertained in a much more detailed investigation. It is also observed from the table that the production is experiencing decreasing returns to scale. It may be noted that the production function is fitted based on the per hectare use of inputs and productivity, and operation of decreasing returns to scale is expected.

Groundnut

As can be observed from Table 1 the yield of groundnut responded significantly to the changes in input use. The estimated production function explained about 69 per cent of variation in yield. Whereas a 10 per cent increase in the use of seed and chemical fertilisers increased yield by about 1.6 to 1.7 per cent, a similar increase in the use of human labour increased yield by only about 1.0 per cent. The elasticity with respect to plant protection chemicals was only 0.02. The results were plausible given the low levels of input use that characterise groundnut production (Appendix). The output response to chemical fertiliser even at such lower levels of use might probably be due to the moisture scarcity in the region and the lack of nutrient-responsive crop varieties. On the other hand, the lower sensitivity to plant protection measures may well be due to the less incidence of pests and diseases, and possible inappropriate use of pesticides. As is the case with rice, decreasing returns to scale are in operation in groundnut production also.

Cotton

The production function coefficients presented in Table 1 indicate that a very high proportion (88 per cent) of the variation in yield was explained by the variables included in the production function. Among the variables, human labour was found to have the most dominant impact on the yield as could be noticed from the production elasticity of 1.4. The changes in the output associated with changes in the use of inorganic and organic fertilisers were relatively small (0.07 and 0.05, respectively), but significant. The negatively significant coefficient for the expenditure on plant protection only indicate the possible over-dependence on, and indiscriminate use of, pesticides, which was widely reported in this region (Subbarao, 1995; Rao and Reddy, 1999). In this region, supply of spurious chemicals, which not only adds to the cost but also harm the crop, and aggressive marketing strategies adopted by the pesticide suppliers are also reported (Chowdry *et al.*, 1998). The positively significant elasticity of seed indicates the importance of good crop stand in obtaining higher yields. The response of output to the seed rate implies that there is scope to enhance yield by increasing the plant population, which is also reflected in the increasing returns to scale.

It can be concluded that the yields of the crops responded to the changes in the use of most of the inputs. However, the response to chemical fertilisers was either absent (in rice) or small (in groundnut and cotton). In the case of rice, the insensitivity of yields to fertiliser nutrients could be due to factors like high rates of fertiliser use, soil salinity, micronutrient deficiencies and imbalanced use of nutrients. On the other hand, limited moisture availability is the major reason for the low yield response in groundnut and cotton. In this connection, it may be mentioned that the method and time of fertiliser application plays a major role in getting higher yield response.

Technical Efficiency

As mentioned before, the technical efficiency and the factors influencing technical efficiency were examined by fitting a frontier production function model including the explanatory factors of technical efficiency. The results obtained for rice, groundnut and cotton are given in Tables 2 to 4, respectively.

Rice

The coefficients of frontier production function for all inputs were significant (Table 2). These coefficients were also higher than those obtained through OLS

TABLE 2. MAXIMUM LIKELIHOOD ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION MODEL FOR RICE IN WEST GODAVARI DISTRICT, 1996-97 (N=40)

	Variable (1)	Coefficient (2)	Standard rror (3)
A.	Frontier production function		
	Constant	0.5766	1.0151
	Human labour	0.2282*	0.0992
	Seed	0.1810@	0.0911
	Fertiliser nutrients	0.0234	0.0121
	Farm yard manure (FYM)	0.0510*	0.0189
	Plant protection chemicals	0.0221**	0.0069
	σ^2	0.1765	0.0194
	γ	0.9012	0.2394
	Log-likelihood	37.67	
B.	Technical inefficiency effects		
	Constant	-0.2297	0.1039
	Age	-0.0137**	0.0054
	Education	-0.0178*	0.0057
	Per cent area under the crop	-0.0046*	0.0019
	Farm size	0.0219	0.0323

**, * and @ indicate level of significance at 1, 5 and 10 per cent, respectively.

procedure, except for human labour, indicating the possibility of increasing the yield with the existing input use and given technology. For example, the output elasticity with respect to seed in the frontier model was found to be 0.18 as against 0.14 obtained in the average production function. A high value for γ (0.90) indicates the presence of significant inefficiencies in the production of the crop. These findings conform to those of Battese and Coelli (1995) for farms in Andhra Pradesh. Such differences between the coefficients of frontier and average production functions were also reported by Datta and Joshi (1992) for Haryana rice farmers, and by Jayaram *et al.* (1992) for rice farmers in Mandya district of Karnataka.

The average level of technical efficiency was estimated to be about 0.85 indicating that it was possible to improve yield by 15 per cent by following the efficient crop management practices. It was also observed that most of the farmers operated at technical efficiency levels between 80 and 90 per cent (Figure 1A). The

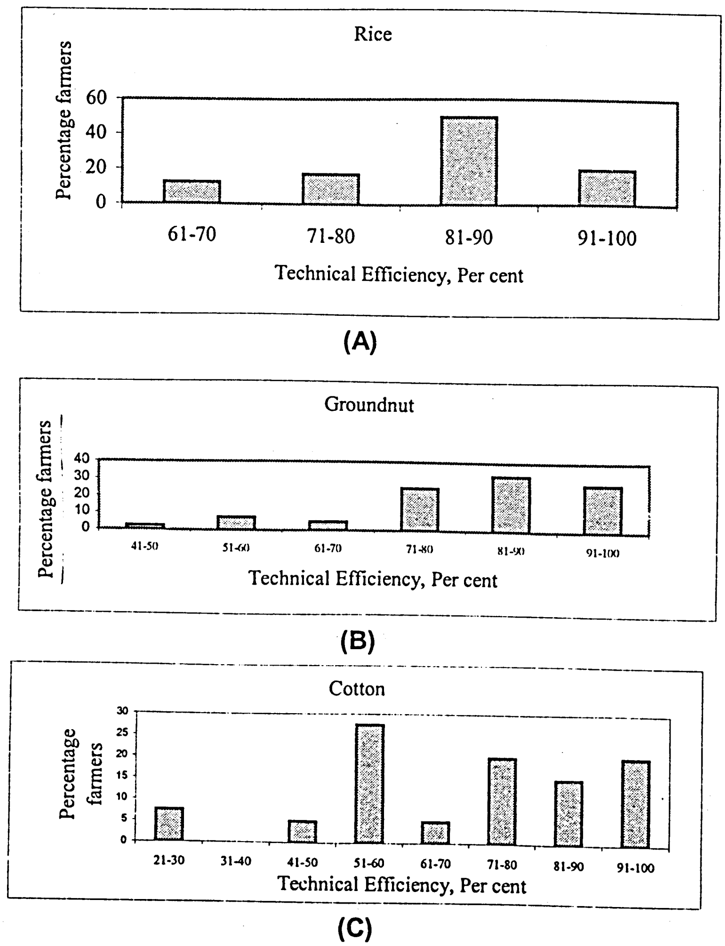

Figure 1. Distribution of Farmers According to Technical Efficiency in Production of Rice, Groundnut and Cotton.

differences in technical efficiency levels were significantly influenced by age and education of the farmers and the proportion of area under rice to the total cropped area. The negatively significant coefficients for age and education suggest that as the age, considered as a proxy for experience, and the education of the farmer improve, the inefficiency decreases, i.e., efficiency improves. The role of education in improving the efficiency and productivity was well recognised. Education not only helps in better crop management decisions, but also places the farmer in a better position to receive the needful information through media and other extension services (Tilak, 1993). The proportion of area under the crop concerned also had negative relationship with the inefficiency. Such a negative relationship could be because a higher proportion of crop indicates a high importance in the overall crop mix, and hence the farmer could spend more time giving attention to the management of the crop (Rama Rao *et al.,* 1997). However, the farm size was not found to have any significant relationship with technical efficiency. Perhaps, various factors such as access to resources, timeliness of farm operations, etc., associated with farm size, might have influenced efficiency differently resulting in a relationship that was not significant.

Groundnut

The maximum likelihood estimates of the stochastic frontier production function are given in Table 3. It is evident from the table that all the variables included in the model significantly influenced the yield of groundnut. The output elasticity was found to be the highest with respect to chemical fertiliser use (0.19) followed by seed

TABLE 3. MAXIMUM LIKELIHOOD ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION MODEL FOR GROUNDNUT IN ANANTAPUR, 1996-97 (N=40)

	Variable (1)	Coefficient (2)	Standard error (3)
A.	Frontier function		
	Constant	1.4524	0.8127
	Human labour	0.1653**	0.0421
	Seed	0.1834**	0.0601
	Fertiliser nutrients	0.1911**	0.0425
	Farm yard manure (FYM)	0.1024**	0.0512
	Plant protection chemicals	0.0229	0.0108
	σ^2	0.2143**	0.0321
	γ	0.7523**	0.2492'
	Log-likelihood	14.26	
B.	Technical inefficiency effects		
	Constant	-0.1127	0.8490
	Age	0.0041	0.1508
	Education	-0.0375*	0.0157
	Per cent area under the crop	-0.0053@	0.0021
	Farm size	0.0630*	0.0264

**, * and @ indicate level of significance at 1, 5 and 10 per cent, respectively.

(0.18), human labour (0.16), farm yard manure (0.10) and plant protection (0.02). These frontier coefficients were also higher than the average coefficients presented in Table 1. Thus, there was a scope to increase the productivity of the crop in the existing conditions and technology. The coefficient for γ, proportion of inefficiency in the total unexplained variation, was high and significant indicating the appropriateness of the model. If the γ coefficient was not significant, an OLS function would have been sufficient, as the technical inefficiency component is small (Battese and Coelli, 1995).

The technical efficiencies of individual farmers were found to vary between 46 and 99 per cent (Figure 1B) with a mean technical efficiency of about 79 per cent. This suggests that it would be possible to increase yields by about 21 per cent with the given level of input use and technology.

A perusal into the factors affecting technical efficiency suggests that education, proportion of area under the crop to the total cropped area and farm size had a significant effect on the technical efficiency of the farmers. As in case of rice, education and per cent area sown to groundnut were found to improve efficiency. Unlike with rice, farm size had a positively significant relationship with inefficiency which can be explained as follows: In the rainfed crop like groundnut timeliness of farm operations is very crucial (Chowdry *et al.*, 1993) and it becomes increasingly difficult to do operations in time as the farm size increases. The age of the farmer was not found to have any significant effect on technical efficiency of the farmer.

Cotton

Table 4 gives the maximum likelihood estimates of the stochastic frontier production function along with the factors affecting technical efficiency. Except the expenditure on plant protection all other variables exerted a positive and significant influence on the yield of cotton. Most of the production elasticities, as estimated by the frontier model, were higher than average elasticities given by the average production function estimated through ordinary least squares (OLS) method. These differences were the result of better management practices, which require more knowledge and time allocation on the part of farmers (Pingali *et al.*, 1997). It is interesting to note that negatively significant coefficient for plant protection in average production function turned into a negative coefficient, though not significant, in the frontier model. This can be attributed to the adoption of integrated pest management practices, that are relatively less dependent on chemical applications. Some of these integrated pest management practices are labour-intensive, which is reflected in the high positive coefficient for human labour.

TABLE 4. MAXIMUM LIKELIHOOD ESTIMATES OF STOCHASTIC FRONTIER PRODUCTION MODEL FOR COTTON IN PRAKASAM DISTRICT, 1996-97 (N=40)

	Variable (1)	Coefficient (2)	Standard error (3)
A.	Frontier function		
	Constant	0.8032	0.5937
	Human labour	1.4506**	0.2997
	Seed	0.3872*	0.1602
	Fertiliser nutrients	0.0823**	0.0352
	Farm yard manure (FYM)	0.0622**	0.0189
	Plant protection chemicals	-0.0764	0.0631
	σ^2	0.6250**	0.2352
	γ	0.8312**	0.3217
	Log-likelihood	16.68	
B.	Technical inefficiency effects		
	Constant	0.0112	0.0164
	Age	0.0212@	0.0091
	Education	-0.0324*	0.0092
	Per cent area under the crop	-0.0183	0.0112
	Farm size	-0.0275@	0.0130

**, * and @ indicate level of significance at 1, 5 and 10 per cent, respectively.

The examination of technical efficiency of the individual farmers revealed that there were wide differences in technical efficiency (Figure 1C). Though the technical efficiency ranged from 26 to 99 per cent among farmers, the average was found to be 72 per cent. As can be seen from the table except percentage of area under cotton to total area, all the other three variables had a significant effect on technical efficiency. Whereas the education was found to have relatively larger influence in improving the efficiency, age tended to negate efficiency as indicated by a positively significant coefficient. Unlike in groundnut, the farm size had a positive relationship with technical efficiency in the case of cotton farmers.

IV

SUMMARY AND CONCUSIONS

Thus, an analysis of technical efficiency indicated that there was considerable scope to improve the yields of the crops in the existing conditions of input use and technology. It is to be added, however, that these estimates of inefficiency may be sensitive to the distributional assumptions made with respect to the inefficiency term in the model. It may be mentioned here that the (in)efficiency, as measured here, is in relation to the 'best peer' who also operate under similar environment, and that the productivity can be improved without any additions to the inputs. Such aspects as time and methods of farm operations like sowing and fertiliser application, holds the key in improving the efficiency. For example, Chowdry *et al.* (1993) observed that most of the groundnut farmers in Anantapur did not place the fertilisers as recommended, losing a significant proportion of the yields. As the time of sowing is very important in realising higher yields, farmers should be educated in this regard.

Also, the government may adjust the timings of release of water in the irrigation projects keeping in mind the optimum time of sowing for different crops in different regions. In the case of rainfed crops, for which sowing time is determined by the onset of monsoon, agrometeorological services for accurately forecasting the rainfall may be promoted so that farmers can plan their operations better. Availability of appropriate farm-machinery for sowing and interculture, especially for small farms and in labour-scarce regions, would also be helpful in following timeliness of operations. As observed, on an average, the yields of rice can be improved by 15 per cent, from nearly 60 q ha^{-1}. This, if realised, can go a long way in improving the profitability of the crop. In other districts, where the rice farmers are not as advanced, the inefficiency may be even higher, and the yields can be improved to that extent. In case of groundnut and cotton also, the technical efficiency is low and some farmers are operating at technical efficiency levels less than 50 per cent. If the efficiency is improved, farmers will gain considerably in terms of higher profits. As it was found that education influenced technical efficiency significantly, efforts should be strengthened to promote both formal and informal education.

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NOTES

1. While India occupied first, second and third positions in the world production of groundnut, rice and cotton respectively, it ranked 68, 52 and 67th positions in productivity levels (FAO,1993).
2. For example, the productivity of rice did not show any significant growth during the period 1990-91 to 1997-98 in West Godavari district of Andhra Pradesh, which is a resource rich region (Rama Rao, 2000).
3. The frontier model of technical efficiency was first proposed independently by Aigner *et al.* (1977) and Meeusen and Van den Broeck (1977). Bauer (1990) and Battese (1991) provide a critical review of literature on technical efficiency estimation. Estimating deterministic and stochastic frontier production functions through econometric and data envelopment analysis are the major tools of efficiency analysis.
4. The main criticism against the deterministic frontier model is that no account is taken of the possible influence of measurement errors and other noise upon the frontier.
5. Some studies (e.g., Parikh and Shah, 1994) have explored the determinants of technical efficiency using a two-step procedure, wherein the technical efficiency levels of individual firms are first estimated and then regressed on the set of variables assumed to explain the technical efficiency levels. It is pointed out that such an approach improves a fundamental contradiction of assumptions. For details, see Battese and Coelli (1995).
6. The details of the quality of inputs such as labour were not available and hence could not be included in the study. Further, there is no much variation in the varieties used by the farmers in the selected villages. For example, TMV-2 variety of groundnut was adopted by all the sample farmers.

APPENDIX

MEAN LEVELS OF INPUTS USE AND PRODUCTIVITY IN RICE, GROUNDNUT AND COTTON IN SELECTED DISTRICTS OF ANDHRA PRADESH, 1996-97

Sr. No. (1)	Variable (2)	Units (3)	Rice/West Godavari (4)	Groundnut/ Anantapur (5)	Cotton/ Prakasam (6)
1.	Human labour	Hours ha^{-1}	1,002.87	325.64	551.22
			(202.79)	(185.59)	(191.57)
2.	Seed	kg ha^{-1}	74.52	72.62	3.87
			(23.60)	(46.64)	(2.61)
3.	Fertiliser nutrients	kg ha^{-1}	190.04	20.68	97.87
			(76.78)	(22.40)	(66.16)
4.	Farm yard manure (FYM)	q ha^{-1}	13.57	6.57	37.95
			(14.78)	((2.16)	(69.57)
5.	Plant protection chemicals	Rs. ha^{-1}	512.43	51.67	1,018.26
			(453.64)	(15.97)	(1,551.99)
6.	Productivity	q ha^{-1}	59.69	4.18	17.45
			(18.63)	(3.25)	(10.39)
7.	Age	Years	54.00	54.17	56.37
			(9.59)	(7.59)	(12.23)
8.	Education	Years	5.68	5.78	5.36
			(3.18)	(3.45)	(3.72)
9.	Area under the crop	Per cent	67.47	57.57	59.25
			(13.75)	(115.92)	(22.56)
10.	Farm size	Ha	2.31	3.18	4.15
			(1.46)	(2.25)	(1.96)

Figures in parentheses are standard deviations.

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