Identification of Factors which Influence the Technical Inefficiency of Indian Farmers

by

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Abstract

The technical inefficiency of Indian farmers is investigated using stochastic frontier production functions. Farm-level panel data from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are used. Of particular interest to this study is the identification of those factors which may cause farms to have large or small technical inefficiency effects. Factors, such as farmer age, level of education and farm size are investigated. A stochastic frontier production function is specified in which these factors are permitted to have a systematic influence upon technical 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. This latter, two-stage method is not considered because of certain statistical inconsistencies. The results indicate that the above factors do have a significant influence upon the technical inefficiency effects of farmers in two of the three villages considered.

1. 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 a "fully-efficient firm". The technical efficiency of a firm is defined as the ratio of its observed output to that output which could be produced by the fully-efficient firm, given the same input quantities. Farrell did not illustrate his ideas with an application, but suggested that linear programming may be an appropriate method of estimating the production function of the fully-efficient firm (now commonly referred to as a *frontier* production function) from input and output data on a sample of firms.

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). Charnes, Cooper and Rhodes (1978) were the first to present a DEA model. Seiford and Thrall (1990) provide a thorough review of the DEA literature, much of which has appeared in management science journals.

The primary criticism of the DEA approach is that measurement errors could 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 address this problem. Stochastic frontiers have two error terms, one to account for technical inefficiency and the other to account for other factors such as measurement error in the output variable, luck, weather, etc. 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) presents a comprehensive review of the econometric estimation of frontiers.

In the agricultural economics literature the stochastic frontier (econometric) approach has generally been preferred. This is probably due to a number of factors. The assumption that all deviations from the frontier are due to inefficiency, as assumed in DEA, is difficult to accept, given the inherent variability of agricultural production, due to weather, fires, pests, disease, 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 also likely to be subject to measurment errors.

This paper does not attempt to review the many applications of frontier production functions to agricultural industries. 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 refer to those applications which attempt to explain farm-level differences in predicted technical inefficiencies using explanatory variables, such as age and level of education of the farmer, farm size, access to credit and utilization of extension services. The vast majority of these applications 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. In the second stage, these predicted technical efficiency effects are related to farmer-specific factors using ordinary least squares regression. This approach appears to have been first used by Kalirajan (1981).

The identification of those factors which influence the technical inefficiencies of farms 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. However, the two-stage approach is not satisfactory from a statistical viewpoint. There are inconsistencies in the assumptions regarding the distribution of the technical inefficiency effects in the two-stage approach. In the first stage, the technical inefficiency effects are usually assumed to be independently and identically distributed random variables. However, in the second stage, the predicted technical inefficiency effects are regressed upon a number of farm-specific factors. The predicted technical inefficiency effects from this second equation are not independent and even their corresponding true values would only be identically distributed if the coefficients of the farm-specific factors were zero.

Recent papers by Kumbhakar, Ghosh and McGuckin (1991), Reifschneider and Stevenson (1991), Huang and Lui (1993) and Battese and Coelli (1993) specify stochastic frontiers and models for the technical inefficiency effects and simultaneously estimate all the parameters involved. The Battese and Coelli (1993) model is specified for panel data and the model for the technical inefficiency effects involves farmer-specific variables and year of observation. Battese and Coelli (1993) apply their model in the analysis of an incomplete panel of ten years of data on fourteen paddy farmers from the village of Aurepalle in India. In the present paper, we consider the analysis of the full set of data provided by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) which involves data from three regions in India.

The remainder of this paper consists of four sections. In Section 2, we briefly describe the data on farmers from the three Indian villages involved. In Section 3, the proposed stochastic frontier, inefficiency model is discussed. In Section 4, the empirical results are presented and several hypotheses are tested. In the final section some conclusions are made.

2. PANEL DATA ON INDIAN AGRICULTURE

During the decade from 1975-76 and 1984-85, inclusive, 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.

We consider the analysis of the agricultural data obtained from the three villages of Aurepalle, Kanzara and Shirapur, which are located in the districts of Mahbubnagar, Akola and Sholapur, respectively, and are located approximately 70 km south, 550 km north and 336 km west of the Headquarters of ICRISAT, 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 size ten 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.

A very brief description of the agro-climatic conditions in the three districts involved is presented below. Walker and Ryan (1990) present a detailed discussion of the regions and the VLS data. Aurepalle is characterized 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. More details on the various input variables, and the age and education levels of the farmers, are presented in Table 1, which is briefly discussed in Section 4.

3. THE STOCHASTIC FRONTIER INEFFICIENCY MODEL

The stochastic frontier production function which is specified for the farming operations in each village is defined by

$$\begin{aligned}\log(Y_{it}) = \beta_0 &+ \beta_1\log(Land_{it}) + \beta_2(IL_{it}/Land_{it}) + \beta_3\log(Labour_{it}) \\ &+ \beta_4(HL_{it}/Labour_{it}) + \beta_5\log(Bullock_{it}) + \beta_6\log(Cost^*_{it}) \\ &+ \beta_7(Year_{it}) + V_{it} - U_{it} \qquad (1)\end{aligned}$$

where the subscripts i and t represent the i-th farmer and the t-th year of observation; Y is the total value of output (expressed in thousands of Rupees, in 1975-76 values terms); Land is the total area of land in hectares which includes irrigated and dryland crop production area; IL is the area of irrigated land that is operated; Labour is the total quantity of family and hired labour (in thousands of man hours)[1]; HL represents the quantity of hired labour employed; Bullock is the total amount of bullock labour (expressed in thousands of hours of bullock pairs) which includes hours of owned and hired bullock labour; Cost* is the total cost of other inputs (expressed in thousands of Rupees), which includes costs of inorganic fertilizer, organic

[1]ICRISAT uses the conversion factors that one hour of female labour and one hour of child labour are equivalent to 0.75 and 0.5 man hours, respectively.

matter applied as fertilizer, pesticides, and machinery costs[2]; Year indicates the year of observation (expressed in terms of 1,2,...,10); the V_{it}'s are assumed to be independent and identically distributed random errors, having $N(0,\sigma_v^2)$ distribution; and the U_{it}'s are non-negative random variables associated with the technical inefficiencies of production of the farmers involved, such that they are independently distributed and arise by truncation (at zero) of the normal distribution with variance, σ^2, and mean, μ_{it}, where μ_{it} is defined by

$$\mu_{it} = \delta_0 + \delta_1(Age_{it}) + \delta_2(Educ_{it}) + \delta_3(Size_{it}) + \delta_4(Year_{it}) \qquad (2)$$

where Age is the age of the principal decision maker; Educ is the number of years of formal education of the principal decision maker; Size is proxied by the Land variable defined earlier; and Year is also as previously defined.

The stochastic frontier, inefficiency model, specified in equations (1) and (2), is estimated in Battese and Coelli (1993) in terms of the parameterization

$$\sigma_s^2 = \sigma_v^2 + \sigma^2 \qquad (3)$$

and

$$\gamma = \sigma^2/\sigma_s^2 \qquad (4)$$

where the parameter, γ, has value between zero and one. Maximum-likelihood estimates of σ_s^2 and γ and the β- and δ-parameters are obtained using a modification of the FRONTIER computer program (see Coelli, 1992).

The stochastic frontier production function, defined by equation (1), is a modification of the Cobb-Douglas functional form. It permits the production elasticity of land to differ between irrigated and unirrigated land and that of labour to differ between hired and family labour. The inclusion of a time trend permits Hicks-neutral technical change. The model, defined by equation (2), specifies that the level of the technical inefficiency effects depend on the age and education of the farmers involved, the size of their farming operations and the year of observation. As stated in Battese and Coelli (1993), all the parameters of the frontier model, defined by equations (1) and (2), are only identified if the technical inefficiency effects are stochastic, which requires that the variance, σ^2, is positive (or equivalently that the

[2]The star on the Cost variable is used because Cost* will take the value, one, if the total cost of other inputs is zero. That is, if we define the dummy variable, D, which has value, one, if total cost of other inputs is positive and has value, zero, otherwise, then Cost* = Max{Cost, 1-D}.

parameter, γ, is positive). If the variance, σ^2, is, in fact, equal to zero, then the intercept parameter, δ_0, and the coefficient of Year, δ_4, in the inefficiency model are not identified. In this case the model reduces to a traditional average response model, in which the explanatory variables would be the input variables, land, labour, etc., and the intercept variables, involving the constant and age, education and year.

The hypothesis that the technical inefficiency effects are deterministic, given the level of the inputs involved, is specified by $\gamma = \delta_0 = \delta_4 = 0$. Further, the hypothesis that the technical inefficiency effects are not related to age or education of farmers, the size of their farming operations and the year of observation, is specified by $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$. Tests of these hypotheses are of interest in assessing the characteristics of the technical inefficiency effects for farmers in the three Indian villages involved.

As noted above, the ratio variables, IL/Land and HL/Labour, permit the production elasticity of land to differ between irrigated and unirrigated land, and that of labour to differ between hired and family labour. The model is a linearized 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, refer to Battese, Coelli and Colby (1989) and Battese and Coelli (1992). A test of the hypothesis 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. Bardham (1973).

4. EMPIRICAL RESULTS

A summary of the sample data on the different variables in the stochastic frontier 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 6.02 ha and 6.68 ha in Kanzara and Shirapur, respectively. The smaller holdings in Aurepalle could be attributed to the greater use of irrigation 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 differ from 43.7 years in Kanzara to 53.9 years in Aurepalle, while average education levels are quite low, varying from 2.01 years in Aurepalle to 4.03 years in Kanzara.

The maximum-likelihood estimates for the parameters in the stochastic frontier, inefficiency model are presented in Table 2 for the three villages involved. The estimated δ-coefficients associated with the explanatory variables in the model for the technical inefficiency effects are worthy of particular discussion. 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 having greater inefficiencies in agricultural production. From the results in Table 2, we observe that age has a negative effect upon the technical inefficiency effects in Aurepalle and Kanzara. That is, the older farmers tend to have smaller technical inefficiencies (i.e., are more technically efficient) than younger farmers in Aurepalle and Kanzara, but the reverse is true in Shirapur. The result for Aurepalle differs from that reported in Battese and Coelli (1993) in the analysis of Aurepalle paddy farmers. However, the size of the farm is not considered as a factor in the inefficiency model in Battese and Coelli (1993).

Education is expected to have a negative effect upon technical inefficiency effects. The coefficient of the education variable is observed 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 technically efficient in agricultural production. The positive value obtained for Kanzara is unexpected, but could be due to the generally small numbers of years of formal schooling observed throughout the sample. We hypothesize that if a wider spread of education levels were observed, the result may have been different.

The sign of the estimated coefficient of the size variable in each village is negative, as one would expect. This indicates that farmers with larger farms tend to have smaller technical inefficiency effects than farmers with smaller operations.

The coefficient of year of observation in the model for the technical inefficiency effects is also estimated to be negative in all three villages. This implies that the levels of the technical inefficiency effects of farmers in the three villages tend to decrease over time. That is, farmers tend to become more technically efficient over time. This time-trend variable may be picking up the influence of factors which are not included in the inefficiency model. For example, it may reflect the positive influence of government agricultural extension programs over the sample period.

Overall, the signs of the estimated δ-coefficients conform quite closely with our expectations. Only the coefficient of education in Kanzara has a sign which is contrary to our expectations. Note, however, that the ratio of this estimate to its estimated standard error (t-ratio) is only slightly larger than one in value, indicating that this may not be a significant influence.[3] Also note that this t-ratio is the smallest of all associated with δ_1 to δ_4 in any of the three villages.

The γ parameter associated with the variances in the stochastic frontier is estimated to be between 0.9 and the upper limit of 1 in all of the three villages. Although this parameter cannot be interpreted as the proportion of unexplained inefficiency variation relative to all random variation, it is significantly different from zero in all three villages, indicating that technical inefficiency does make a contribution in the analysis of agricultural production in the Indian villages involved.

Formal tests of hypotheses associated with the technical inefficiency effects are presented in Table 3. These tests of hypotheses involve the use of the generalized likelihood-ratio statistic, which has approximately Chi-square distribution with degrees of freedom equal to the number of restrictions in the appropriate null hypothesis. The generalized likelihood-ratio test is often preferred to the asymptotic t-test since the estimated standard errors can sometimes be unreliable when they are calculated as a by-product of the iterative estimation procedure. Furthermore, the t-test can only be used when the null hypothesis contains a single restriction.

The first null hypothesis considered in Table 3, H_0: $\gamma=\delta_0=...=\delta_4=0$, specifies that all the coefficients of the explanatory variables in the

[3]Given normal asymptotic theory, if the ratio of an estimated coefficient to its estimated standard error exceeds 1.96 in absolute value, then it indicates that the coefficient is significantly different from zero at the five percent level. All tests of hypotheses are conducted at the five percent level unless otherwise stated.

inefficiency model are zero, in addition to the variance, σ^2, associated with the inefficiency effects. This hypothesis implies that the technical inefficiency effects are absent from the model, which, in turn, implies that the stochastic frontier model, defined by equation (1), is equivalent to the traditional average response function. This null hypothesis is clearly rejected by the data for all of the three villages involved. 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 inefficiency model, defined by equations (1) and (2).

The second null hypothesis in Table 3, H_0: $\gamma=\delta_0=\delta_4=0$, specifies that the variance of unexplained technical inefficiency effects is zero and so the inefficiency effects are non-stochastic. The intercept parameter and the coefficient of year of observation are simultaneously specified to be zero because these coefficients are not identified in the model if the variance parameter is zero, given that the frontier model, defined by equation (1), contains an intercept parameter and accounts for technical change (i.e., year of observation is included). This null hypothesis is also strongly rejected for all three villages.

The third null hypothesis in Table 3, H_0: $\delta_0=\ldots=\delta_4=0$, specifies that all the technical inefficiency effects in the stochastic frontier production function have half-normal distribution. This hypothesis is also strongly rejected for all three villages.

The final hypothesis considered in Table 3, H_0: $\delta_1=\ldots=\delta_4=0$, specifies that the explanatory variables in the inefficiency model do not have any influence on the level of the technical inefficiency effects and, also implies that the technical inefficiency effects have truncated-normal distribution. This null hypothesis is rejected for the villages of Shirapur and Kanzara, but accepted for Aurepalle. Thus for Aurepalle, it could be concluded that the technical 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 inefficiency model, defined by equations (1) and (2), the technical inefficiency effects can be regarded as independent and identically distributed random variables which arise from the truncation of a normal distribution with non-zero mean.

The estimated coefficients of the production function, defined by equation (1), reported in Table 2, have sizes and signs which generally conform with those obtained in past analyses of these data. The estimated coefficients of land and labour are both positive in each of the three villages. The coefficient of IL/Land is expected to be positive, reflecting the higher productivity of irrigated land. If the productivity of hired labour was lower than that for family labour, then the coefficient of HL/Labour would be negative. Negative estimates are obtained in Aurepalle and Kanzara, but for Shirapur the estimated coefficient is positive. However, the ratio of the estimated coefficient to the estimated standard error suggests that hired and family labour in Kanzara and Shirapur are equally productive. The generalized likelihood-ratio tests of the hypothesis that the coefficient of the hired-labour ratio is zero are presented in Table 4. 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 coefficient of bullock labour is negative in all three villages. This is contrary to what one would expect, but conforms with earlier analyses, reported by Saini (1979) and Battese and Coelli (1992). A number of explanations have been suggested for this result, the most often quoted 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.

In our stochastic frontier production function, the cost of other inputs, such as fertilizer, manure and pesticides, is included as an explanatory variable. It has been suggested that this variable should not be used in a frontier production function, because it is a composite variable which contains the costs of various items which are likely to influence production in different ways. We maintain that the inclusion of this variable is preferable to its exclusion, on the grounds that it should reduce the degree of mis-specification. Also considered in Table 4 is a test of the null hypothesis that the coefficient of the cost of other inputs is zero, i.e., H_0: $\beta_6=0$. For Aurepalle and Shirapur, the null hypothesis is accepted, while 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 insect pests. Thus, the regular use of pesticides is an important part of cotton production.

The final hypothesis considered in Table 4 relates to the question of technical change. This involves a test of the null hypothesis that the coefficient of year of observation in the stochastic frontier is equal to zero, i.e., H_0: β_7=0. The test statistics indicate that the null hypothesis is rejected in Aurepalle and Kanzara, while the hypothesis of no technical change is accepted for Shirapur. We note that the coefficient of year of observation in the stochastic frontier, β_7, is positive for Aurepalle, but negative for Kanzara. The latter result is surprising and merits further investigation.

Finally, it is interesting to note that the conclusions of the Chi-square tests listed in Table 4 are the same as those that would have been made if asymptotic t-tests had been used. Thus, in this application, the standard errors appear to be well estimated.

The technical efficiency of farmers are predicted for each year in which they were observed, using the method proposed in Battese and Coelli (1993). The predicted technical 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 technical efficiencies of each farmer (over the ten-year period) and the mean technical efficiencies for farmers in each of the years involved. The predicted technical 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 technical efficiencies of the farmers range from 0.353 for farmer 32 in Shirapur to 0.921 for farmer 28 in Kanzara. The mean technical efficiencies of the farmers in the three villages do not 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 technical efficiencies, frequency distributions of the technical 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) for the inefficiency effects, such as the general truncated-normal distribution used in this study.

The annual mean technical 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 technical efficiency is observed over the sample period in all three villages. The mean technical 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 technical 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.

5. CONCLUSIONS

Stochastic frontier inefficiency models are estimated for each of the three villages from diverse agro-climatic regions of the semi-arid tropics of India. The production functions 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 technical inefficiency effects includes the age of the farmer, education of the farmer, size of the farm and the year of observation as explanatory variables. A number of hypothesis tests are conducted to assess the relative influence of these factors and other random effects. The results indicate a significant random component in the technical inefficiency effects in all three villages and that the above four factors have a significant influence upon the size of farm-level technical inefficiencies 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 technical inefficiency effects.

The technical efficiencies of each farm, in each year that the farm was surveyed, are predicted and tabulated. Technical efficiencies are observed to range from below 0.1 to above 0.9. The mean technical efficiencies for the three villages are estimated to be 0.747, 0.738 and 0.711, for Aurepalle, Kanzara and Shirapur, respectively. The mean level of technical efficiency follows an upward trend over the ten-year period in all three villages. The lowest annual mean technical efficiency was 0.434 in Shirapur during 1975/76 and the highest was 0.880 in Aurepalle during 1982/83.

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 the ICRISAT Village Level Studies. Although our empirical study does not include discussion of various variables which might be important in modelling output and inefficiency effects, e.g., rainfall data, use of agricultural extension services and access to credit, our work 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 technical inefficiency effects which are consistent with such policy orientations.

REFERENCES

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

Bardham, 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. 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, 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.

Charnes, A., W.W. Cooper and E. Rhodes (1978), "Measuring the Efficiency of Decision Making Units", *European Journal of Operations Research*, 2, 429-444.

Coelli, T.J. (1992), "A Computer Program for Frontier Production Function Estimation: FRONTIER Version 2.0", *Economics Letters*, 39, 29-32.

Farrell, M.J. (1957), "The Measurement of Productive Efficiency", *Journal of the Royal Statistical Society*, A CXX, Part 3, 253-290.

Huang, C. and J-T. Liu (1993), "Estimation of a Non-neutral Stochastic Frontier Production Function", unpublished paper, Department of Economics, Vanderbilt University, Nashville, pp.13.

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

Kumbhakar, S.C., S. Ghosh and J.T. McGuckin (1991), "A Generalized 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.

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.

Seiford, L.M. and R.M. Thrall (1990), "Recent Developments in DEA: The Mathematical Approach to Frontier Analysis", *Journal of Econometrics*, 46, 7-38.

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

TABLE 1

Summary Statistics for Variables in the Stochastic Frontier Inefficiency Models*

Variable	Sample mean	Sample stdev	Minimum	Maximum
Value of output (Rs in 1975-76 values)				
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	2352.3	6	14130
Shirapur	719.1	768.4	24	4823
Bullock labour (hours of paired bullocks)				
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 (Rs)				
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
Education 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.

TABLE 2

Maximum Likelihood Estimates for Parameters of the Stochastic Frontier Inefficiency Models*

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)
Bullock	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	-1.75	0.80	1.37
		(1.46)	(0.35)	(0.50)
Age	δ_1	-0.0150	-0.015	0.0133
		(0.0092)	(0.010)	(0.0099)
Educ	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		-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 for Coefficients of the Explanatory Variables for the Technical Inefficiency Effects

Null Hypothesis (H_0)	Log-likelihood (under H_0)	χ^2-value≡c	$P(\chi^2>c \mid H_0$ true)
H_0: $\gamma=\delta_0=...=\delta_4=0$			
Aurepalle	-138.02	77.02	<0.005
Kanzara	-106.03	51.48	<0.005
Shirapur	-183.68	109.74	<0.005
H_0: $\gamma=\delta_0=\delta_4=0$			
Aurepalle	-137.86	76.70	<0.005
Kanzara	-100.18	39.78	<0.005
Shirapur	-177.54	97.46	<0.005
H_0: $\delta_0=...=\delta_4=0$			
Aurepalle	-113.12	27.22	<0.005
Kanzara	-93.27	25.96	<0.005
Shirapur	-161.58	65.54	<0.005
H_0: $\delta_1=...=\delta_4=0$			
Aurepalle	-101.92	4.82	0.306
Kanzara	-91.13	21.68	<0.005
Shirapur	-151.98	46.34	<0.005

TABLE 4

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

Null Hypothesis (H_0)	Log-likelihood (under H_0)	χ^2-value≡c	$P(\chi^2>c \mid H_0$ true)
H_0: $\beta_4=0$			
Aurepalle	-104.90	10.78	<0.005
Kanzara	-80.31	0.04	0.841
Shirapur	-128.97	0.32	0.572
H_0: $\beta_6=0$			
Aurepalle	-99.69	0.36	0.549
Kanzara	-111.28	61.98	<0.005
Shirapur	-128.81	0.00	1.000
H_0: $\beta_7=0$			
Aurepalle	-103.32	7.62	0.006
Kanzara	-83.04	5.50	0.019
Shirapur	-129.80	1.98	0.159

TABLE 5

Predicted Technical Efficiencies for Farmers in Aurepalle

Farmer	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 Technical Efficiencies for Farmers in Kanzara

Farmer	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	-	-	.5[illegible]9
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

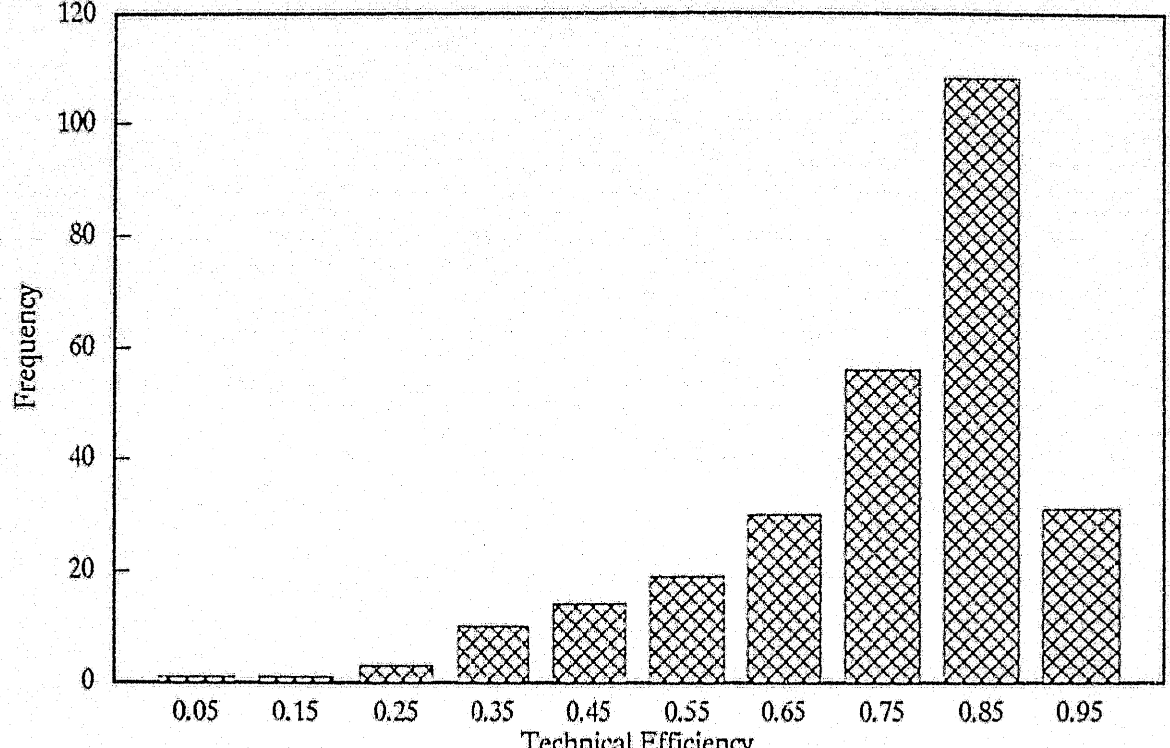
TABLE 7

Predicted Technical Efficiencies for Farmers in Shirapur

Farmer	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

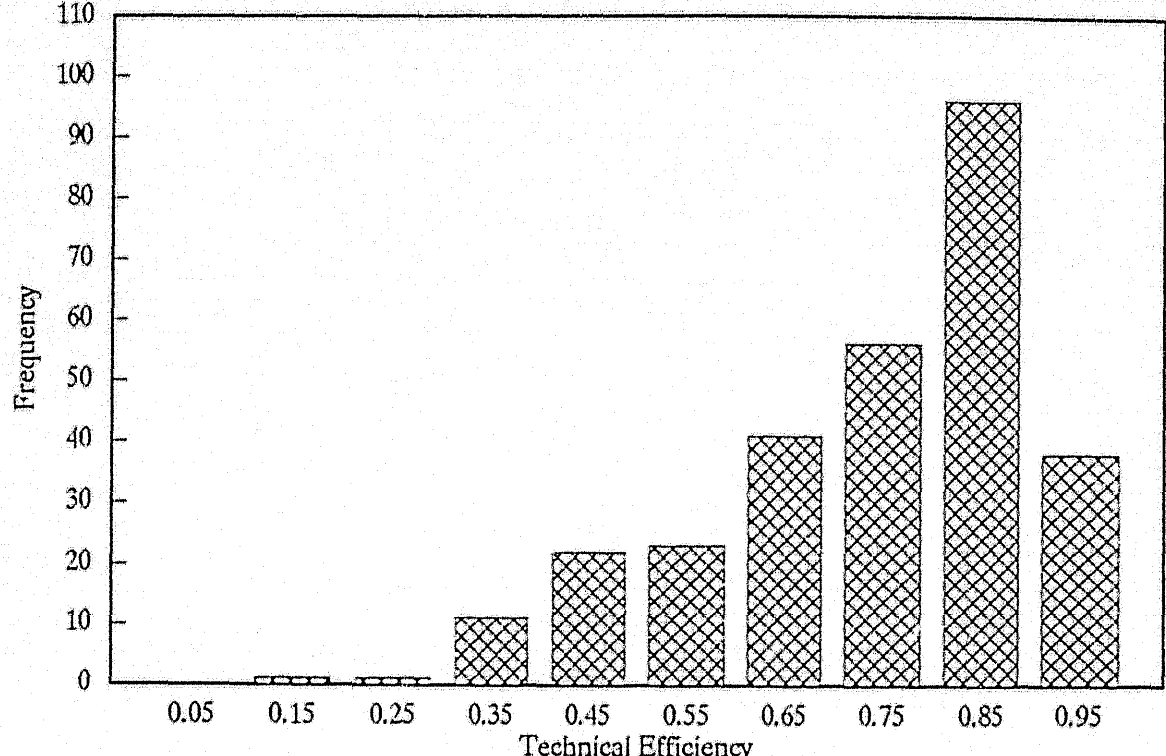
Predicted Technical Efficiencies of Farmers in Aurepalle



Note: Numbers on the horizontal axis refer to the mid–point of the interval.

Figure 2

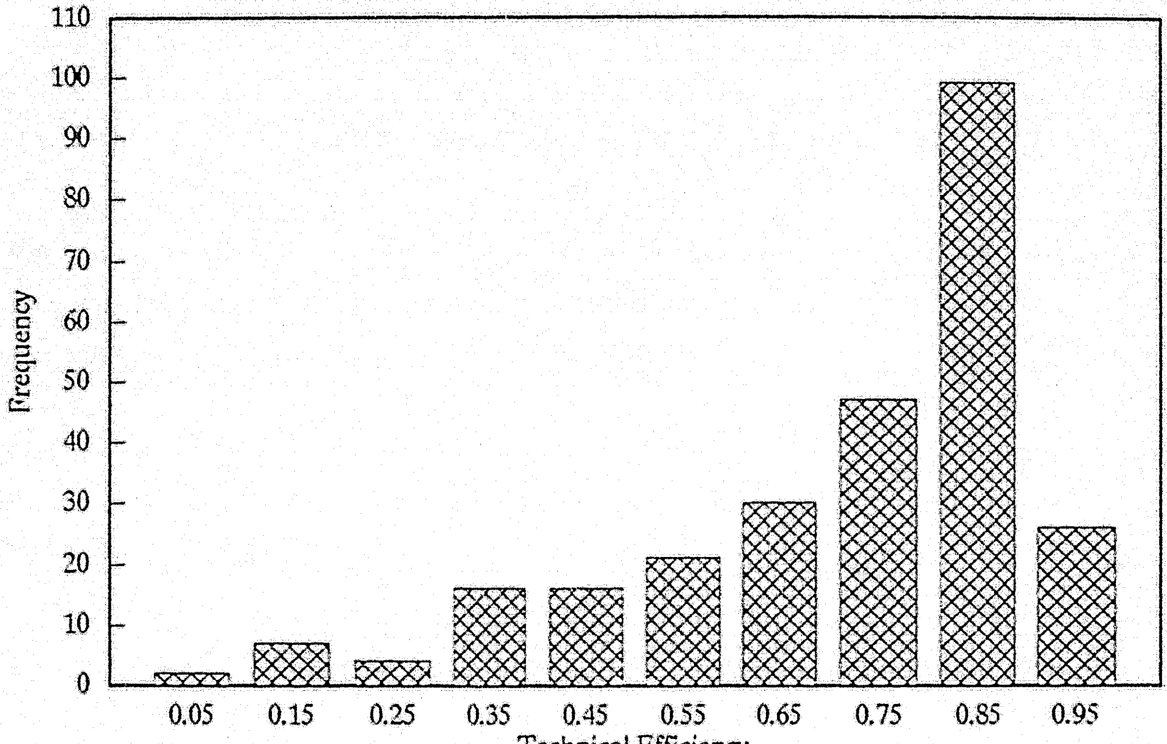
Predicted Technical Efficiencies of Farmers in Kanzara



Note: Numbers on the horizontal axis refer to the mid-point of the interval.

Figure 3

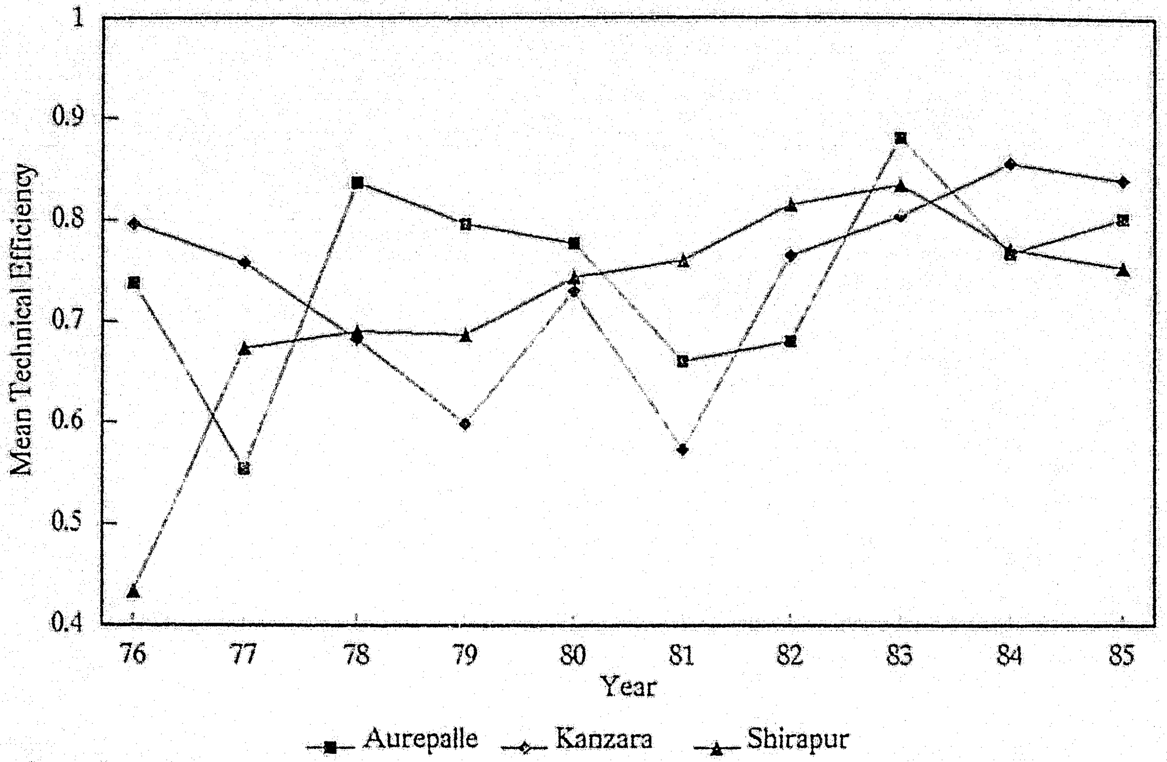
Predicted Technical Efficiencies of Farmers in Shirapur



Note: Numbers on the horizontal axis refer to the mid–point of the interval.

Figure 4

Mean Technical Efficiencies



Note: Year 76 refers to the agricultural year, 1975–76, etc.